Analysis of LCC and BIM during Operations and Maintenance phase from the Perspective of Cost

Master thesis

International Master of Science in Construction and Real Estate Management

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I am grateful to HTW Berlin and Metropolia university of applied sciences, Helsinki for allowing me to write my Master Thesis.

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Conceptual Formulation

Hochschule für Technik und Wirtschaft Berlin
University of Applied Sciences

Metropolia

International Master of Science in Construction and Real Estate Management

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Conceptual Formulation

Master Thesis for Ms. Sowmya Gurum

Student number: **s0557525**

Topic:

ANALYSIS OF LCC AND BIM DURING OPERATION AND MAINTENANCE PHASE FROM THE PERSPECTIVE OF COST

Thesis Description:

The confession of this master thesis is about identifying the benefits of Life Cycle Cost (LCC) during facility management phase from the perspective of cost and the support of BIM (Building Information Modeling) for efficient work.

The Construction project is a combination of development, management, research, operation, and maintenance. Operation and maintenance involve maximum lifespan compared to the construction phase. Currently, BIM is the flourishing technology in AEC (Architecture, Engineering, and construction) industry which is been implementing in different stages of construction to reach the effective performance. Accordingly, Life cycle costing of construction aids to save the entire lifetime costs and benefits for both builders and investors. A lot of research undergone and implementing advanced technology in the AEC industry to increase the efficiency of work. Although, implementation of BIM is at the greater level during the construction phase than in the latter phase. Hence, the objective of the study is to provide how LCC and BIM assist to reduce the functioning cost of building and how it is more effective in saving entire lifecycle cost.

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Research methods:

Information for writing paper will be gathered from journals, publications, articles, literature, researches, industrial interviews, case studies, and possible comparisons. The aim of this study requires the following research methods:

a. Analyzing literature associated with BIM and LCC from the view of cost.
b. Evaluating the case studies related to both the concepts.

Research questions:

This research methodology will be intended to answer the following questions.

- ✓ What is the Life Cycle Cost of a building and how it affects operational and maintenance cost?
- ✓ Does LCC support to reduce the cost of facility management and how it impacts the lifetime cost saving of a building?
- ✓ What is the importance of implementing BIM during the Facility management phase?
- ✓ Does BIM assist in reducing the cost of building maintenance?
- ✓ How does it help to reduce the maintenance cost by implementing both the concepts?

Research time frame:

The duration of this thesis work planned to carry out from January 2018 and submission date would be Friday, 24th August 2018. The study will provide the benefits of implementing LCC and BIM at the time of facility management phase to save excess expenditure.

Signature of the Supervisor

Abstract

The application of different techniques and technology in the construction sector provided immense advantages to optimize construction cost. However, the later period Operations and Maintenance (O&M) phase of the building with maximum lifespan consume excess cost from the owner budget and it is essential to reduce facilities costs. The Life Cycle Cost (LCC) technique and Building Information Modeling (BIM) technology have a greater influence on building usage period. Therefore, the primary objective in the research is to analyze the benefits of LCC and BIM during Facility management (FM) phase. The theoretical approach of research work helped to determine how LCC and BIM can facilitate to reduce operational cost.

The research work started with the background and problems related to O&M, following the literature review and theoretical framework to know about concepts and current situations. The case studies from several research papers were analyzed to support the research study and finally concluded the results for the theoretical approach of work. The findings of the literature review and case studies analysis provided different outcomes, limitations, and benefits of implementing LCC and BIM.

With the implementation of LCC and BIM in FM phase can enhance the facilities operations and maintenance process that reduces the service cost of building's life. There are several limitations from the two concepts BIM and LCC, however proper Lifecycle analysis of building components, systems and equipment before evaluating design alternative and integration of BIM at the early design stage can even improve the construction process which benefits to reduce entire Life Cycle Cost of the building.

***Keywords**: Operations and Maintenance (O&M), Life Cycle Cost (LCC), Building Information Modeling (BIM), Facility management (FM)*

Table of Contents

Table of figures

List of Tabulations

List of Abbreviations

AEC	Architectural Engineering and Construction
BIM	Building Information Modeling
CMMS	Computerized Maintenance Management Systems
COBie	Construction Operation Building Information Exchange
FM	Facility Management
ICT	Information Communication and Technology
LCC	Life Cycle Costing or Life Cycle Cost
LCA	Life Cycle Assessment
MEP	Mechanical, Electrical and Plumbing
NIST	National Institute of Science Technology
O&M	Operations and Maintenance

1 Introduction

A lot of research undergone and also implementing advanced technology in the AEC (Architectural Engineering and Construction) industry to increase the efficiency of work. The advanced techniques and developing technology focusing majorly on the construction phase of the building's lifespan offering little priority when the building in use. The service phase of the building has a longer duration than the construction phase which requires proper maintenance to enhance the performance of the building and building systems.

Adequate maintenance process and prior measures are the important aspects to increase the functioning duration as well as to reduce the excess cost of accommodation. Nevertheless, the emerging development of construction sector emitting various studies to increase prominence in the second stage of project life that is after construction. In recent decades, maintenance of buildings is aroused as an extensive research area of study.

The general mistakes employed in utilization are the improper process of maintaining and lack of maintenance practice. This drives to expend excess money by the landlords and tenants in the course of severe damage. It is observed that around £1 billion was paid out for resolving faults in new buildings which were neglected at the design phase in the United Kingdom during the latter period of the 20th century (Mydin, 2017). US National Institute of Science Technology (NIST) interoperability study indicates that due to inefficiencies during operation and maintenance phase a large amount of estimated cost is lost in the US. Aziz et.al denoted there will be surplus overheads in utilization period than estimated in case of meager management. (Aziz*, et al., 2016).

Due to the maximum proportion of building life comprises of a later phase of construction, managing and maintaining are obligatory. In the course of O&M phase of a building lifecycle, employing the efficient techniques of managing the maintenance of system can create the variance from a loss to profit of an organization (Fourie & Tendayi, 2016). Therefore, conservation and supervision at the stage of building use are crucial.

In the view of economic concern, priority is applicable to Life Cycle Costing (LCC) which involves the budgeting of the entire life of building from designing to demolition. Life Cycle Cost is usually adopted at the stage of design for the purpose of decision making which is a whole inclusive of costs in all the phases. Further, in recent studies, global warming, environment, and social aspects become a noteworthy topic in the AEC industry. Consequently, it is essential for architects to incorporate life cycle assessment (LCA), Life Cycle Cost (LCC) as well as Life Cycle CO_2 ($LCCO_2$) as a part of sustainable goals and for facility managers to enrich internal environment meanwhile minimizing operational cost (Kimoto, et al., 2013).

Lifecycle cost analysis is one of the prominent concepts which has been implementing in different methods at a different phase of projects to minimize overall budget and increase efficiency. From the view of total lifetime cost, O&M expenditures appear substantial. The benefits from lifecycle cost analysis and assessment are to choose a relative and efficient design in the perspective of future saving.

On account of an analysis to find the benefits of LCC in reducing building operational cost is the primary chore in this research paper. Correspondingly the emerging technology in the construction sector has a compelling influence upon utilization stage and its advantages also considered as a plus to trim down maintenance cost.

The technology Building Information Modeling (BIM) in construction industry nowadays flourishing as a collaborative tool for different trades minimize the risk of information sharing. Thus, it acts as a bridge between the pre-construction, construction and post-construction period of projects. Therefore, BIM is engaged as the supporting concept in Life Cycle Costing to optimize redundant cost expenditure in maintenance management. So, as the research is in sequence from LCC and BIM in running performance of the building.

This research concentrating essentially on operation and maintenance (O&M) phase or the facility management phase of the construction project from the perspective of cost. The report mainly focuses on the influence of LCC and BIM in the reduction of operation and maintenance cost. Although the development of information technology in the AEC industry is expanding progressively, most of developing countries still trailing behind and the concept of facility management, life cycle costing and BIM are yet to implement. Thus, it is an approach to find the benefits of all these factors to save excess cost incurred in building lifespan.

Initially, the report follows with an introduction, emphasizing problems, the scope of work, the importance of adopting LCC and BIM during facilities management phase from literature review, analysis of case studies and conclusion.

1.1 Research Problems

In the conventional method of the construction industry, any economic consideration in a project was basically from the start of construction until the user dwells in neglecting operational cost. However, operation and maintenance of any construction project partake maximum overheads than the earlier phases. As a result, it is certainly essential to acknowledge post-construction cost while deciding on construction design. The major faults in maintenance are basically due to the design decision, materials, and type of system selected at the early stage. The other kind of defects is by deterioration. In contrast to another stage of lifespan, the design stage has a massive impact on the maintenance of a project. The general faults in design phase infer impression in the operational phase are below:

- Improper selection of materials and structural systems to minimize investment cost
- Aiming for physical properties of materials instead of durability and efficiency
- Lack of testing the materials before use
- Communication space among different stakeholders
- Lack of practical data from previous experience and reference
- Deficiency in preventive measures

Above mentioned defects are most influencing in the operational phase. Whilst it not only impact on maintenance features but also on financial aspects. Implementation of entire cost including operation, maintenance in projects supports owners or investors to make appropriate decisions. In the recent development of the construction sector, Life cycle costing conquers a significant role in perspective to cost.

Life cycle costing of the building aids to save the entire lifetime costs and benefits for both builders and investors. But there are several problems residing in facilities stage even after integrating Life Cycle Cost due to lack of information and standards. Building life cycle process is complex and information available and requirements from each stage are different and serve different purposes. There should be a continuous process of information carried from one stage to another stage throughout the entire life-cycle of the building. However, most of the created information is disconnected at some phase which leads to a lack of feedback during the operational phase. Insufficient information on building system effects to make further improvements in future design and maintenance (Pinheiro et al, et al., 2015).

In many of the case, building databases are less available and it is difficult to analyze other similar building databases for rectification and repairs. Sometimes the records of maintenance are not available or outdated to track the information which results in overspending of money and time (Mydin, 2017).

In case of a change in the FM contractor for the maintenance and management of building after few years, again causes a poor handover which directs owner to pay an additional cost to the contractor for the survey. This process continues to carry forward replicated information (Kassem, et al., 2015).

The primary drawbacks in maintenance or facility management are that there is a notable gap between the construction and post-construction phase. For this reason, it is necessary to have a continuous flow of information from beginning to end without missing any data or pay the additional cost for each time of survey which eases the facilities management tasks.
The concept Life Cycle Cost displayed the importance of O&M cost of building apart from construction cost. To have a constant flow of information BIM tool can facilitate as an information exchange. This research tried to find possible benefits of adopting LCC and BIM and how they can influence to minimize excess costs during facility management.

1.2 Motivation and scope of research

The motivation for this study is mainly to understand the concept of Building information modeling and Life Cycle Costing facility management phase. The problem statement gives an overview to evaluate the questions for conceptual study. Currently, maintenance and operation phase becoming vital study to preserve the structure for a longer duration. Also, cost and budgeting is the most influential aspect and must accountable. The inspiration to study the research based on these grounds is carried out with basic research concept on adopting the type of methodology. The main intention is to understand the theories and to support the research work, life cycle costing is an important aim to focus. The booming technology and implementation of BIM in different areas evidently have scope for future development. This motivated to bring in two foremost conception analysis.

1.3 Research Questions

Considering economic aspects in the construction sector, the research has been chosen to comprehend the concept of Life cycle costing and the role of building information modeling in the post-construction phase. The research questions emphasis mainly on the understanding of the process, accompanying structure of data, methodologies, integration of tools and applications on implementing the technology.

The initial sort of questions related to the importance of Lifecycle costing, and the benefits of LCC in the operational phase

Research question 1: What is the Life Cycle Cost of a building, how it affects operational and maintenance cost?

Research question 2: Does LCC support to reduce the cost of facility management and how it impacts the lifetime cost saving of a building?

The technology influence on construction sector increasing gradually to attain the efficiency and cost-effective process all through the lifespan of a project. Hence the adoption of Building information modeling tool is more influencing in AEC industry in current development. BIM is a tool of collaboration among different stakeholders, increase the work efficiency and assist to complete the project in stipulated time. There is a massive advantage in adopting BIM in construction projects. Thus, to analyze the importance and advantages of BIM in facility management the concept is incorporated in this study. Thus, the research questions associated with BIM application are

Research question 3: What is the importance of implementing BIM during the Facility management phase?

Research question 4: Does BIM assist in reducing the cost of building maintenance?

The overall effect on service phase in accounting the two major concept LCC and BIM to decrease cost is an essential view. To gather the most valuable factors from the two concepts, their limitation and possible recommendation to future act provide a way to conclude and stimulate to adopt. The questions below support to gather the evidence and conclude the possible advantages:

Research question 5: How does it help to reduce the maintenance cost by implementing both the concepts?

2 Research Methodology and structure

It is important to understand the research sequence before arriving at the research methodology. There are several methods to follow in research work, the flow of work in this paper is based on deciding the basic parameters of the study. The sequence following basic parameters by understanding these five aspects- Research application, research type, research paradigm, research methodology, research approach, and research structure.

2.1 Application

From the two contrast research applications- Pure research and applied research, this research is conducted as pure research. The foremost purpose of this research is to understand and attain knowledge of parameters related to the focused area. It basically involves studying, testing, progress, substantiating theoretical features and hypotheses.

2.2 Type

The type of research is categorized into five different studies: *1. Descriptive, 2. Correlational, 3. Explanatory, 4. Explanatory and 5. Constructive.* In this research work, Descriptive and correlational research type is adopted. **Descriptive research** is defined as "*an effective way to obtain information used in devising hypotheses and proposing associations*"[1]. A qualitative way of research which is instinctive and informative in nature. **Correlational research** states that *"Type of non-experimental method that describes the relationship between two measured variables"*[2] which comprise of two or more studies. Here research carried out considering two aspects Life cycle costing and BIM in facility Management phase or operational phase of building. The study of two concepts in profiting facility management.

[1] Monsen & Horn, Research: Successful Approaches, 2007

[2] Jackson, Research methods and statistics: A critical thinking approach, 2015

2.3 Paradigm

Research Paradigm is defined as *"the theoretical outline or structure that guides how the research is viewed and approached by the researcher(s)"*[3]. The theoretical outline basically involves the hypotheses or theories of different individuals on a concept from their perception. A qualitative method of research is embraced. This method is to gather thorough knowledge of research to attain the expected outcome.

2.4 Methodology and approach

There are numerous studies offered on Facility management, LCC, and BIM concepts already. The descriptive type and qualitative analysis of this research aim to discover the possible advantages of LCC and BIM to consider in Facility management. Therefore, a preliminary step is to review related article, journals, publications and research papers. The data collected in Literature review amends the possible benefits of Life Cycle Cost management and BIM associated in Facility management phase.

Followed by literature review a theoretical context is described to understand the concepts well. The possible benefits of LCC and BIM in facility management can be justified with supporting case studies which are already executed in different research works. A better understanding of the advantages for operation and maintenance from the two concepts and understanding of their limitation to get the possible outcome are the main objectives. The essential points to be noted while implementing both concepts will be a recommendation for future use. All the results exhibited in this report connecting to the theoretical studies. Information for this research work gathered from journals, publications, articles, literature, researches, and case studies. Analyzing literature associated with BIM and LCC from the perspective of cost. Evaluating the case studies related to both the concepts. In total 13 cases are studied from various research works and described in the report to show how LCC and BIM impact the operation and maintenance stage. Later, the analysis is carried out to find the benefits, limitations and future recommendations. Finally, the conclusion of the study is illustrated from findings and analysis.

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[3] Yalcinkaya 2017

2.5 Approach

An inductive way of approach to conducting qualitative research can be the suitable term for the analysis carried in the research paper. The collection of data from the available sources and creating a theory to link with the objective of research work and examining the effect of various studies and researches on the subject. The possible approach to claim knowledge and relate to the research objectives from the analysis of case studies and literature review. To discover bona fide profits of Life Cycle Costing in Operational and maintenance time and the factual advantages of integrating building information in facilities operation and maintenance is the main factor to this qualitative approach.

2.6 Structure

The structure of the research work is as shown below:

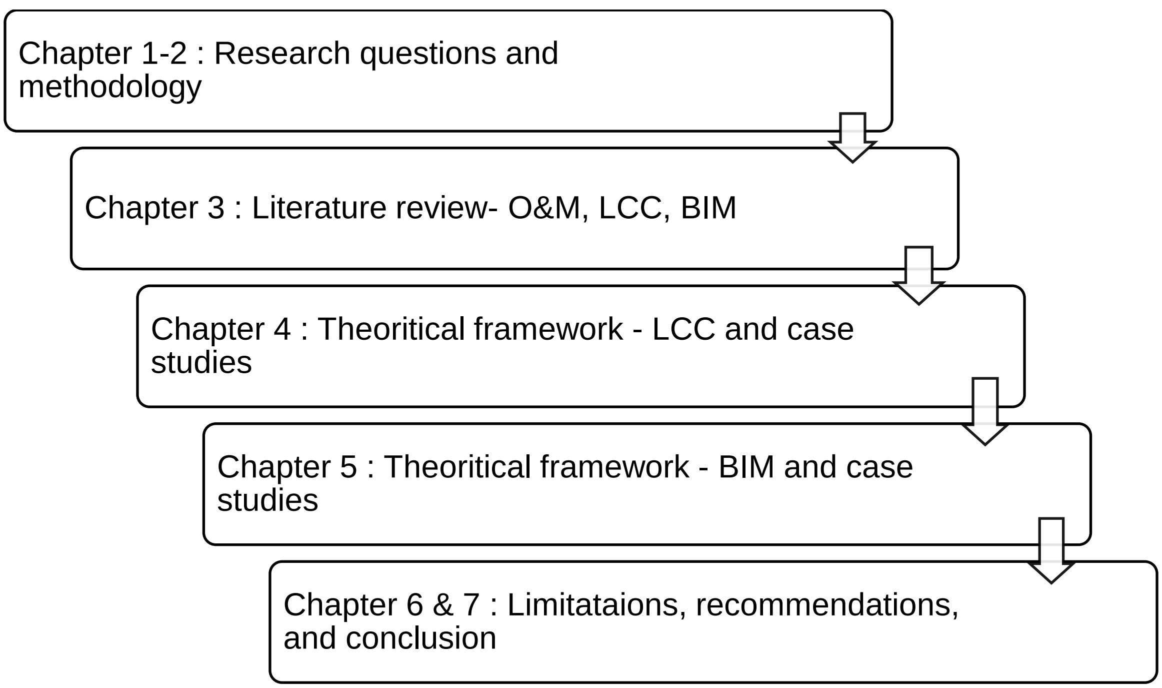

Figure 1 Structure of research work

3 Literature Review

3.1 Towards the importance of Operation and maintenance

Facility operation is essential which can manage the machine or system to function on daily basis without extra funding. Therefore, it is a multidimensional function and regular maintenance management is obligatory so that 90-97% of issues in the organization can be solved also can concentrate more on the other major issues (Cotts, et al., 2010).

Maintenance is required all along the service of a building until the end of life. In most of the cases of construction projects, the users of the building are least counted. Contractors only fulfill the contracts with documents until the building is built with least interest about users' needs and wants. Foremost step is to provide necessary importance towards operation and maintenance phase at the early stage of design. It is important to guarantee the design of a building is maintenance-friendly and sustainable throughout its lifespan. By means of appropriate maintenance methods, the system lasts longer so that to curtail restoration or renewal (Mydin, 2017). Figure 2. Shows the impact of building maintenance on lifespan. With preventive maintenance, breakdown frequency can be prolonged.

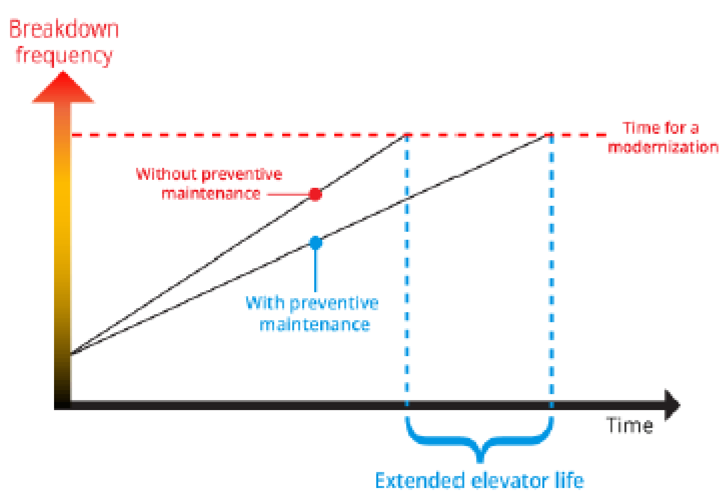

Figure 2 Extended Elevator life (Source: (Mydin, 2017))

Building maintenance has a principal role in the health and safety of our lives. Although it is more influencing the economy of any development industries, there is an additional impact on socio-environmental aspects. Thus, the purpose of maintaining is to create a Healthy environment, ensuring safety, giving proper services, preserve quality and finally to maintain the value of the building (Mydin, 2017). It basically helps the owner to retain the asset as per economic perception. Because depreciation cost decreases over the period of time if not properly maintained.

Regardless of maintenance, preserving the building database has a significant role. Moreover, it helps to conduct the condition survey and inspection effortlessly without spending extra time and money for gathering information. Advanced technologies, the computer-aided database can aid to track data and collect information of maintenance systems. It is also possible to assign operational service to the maintenance provider or facility manager so that the entire database can be maintained by them implementing corresponding strategies. This enhances the functioning of the building and reduces operational costs (Mydin, 2017).

Alshehri et al said the cost for maintenance is completely based on old records with additional interest of rates. While there is a difference in expenses because of unexpected technical defects and is hard to quantify. Accordingly, the actual cost might vary sometimes resulting in excess cost and undervaluation. There is a requirement of technological support to store maintenance and operation data access modifications while taking decisions. This assist to evaluate the even distribution of the total financial plan in the entire lifespan (Alshehri, et al., 2015).

Similarly, support from the owners, tenants, facility managers, and companies also have a huge impact on facility management. Facility management (FM) is a combined tactic for a firm to function, conserve, progress and withhold the building structure so as to abet all the mentioned participants. Out of many sections in FM the highest cost involved in Facility maintenance management i.e. about 65% to 85% of FM occupations (Chen, et al., 2018). Due to the longer life of operation and maintenance phase automatically cost involved is high.

The indicators for the performance of the product can be measured during the functional phase in reaching the targets measured in terms of reliability, availability, maintainability, and safety (RAMS). Suppose the target is maximum, the entire product cost is high including operation and maintenance, but if it is minimum, it affects the quality of the system (Fourie & Tendayi, 2016). It is usually like that the higher quality system always possesses greater price and performs well for a longer duration. In some cases, it might differ however utmost product cost escalates according to the quality.

Maintenance and operation are always set as a difficult part in all sectors. It is not only due to the deficiency in knowledge, but also there are many barriers to relate to this phase. Jensen et.al quoted that the primary barrier is the intense attention on capital investment than on entire projects life-cycle cost (JENSEN, et al., 2009).

3.2 Review on Life Cycle Cost

The National Institute of Standards and Technology Handbook 135 (1996) defines Life Cycle Cost as "the total discounted dollar cost of owning, operating, maintaining and disposing of a building or a building system"[4] over a period of time.

It is pictured in the sustainable building technical manual that only 10-20% capital cost encountered for an office building and remaining 80-90% is on the operation, maintenance and financing of total life cost**.** The author also claimed that Net Present Value (NPV) is a suitable method for evaluating Lifecycle cost because it weighs with the time value of money.

Net present value is the sum of investment costs, replacement costs, O&M cost yearly, and O&M costs non- annual excluding resale value at the end of life (Kshirsagar, et al., 2010).

NPV = $C+R-S+A+M$ *Where, C – investment cost*

R – Replacement costs

S – Resale value at the end of life

A - Annually recurring operating, maintenance and repair costs (including energy costs)

M - Non-annually recurring operating, maintenance and repair cost.

[4] Kshirsagar, et al.,Sustainability of Life Cycle Cost Analysis (LCCA) as asset management tools for institutional buildings ,2010

Series of steps to determine life cycle costing analysis involving all the expenditures such as initial acquisition, operating, maintenance, overheads, critical costs, current costs, escalating cost, discounts, and end of life together structures life-cycle cost analysis (Kshirsagar, et al., 2010).

The detailed study of whole life provide maximum information and allows to track expenses at each stage. The control over the entire process of the cycle facilitates to manage costs and timely corrections as and when required to uphold within the estimated budget (Dawei & Xuefeng, 2012).

An attempt to lifecycle cost management is to minimize the entire cost comprised in all the stages of projects which bring in construction, utilization, renovation, and removal stages (Figure 3). Life cycle cost analysis is an aggregation of initial expenses, maintenance charges, operational performance, externalities, and uncertainty value. Henceforth this whole estimation allows to manage with errors and apply possible corrections during the process and abets to maintain budget under tolerable margins. (Dawei & Zhao, 2012).

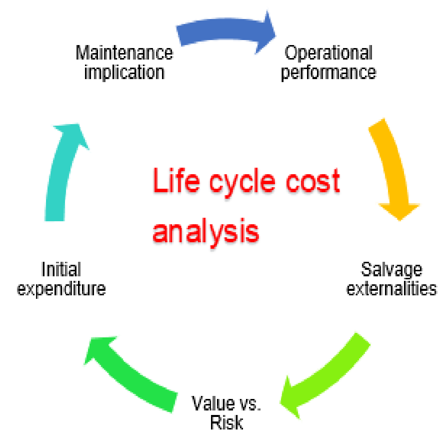

Figure 3 Life cycle cost analysis of a building (Source: Mydin, 2017)

Life cycle cost analysis (LCCA) is to admit entire cost, an advantage to cost ratio and internal rate of Return. American economy sets a series of cost analysis standards for buildings. The method to find the entire cost of owning and operating a service over a certain period based on financial circumstance is named as LCCA. It is a tool to measure and control the preliminary and future cost of building possession. The influential factor is LCCA can be implemented in any stage of the process to evaluate the system in present condition (Kshirsagar, et al., 2010).

According to Bradley et al, life cycle assessment is to intersect with environment and society, to support this economically, there is a demand for life cycle cost model that impels the way out to sustainable development of the product with a vision of the economy. On an average, highest initial investment is essentially the most feasible preference in the view of the life cycle. However, there are limited proofs to adopt it requires standard data and closed ring for the flow of work (Bradley, et al., 2018).

As stated in the book *Pay now or pay later* (1991), designers and owners always diagnose that there are alternatives in attaining decisions either considering only initial cost or adding benefits of operation and maintenance cost to it. The performance of a building can be estimated according to the choice of determining the type of building system and materials, keeping operational phase in mind (National Research Council, 1991). The property of the mechanical and electrical system and materials are to be analyzed along with the variation of the environmental condition before opting.

The initial phase of design and decision is always having a high influence on later period (Figure 4). Although the construction phase contributes minimal expenses in comparison with the operation, this early period donates probable upturn to the latter (Aziz*, et al., 2016).

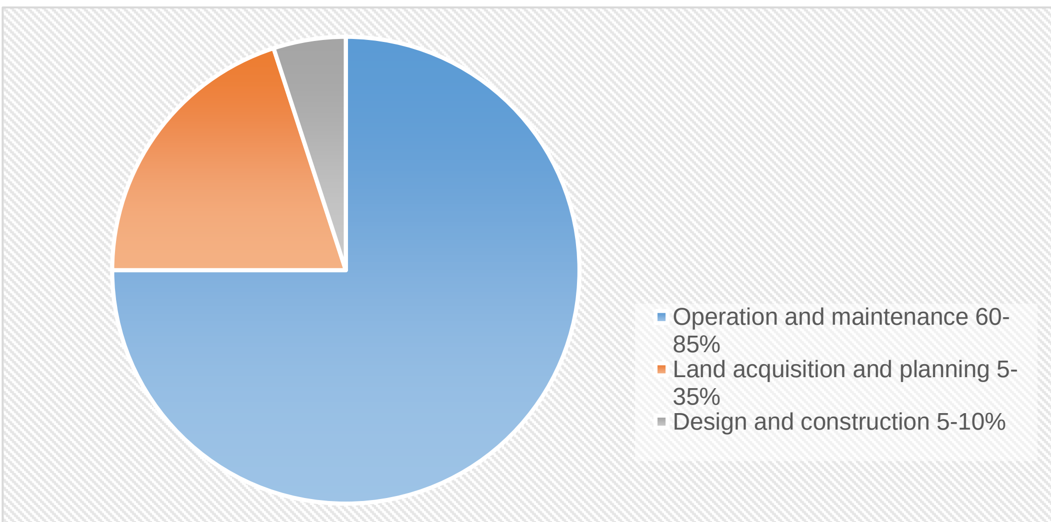

Figure 4 Life cycle cost budget division of a building (Source: Aziz et al 2016 (Hardin 2009))

It is noticeable that life of a building at service is long and to utilize it to the maximum extent, the quality of construction, building type, intensity of use along with specified lifespan plays a major role. It is said that these early design stages influence up to 80% of building operational costs. In the later design phases, the possibility of change rapidly decreases with simultaneously increasing costs. Both academic research and the industry itself claim that an integrated design process, including life cycle costing and optimization, can significantly reduce the operating and maintenance costs. The utilization of LCC analysis allows an early estimate of the operational saving potential and/or collection and assessment of alternatives. (Heralova, 2017)

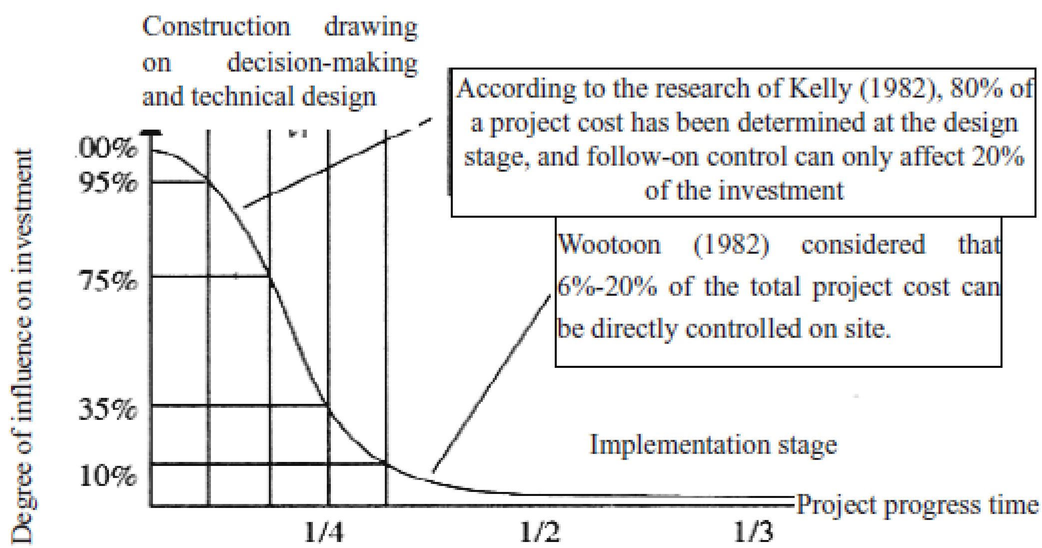

Figure 5 Analysis of the degree of influence of various stages of the project life cycle on investment (Dawei & Zhao, 2012)

Dawei and Xuefeng justified that the stimulus of investment for whole life cycle at the early stage has a greater impact and the economic flow reduce gradually over the time. For that reason, decision making i.e., the preliminary phase is the decisive phase has maximum impact on project cost and a key mechanism to control the economy of entire life. From the above Figure 5, it shows 75 to 95% of the life cycle is based on the influence of decision-making and design. 35 to 75% impact from designing of the technical aspect, up to 35% on construction design drawing and finally 5%-10% on dealing with technical and economic part of the construction. Substantially, preliminary prior decision phase augments construction efficiency meanwhile reducing the modifications in later stages (Dawei & Zhao, 2012).

Due to the deficiency in guidelines for recounting life-cycle costing and minimal attributes turn out to be a hurdle for recording Life-cycle execution. However, to give an overview of the budget to the investor, life-cycle costing can be accomplished as the most prominent clarification for designing in detail, to accept the most efficient tender, or to find the favorable process to approach operation and maintenance (Heralova, 2017).

Author Kaming said that the implementation of Lifecycle cost in the construction sector can change the structure and usage of building from the traditional type. But, the construction budget is certain on the contrary the expenses vary during the later stage due to unexpected arise of situations.

The author proposed previously studied cases regarding Life cycle cost of building and the real case of a residential apartment building located at Yogyakarta. In the previous cases considered, the operation and maintenance cost of building employs more than 60% of overall. In one of the cases called the Diamond building green at Malaysia, the operating cost is lower than the initial cost concluding the feasibility study to reduce lifetime cost. For the residential building at Yogyakarta, the LCC is estimated and results concluded that around 60% of cost occupies for operation and maintenance and about 40% of cost as initial for construction. Therefore, the thorough study of cost encountered in utilization and demolition stage is significant (Kaming, 2017). Lack of knowledge about the LCC approach and its application is the major hurdle to popularize in the construction industry (Dwaikat & Ali, 2018).

Although the introduction of green building concept influenced life cycle assessment and life cycle cost to the greater extent. Development of this life cycle costing to support sustainable assessment became an economic stand for sustainable development (Dwaikat & Ali, 2018). The author estimated the Lifecycle cost of a green building in Malaysia, and the results disclosed the energy consumption cost was 48% of the total lifecycle cost of the building. The cost occupied for energy consumption was greater than the design and construction cost (Dwaikat & Ali, 2018). Therefore, it is significant to reduce energy consumption to minimize lifecycle cost

3.3 Building Information Modeling – Contribution to FM

Building information modeling (BIM) has various definitions according to the perspective of several authors. Ultimately the main purpose is to provide efficient workflow productivity, reduce risk, increase profit and ease of communication between different stakeholders.

Aziz et al identified different definitions to BIM in the view of FM operation. BIM acts as a storage model collecting all the information and applications in life cycle acts as a sharing platform consisting of different departments. This can be utilized as a database for final facility management operation (Aziz*, et al., 2016). Aziz defined BIM in FM perspective as “a collection living document tool in the repository to manage accurate building information over the whole life cycle that at the FM stage, the owner can use to manage facilities”[5].

[5] Aziz et al, Building Information Modeling (BIM) in Facilities Management: Opportunities to be considered by facility managers, 2016

BIM can be integrated into all possible ways since it has that substantial feature to adopt environmental consideration accessing life cycle operation and maintenance costs. It acts as a performance data for various department work productivity can support to efficient cost management balancing other two aspects of project management time and quality. Regardless of complexity in workflow and financial factors, BIM aids to reduce a lot amount of loses. This intern help to reduce operational cost and maintain the quality of life in the workplace. Moreover, making use of BIM entirely in life cycle also advantageous in work transparency, to manage asset and effective financial planning. (Aziz*, et al., 2016)

Facility Management Handbook also mentioned that BIM is a digital version of the building and its process which enables interoperability. The three-dimensional model allows the user to see the mockup building in detail from structural components to all MEP works which are more equivalent to reality and allows managers and users to take a visual tour of the building. It provides a conflict-free mockup with detailed information about as-built and documentation. Automated estimation, specifications of components provides a detail data which help facility management during emergencies (Cotts, et al., 2010).

In addition to building a model, BIM is a virtual reality dais in which all the stakeholders from structure, architecture, and engineers can share design, information, and problems working correspondingly not consecutively. Thus, it is a real-time collaboration, quality management and logistics raised area (Jaspers, 2016).

BIM facilitates to transfer information after construction. Thus, the owner can obtain valuable information and for operation and maintenance, the management after construction have more precise, integrable and easily approachable information system (Liu, 2010).

Liu mentioned that there should be a project BIM process for every project as they differ and unique. It also provides detailed data on each procedure for implementing BIM. The author used BIM Revit software to develop an existing model and provided the way to facility management access information system of a college building (Liu, 2010)**.**

Facility management can obtain a source to assist the maintenance activities and strategies in both existing and new buildings in consort with a source of information from Building information modeling (Patacas, et al., 2015).

There is an enormous advantage to the owner on adopting BIM processes. It eases the communication between different stakeholders, minimize faults, and execute consistent and efficient hand over which in turn reduce the cost and time of the project (Eastman, et al., 2011).

- BIM-based design for energy and lighting to enhance the performance of building
- Most reliable estimation of cost and reduce risk associated to finance
- Proper collaboration among various teams shortens project duration, and prefabricated design to reduce the time of field labor
- Provides detail information of equipment which optimizes facility management and maintenance
- Ensure program agreement through analysis of as well as local code prerequisite and owner (Eastman, et al., 2011)

Facility Building information model delivers a compound of facilities and models for the benefit of the owner in asset management. The post-construction asset management of BIM applications is configured to pre-sales, as-built, commissioning, facility management, financial asset management, operation simulation for an emergency, performance monitoring and retrofit configuration (Eastman, et al., 2011).

BIM has the capacity to empower competences and bring substantial worth to facility managers, whereas the practice necessary should be highlighted and totally planned to take up the upcoming challenges (Jaspers, 2016)

During the lifetime of building after construction, the maximum cost incorporated in operation and maintenance of energy consuming materials. Thus, to keep track of these components proper conservation is essential. If there is a damage in any part of the system, it would cost more expenses only to check and analyze the problem. Therefore, the BIM tool assists to overcome these expenditures (Chen, et al., 2018).

For the reference of facility managers, all the data of asset, the schedule of maintenance can be stored in CMMS (Computerized Maintenance Management Systems). Even though with CMMS, the technicians need to search for the document when required. In due time some documents are lost or moved which again grabs additional time and cost for the job to finish activities related to operation and maintenance (East, 2016).

However, the open-standard electronic information accessibility to technicians can save up to 8% annual budget of maintenance as concluded from a study in 2011. Thus COBie (Construction-Operations Building Information Exchange) assist to solve this difficulty and provide information of electronic operations, asset management, and maintenance to assist mechanics and contractors (East, 2016).

COBie supports the exchange of structural specification information and another standard which supports workflow and exchanging data is Industry foundation classes (IFC) (Chen, et al., 2018).

Cheng et.al demonstrated the framework for maintenance management prediction entailing three modules; condition assessment, predicting failure and maintenance schedule, and budgeting. The monitoring and controlling equipment data for preserving and precautions are done using sensors implemented with the BIM model. To map with sensors a plug-in Revit .NET API (Application Programming Interface) was developed. These sensors are created in such a way that including all the monitoring aspects from performance to climatic condition (Cheng, et al., 2016).

The transfer of data or exchange of information among the parties is framed as shown in figure 6. The work order can be easily prioritized from the data obtained and generates the cost for each order which can then balance and cross check with an estimated annual budget (Cheng, et al., 2016).

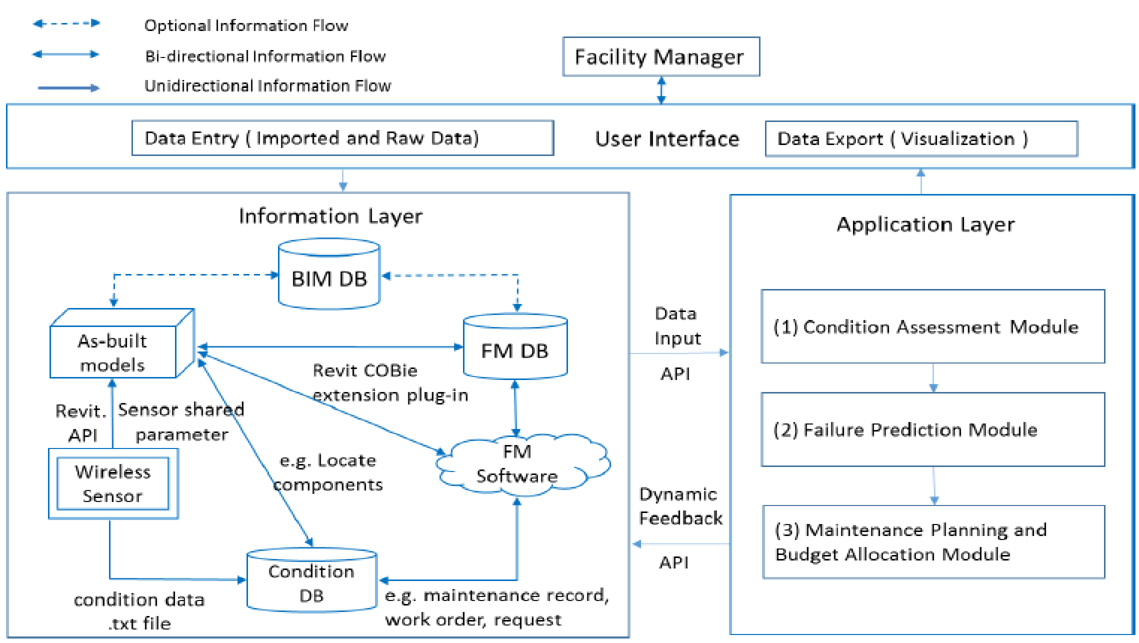

Figure 6 Framework for predictive maintenance management based on BIM decision support system (Source: (Cheng, et al., 2016))

Lin & Su, 2013 researched the BIM-based facility maintenance management (BIMFMM) system and integrating webcam notebook or tablet as an information and tracking tool for the maintenance staff. BIM model is created using Revit Architecture and Revit MEP. To read and information integration with facilities Autodesk Navisworks was utilized. The webcam-enabled notebook or tablet was used as information transformer to the server or client.
The analysis is performed on the commercial building in Taiwan and analysis test is conducted on an escalator in the building. The authors concluded from tests and survey that it is an easy way of updating facility information with the help of mobile devices.

The results showed that the integration of BIMFMM system with tablet or notebook which are webcam enabled is comfortable to perform maintenance management and facilities on site. It enhances the facility works and efficiency. The survey outcome from users also showed 98% satisfaction to adopt this technique for maintenance. This platform provides effective maintenance tracking, monitoring and controlling of equipment in commercial buildings. BIM technology during building use has an immense possibility to enrich facility management works (Lin & Su, 2013)

Kimoto *et al.* mentioned that BIM can efficiently be used for building information on the conventional post-process of architectural design. The major area of the support is for quantity surveys and the master program of the construction project. And reported how BIM is used to choose the methods for Reinforced cement concrete construction as well as wall type of curtain wall design and interiors (Kimoto, et al., 2013).

3.4 BIM in LCC

The authors Shin and Cho in an article exhibited the implementation of BIM in Life Cycle Assessment (LCA) and Life cycle cost analysis for selecting the suitable design alternative. LCA is conducted to find the environmental impact of any material used in the building construction throughout its life cycle. That is the material considered to be less effective for the environment which tends to reach all sustainable goals.

LCCA is the cost of a product or material includes manufacturing, usage, maintenance and until the end of its life. A test was conducted on an office building to find the appropriate material for low carbon emission wall type, highly insulated and durable. A spreadsheet framework is prepared to calculate the LCA and LCCA for the different alternatives.

On implementing BIM at the early design stage, material quantities are obtained accurately and immediately without spending additional time for quantity take-off. Assuming 40years of a lifetime, the operational cost of the building was determined by applying discounting factor. After evaluation of different alternatives, a design was selected which was durable, economical and low carbon emission. A framework is created in BIM to get the details of quantity and energy usage. The information related to machinery and their fuel consumption was unable to determine using BIM. But this can be obtained with the support of COBie spreadsheet. Accuracy verification was not conducted in the case study other than applying to the created framework. Further authors recommended building a library which should include all the information regarding Life cycle inventory database (LCI DB) to perform LCA and LCCA (Shin & Cho, 2015).

Lai et.al concluded that it is possible to optimize the life-cycle cost of a building using Autodesk Revit’s Ecotect software (aim to provide more performing and high energy efficient building). Conversely, the research resulted is not up to the expectations due to the lack of information availability (Lai, et al., 2010).

In general, during quantity estimation, a percentage allowance is provided considering the future uncertainties adjustments during construction. However, BIM produces accurate quantities without resulting additional margin. The additional allowance is an essential factor to account. It is recommended to include such functions in the BIM tool. This could provide a more precise process to manage the life cycle analysis and lifecycle cost analysis. Ultimately, it is required to include a library that has the function to create automatic data to add supplementary to let LCCA for BIM to support forthcoming. That leads to implement required data framework (Shin & Cho, 2015).

Usually, the approximate life of the building is about 30 years. During this period or later there can be a requirement of additional maintenance like repairs, modifications, or renovations where BIM could be an effective tool to keep a record of data and details of building component for better maintenance management and building use (Juan & Hsing, 2017). From the studies undergone about BIM, there are many advantages to adopt BIM in the lifecycle of a building.

In case of failure, it is easy to track if the BIM implemented during the design stage itself and coordinating with MEP (mechanical electrical and plumbing) trade is easy to avoid clashes with other structures. Simulation and integration with building system are also effortless that can save 15% to 40% of the construction cost. Additionally, benefits after construction to carry maintenance work smoothly (Juan & Hsing, 2017).

Kimoto et.al derived LCC of the educational institutions to generate efficient facility management. Due to the greater difference between the predicted cost and actual running cost, the researchers illustrated that the costs for facilities of university buildings depend on the operational policy adopted by the administration. There was an unpreventable expense found in case of repair and renovation under conditionally based facility management. Thus, they proposed a plan for facility management considering the previous data and expenses. Designed the building model showing all the structural and finishing components of building using BIM tool. Finally concluded a preparatory research by tying LCC planning information in a BIM model to determine the effective FM system (Kimoto, et al., 2013).

4 Theoretical Background

This chapter derives the detailed theory of the three concepts involved in the work. A description to Facility Management focusing on services, objectives, operations and maintenance management. Following the focus on Life cycle costing, detail description of cost consideration in LCC and the role of LCC in operation and maintenance. Finally, the third concept Building information Modeling, functions of BIM and software used in the FM phase.

4.1 Facility Operations and Maintenance

Facility operation and maintenance is a servicing method and management of tools to make sure the performance of the building is operating as assigned. Operations and maintenance basically a mundane task required for the building structure and systems. Operation of facilities cannot be processed every day without maintaining, therefore it is a mixture of facilities operations and maintenance in short O&M (Don, 2017).

“Facilities Operations and maintenance acts as supervision in these sections:

- ✓ *Real Property Inventory (RPI):* to maintain and manage asset their facilities and supporting infrastructure.
- ✓ *Computerized Maintenance Management Systems (CMMS):* Process description and measures for maintenance of property and cost related to O&M.
- ✓ *Computer Aided Facilities Management (CAFM):* information related administration like space, lease details, incomes, tenant, and charge-back. Generation and application of information technology-based system in the built environment.
- ✓ *O&M Manuals:* manual of processes, methods, tools, components, and frequencies concerning essential operations and management of the property.
- ✓ *Janitorial/Cleaning:* keeping and maintaining a better environment in building with facilities like internal, external, and ground cleaning.
- ✓ *Historic Buildings Operations and Maintenance:* preserving old buildings and art, maintaining the old system as much as possible to increase their life. However, it is a complicated thing to maintain and retain the old building’s essence.

- ✓ *Project Delivery Methods:* Efficient delivery of the as-built details providing all required details to manage and maintain the physical asset.*"*[6]

Facility operations include 50-75% of the budget assigned for facilities. Facility operation and maintenance involves in these regions; "Plant operations (HVAC and MEP), Energy management, hazardous waste management, recycling, inventory management, communications and wire management, alterations management, relocation and move management, furniture installation, disaster recovery, maintenance and repair, security, and fire and life safety."[7]

Managing the function of these two i.e. operations and maintenance by an administration, organization for the facilities is denoted as Facility management.

Facilities management is a set of all management involving communication, maintenance management, asset management, strategy, precautions, preservations, quality, technology, and services likewise to integrate company, people process, location, and technology to attain the quality of life (Aziz, et al., 2016).

In the earlier definition of facility management was people, place, and process integration for the better living environment. While the updated definition of facility management is "a profession that encompasses multiple disciplines to ensure functionality of the built environment by integrating people, place, process, and technology."[8] Here technology is added newly as there is a gradual up gradation of technology from email to Building information modeling.

The cost of facility management involves two main activities; Operational cost and maintenance cost.

- **Operational cost** is basically the running costs of building use such as; rents, energy cost, insurance, inspection cost, cleaning, local taxes and charges all these expenses to support administrative services to manage the facilities or built environment.

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[6] Website: WBDG Whole Building Design Guide – a program of the National Institute of Building Sciences

[7 & 8] Cotts, et al. The Facility Management Handbook, 3rd Edition, 2010

- **Maintenance cost** covers the cost involved in keeping the building components function without fail by regular inspections and preventive measures. The repair and replacement of equipment also included in maintenance which influences on the constructed assets (Krstić & Marenjak, 2012).

The responsible of O&M is to run the system and its components without fail with gradual maintenance. The maintenance program includes "the optimum mix of reactive time or interval-based, condition-based, and proactive maintenance (predictive/planned) practices. These primary maintenance strategies, rather than being applied independently, are integrated to take advantage of their respective strengths in order to maximize facility equipment reliability while minimizing Life Cycle Costs" [9]

The types of maintenance to be considered as per ISO 15686 are; preventive, scheduled, conditional-based, corrective, emergency, predictive, differed, on-site/off-site maintenance (Krstić & Marenjak, 2012).

Preventive maintenance involves a time-based process which acts as a source for scheduled maintenance, generally comprises minor adjustment of components, cleaning, replenishing, oiling and greasing (Don, 2017).

Predictive maintenance is for restoring the components of the system with repairing and replacing in prior which can be initiated by regular inspection.

The definition of maintenance as stated in ISO15686-1 is the "Combination of all technical and associated administrative actions during service life to retain a building or its parts in a state in which it can perform its required functions."[10]

[9] Website: WBDG Whole Building Design Guide – a program of the National Institute of Building Sciences

[10] Patacas, et al. BIM for Facilities Management: Evaluating BIM standards in Asset register creation and service life planning, 2015

The primary objective of maintenance are:

- To make sure all components of building correlated to services are safe and secure
- The condition of building reaches the living requirements and fit to use
- to ensure regular maintenance work carried permissible to maintain the value of the assets
- maintain the quality of a building (Krstić & Marenjak, 2012)
- reduce overhauls, reduce impulsive failures
- prolonging systems life and attaining Life Cycle cost savings (Don, 2017)

ICT in FM:

The detailed information of asset to the facility maintenance can be stored in a system or software. From which the most supporting systems are Computerized Maintenance Management Systems (CMMS) and Facility Management Systems (FMSs) available in early 1985s. On the other hand, there are a variety of CMMSs and FM systems obtainable in the market that are information collectors and source providers. They are ARCHIBUS, EcoDomus, Maximo, and FM system. Despite this, automatic scheduling is not possible for enormous maintenance work orders from many of the present systems (Chen, et al., 2018). Aziz, et al stated that the development of facility management software emerged during the 1970s which is at the period of email started to use by people in common globally (Aziz, et al., 2016).

There are many softwares developed in supporting FM. The evolution software from 1970 to 2005 is shown in the figure below.

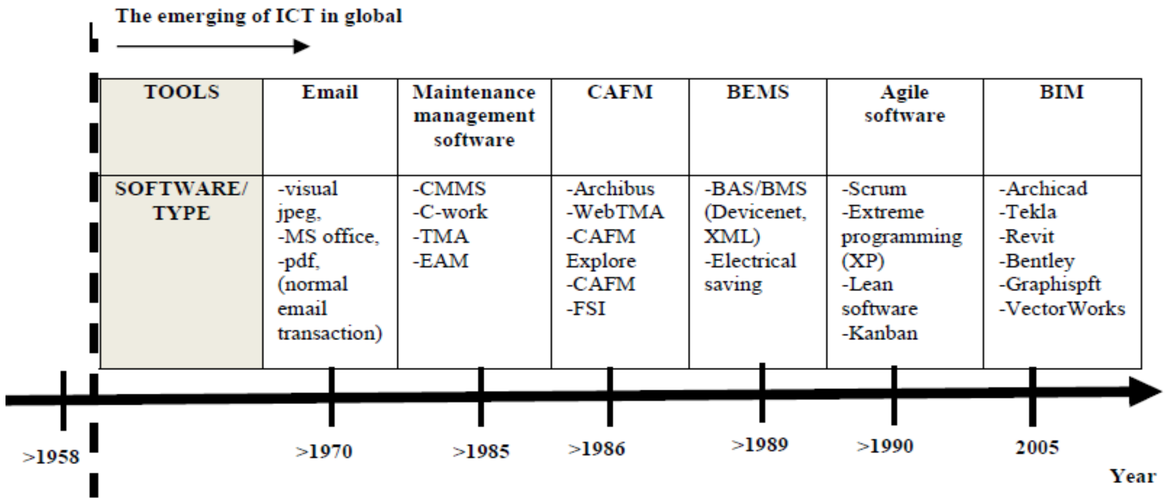


Figure 7 Information communication and technology evolution in FM over 40 years
Source: (Aziz, et al., 2016)

CMMS is basically to track the daily operations, collecting work orders, creating service applications, managing assets, and control records. The other system, Facility management systems (FMSs) or computer-aided facility management (CAFM) systems incorporate CAD (Computer Aided designs) graphical units along with the database management and space management initiated as space planning tool.

Additionally, assist to link other software like CMMS as an information provider. However, both the systems cannot generate a service order agenda automatically and sometimes fails to give exact detail to FM operators (Aziz, et al., 2016). Nowadays a lot of measures are applied to enhance the facilities operations by integrating CMMS systems with Geographic Information System (GIS), Building Information Modeling (BIM), and Construction-Operations Building Information Exchange (COBIE) (Don, 2017).

The facility management emerged from the view of cost reduction to the point of computing its influence on the social orders. Conversely, the growth of information and communication technology in the FM line of work also brought a great difference. Integration of growing technology in FM further leads the business process and management economically efficient (Adama & Michell, 2017).

4.2 Description on Life Cycle Cost

Life-cycle cost of a building provides an overall budget of the project from the initial stage to maintenance and finally demolition. This assists with a feasibility study and eases the owner to seize prim decisions at the initial stage.

The components considered to calculate LCC has a structure called Cost breakdown structure (CBS). In ISO 15686 it is clearly mentioned the various parts involved in CBS defining all the cost components incorporated in LCC. The principle of the CBS is to mention the clear definition of all costs, which are identifiable, allowance to different options of choice, and the possibility to analyze each element in detail discretely. Based on CBS, European committee for construction economics (CEEC) endeavor to issue harmonization of work structure for easy information exchange about construction works. Clear detail of matter according to the area defining in all local terms comforts to measure contrarily adjusting to square meter prices is the main purpose of CEEC code (Davis Langdon, 2010).

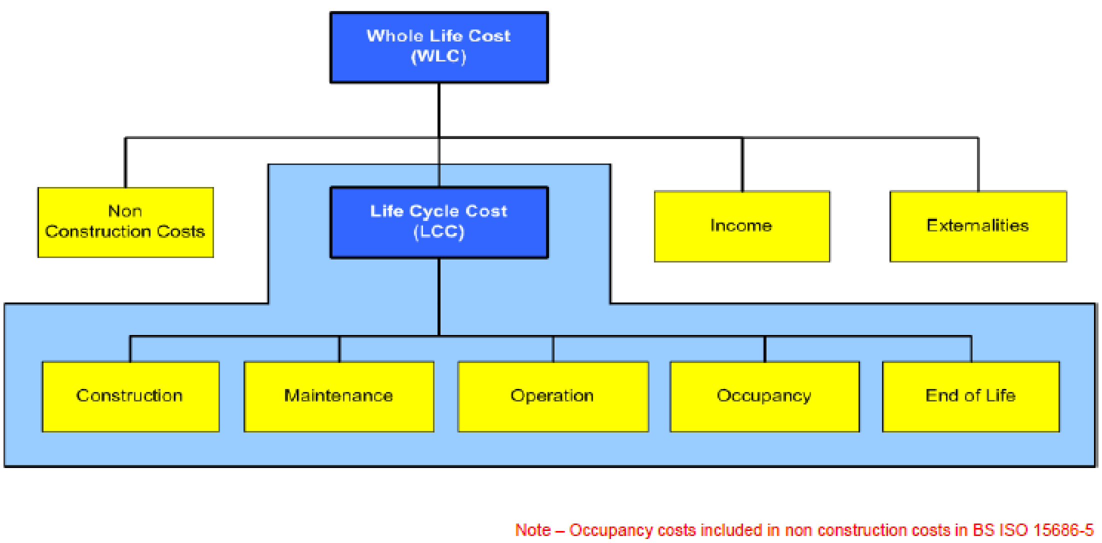


Figure 8 Cost Breakdown Structure as per definitions (International Organization for Standardization ISO 15686-5:2008, 2008)

According to BS ISO 15686-5:2008, Life cycle costing is *"a methodology for systematic economic evaluation of the life cycle costs over the period of analysis, as defined in the agreed scope"*[11]

As per the definition of Life Cycle Cost, the elements involved in calculating entire budget are limited to the process of the project whilst the whole life cycle cost incorporate additional costs like non-construction cost, other income, and externalities (Figure 8)

Whole Life Cycle costing can be defined according to ISO standards *"is a methodology for systematic economic consideration of all the whole life cycle costs and benefits over the period of analysis, as defined in the agreed scope"*[12].

The principal advantage of LCC data is that it can be employed at any stage of work. The flexibility to adopt LCC during construction, post construction, for existing building, refurbishing work, renovation or activity-based works helps to track and maintain the financial plan. Most of the countries follow the ISO standard of CBS while few countries formatted their own standards by adding other details to common CBS which are necessary to include according to the country's criteria. The table 1 below gives the common database of cost elements.

[11 & 12] International Organization for Standardization ISO 15686-5:2008, 2008

Table 1 List of cost items proposed for the common database (Davis Langdon, 2010)

Category	Description
Capital costs	Initial construction cost – capital expenditure. All investments towards completion including decommissioning by the end use of the facilities.
Administration costs	Activities for administration required payments and insurance costs. This requires principles for cost allocation; which cost should be allocated to the individual building.
Operating costs	Include daily, weekly and monthly activities that are repetitive within a one-year period for building and technical installation systems that shall satisfy given functional demands and requirements.
Maintenance costs	Include all activities and efforts put forward in a period of more than one year. For example, planned maintenance, replacement, and emergency repairs, so that the building and technical systems satisfy the original level of quality and functional requirements. The cost for maintenance can in a planning process be determined by making maintenance scenarios, which building parts have to be maintained or replaced, how, and when. It can also be made scenarios for emergency repairs and other maintenance scenarios.
Development costs	Includes activities as a result of a change in demand from core activities, the authorities, total refurbishment, or all activities to raise the construction standards in relation to the original level. This cost here will usually have to be activated, increasing the "value" of the building. The cost of development is more difficult to describe; as they are depending on not known requirements.
Consumptions costs	Consumption includes resources in terms of energy, water, and waste handling.
Energy	All costs related to energy supplies including oil, electric and heating.
Water and drainage	All costs related to water consumption including intake water, wastewater including cleaning
Waste handling	Includes all costs from internal transport, compression, source separation, collecting (hired container), transporting related to waste and taxes for landfill.
Cleaning costs	All activities inside and outside for satisfactorily meeting cleaning demands. Cleaning as an activity in a maintenance process is regarded as maintenance.
Service costs	All non-building related activities in support of the core activities.

A further study of LCC illustrates that it can be engaged in a comparison of discrete substitutes of materials. In figure 9, it shows the cost and maintenance operation and management (MOM) of various marbles and granites along with chosen the appropriate one with viable cost and durability. Marble (M4) was picked in the place of granite even though the investment and maintenance costs are high. This is because the suitability of architectural design. Despite this, the LCC assessment is to provide different alternatives to pick and make an aforementioned judgment (Davis Langdon, 2010).

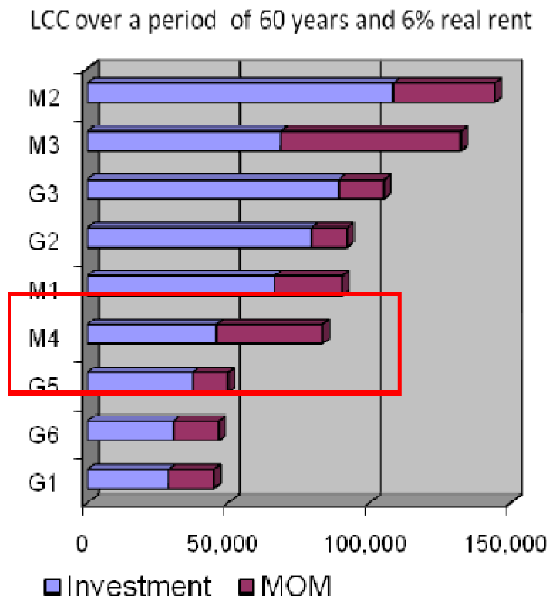


Figure 9 cost and maintenance operation and management of marble and granite

4.3 Case studies relating Life Cycle Cost Analysis

Different case studies are analyzed on Life Cycle Cost in construction. The literature review on LCC ensued that the fundamental purpose is to determine the suitable alternative while deciding the design at the early stage. Nevertheless, it is as essential to consider the operation and maintenance stage because it has the maximum life that cannot be neglected.

Several research works are studied to examine the role of Life Cycle Cost in facility management and its importance. Relevant cases are analyzed to gather the information related to the subject. Out of all the examined researches, eight suitable cases are considered in this report. The cases demonstrated below are chosen from the perspective of the operation and maintenance stage. The first two cases are from the same author in which two distinct buildings are considered for the study. Similarly, the last four case studies are gathered from the same research work from the same author. Each case has a different determination regarding Life Cycle cost. Analysis of all cases is done at the end of this chapter.

4.3.1 Case 1: Life Cycle Costing – A feasibility study

'Life cycle costing as an important contribution to the feasibility study in construction projects' by Renata Scheiderova Heralova (Heralova, 2017)

Here the author proposed two different buildings cases to conclude the contribution of Life Cycle costing towards a feasibility study. The primary aim is to find the total life-cycle cost of building in various view to make a feasible decision.

A feasibility study is a preparatory analysis to get the possible outcome of a construction project cost having different alternatives. This benefits to decide the reasonable proposal at the very beginning of the project. Feasibility study assists to cultivate further documents related to the business case and strategic planning.

Building 1: Supreme Audit Office (SAO) in the Czech Republic is an independent function to take care of auditing in the Czech Republic related to the economic activities. This office of the supreme audit is 40years old and leased of net area16955 m^2 and built volume of 70000 m^3 and choice is made to purchase the same office building. The feasibility study considered whether to buy the same office or build a new one. The estimated cost is derived for 20years and calculated LCC for two alternatives (Table 2).

Table 2 LCC of alternatives, Study period 20years (Source: (Heralova, 2017))

Description	**Current rental office**	**Building a new office**	**Purchase of current office**
Construction cost/purchase cost *(€)*	0	21.050.000	15.200.000
Rent *(€)*	12.400.000	1.860.000(a)	0
Operating cost *(€)*	11.200.000	8.140.000(b)	11.200.000
Maintenance and renewal cost*(€)*	0	3.590.000	10.320.000
Total *(€)*	23.600.000	34.640.000	36.740.000
Salvage value (estimate) *(€)*	0	15.000.000	10.000.000
Total LCC *(€)*	23.600.000	19.640.000	26.740.000

a) rental cost in current office (620.000 EUR/year) during the construction of the new building (3 years)
b) operating cost in current office (560.000 EUR/year) during the construction of the new building (3 years), operating cost in new seat 380.000 EUR/year

From the Table.2, the total cost for purchasing the old building and the cost for O&M exceeds about 83% then a new building which is very huge. Since the building is old and operating and maintenance cost is high. When comparing the total LCC cost of each scenario building a new office base is more feasible than purchasing the same building and spending the excess amount on maintaining it.

From this feasibility study, the committee of SAO office decided to go for new construction, the total life-cycle cost of this alternative is lower (see Table 2). The payback period based on the cost savings on rental cost (620.000 EUR/year) and operating cost (180.000 EUR/year) was calculated. 26 years is an acceptable payback period for the public sector because it is shorter than economic, technical, physical and utility lifespan. The construction work for the new building is already in progress (Heralova, 2017).

At this point, the focus is mainly on operating cost for 20years. The construction cost for the new building is naturally high but when considering operating and maintenance there is a huge difference. Even though considering operation cost of old building with reduction of 40% total and arriving value for 20years (assuming 40% reduction as it is older), the cost variable from new construction surpass 10% as shown in Table 3.

Table 3 Comparison of operation and maintenance cost

Description	**Building a new office**	**Purchase of current office**	**Remarks**
Operating and maintenance cost for 20years after the construction phase*(EUR)*	11.730.000	12.912.000	Adding of operating and maintenance from table 1 and deduction 40% in current office
Current operating and maintenance cost for 20years*(EUR)*	11.730.000	21.520.000	The estimated value for 20 years as per data

The study of feasible decision logically conveys that the construction cost of the project is high due to the adoption of good raw materials and systems to save functioning cost throughout the lifespan. After examining the functioning cost alone of supreme audit office, service cost is excessive than production cost. Likewise, the overflow of operating cost can be reduced wisely while quantifying the entire budget of the life cycle.

Building 2: Depository building for Náprstek Museum of Asian, African and American Cultures is the second case accounted by Heralova. The purpose is to build a new gallery for the museum which could accommodate important national and international exhibits of more than 150,000 count to preserve them about 50 years beyond in 4600m^2 area.

The feasible analysis is carried out for life cycle costing of the economically sustainable project. The calculation is conducted in three ranks – maximum, minimum and average values (Table 4). The construction budget is collected from the database of the author including the price of the similar project. Operation, maintenance and renewal price for feasibility evaluation is accounted from the reference project.

Table 4 LCC of depository building, Study period 20years (Source: (Heralova, 2017))

Description	Minimum(EUR)	Maximum(EUR)	Average(EUR)
Construction cost	2.880.000	3.600.000	3.240.000
Operating cost	1.500.000	2.300.000	1.900.000
Maintenance and renewal cost	580.000	720.000	650.000
Total LCC *(EUR)*	4.960.000	6.620.000	5.790.000

The results are recommended to initiate investment plan for project construction. According to the outcome of possible findings, the operating maintenance price is obtained from the reference building. For the study of sustainable buildings, the initial budget is always high, and it is challenging to conclude the economically sustainable project. If the project proposed is sustainable, the post-construction cost is simultaneously less compared to the normal building structure. Due to the lack of data and records, the budget for services considered in the case study is as per reference building. The functioning of sustainable materials and system are unable to reflect in the estimation. Therefore, the evaluation of exact quantity is inconsistent.

4.3.2 Case 2: Suitability of LCCA as asset management

Suitability of life cycle cost analysis (LCCA) as asset management tools for institutional buildings (Kshirsagar, et al., 2010)

In the research article, the author selected a case study to examine the accuracy of estimated cost over the actual cost of the life cycle. Institutional buildings are considered for the study. Three completed building with 38 to 109 years old is considered to examine. All the data for the buildings are collected from contracts and university database. The data were converted to 2003 dollars from the economic table as a baseline. Present worth annuity (PWA) factor is applied to find the estimated cost. The discount rate is 6 percent and the PWA factor is 28.87. Below table 5 gives the detail of all the cost involved at each stage of three buildings life comparing estimated and actual cost.

Table 5 Estimated cost vs. actual cost of Building A, B and C (Kshirsagar, et al., 2010)

Description of costs	**Building A 109 years old**		**Building B 38 years old**		**Building C 50 years old**	
	Estimated $	Actual $	Estimated $	Actual $	Estimated $	Actual $
Construction	1388750	3897191	2200360.86	4118263	7296785	12852852
Utilities	1310042	0	1176028	0	4697936	0
Maintenance	7860025	442661	705617	393822	2818762	1304392
Custodial	476855	559551	428061	304885	1710049	1840611
Administration	262008	28120	235206	30145	939587	134974
Replacement	105484	59380	848922	2643431	226742	420441

Data for actual utilities cost is not available and tracked. From the calculated data, the actual maintenance cost for Building A, B and C is about 50% of their estimated cost. However, there is a recognizable difference between the actual and estimated cost of all the type of costs. Although maintenance cost exceeds in the estimated budget than actual which look like a planned estimation to avoid prevention and excess cost in actual. It is essential to have planned estimation with some margin and many of organizations follow. The procedure is constrained to predict actual value due to lack of data tracking. The author also concluded that the method is more suitable to compare alternate building systems and types than predicting facility performance.

4.3.3 Case 3: Role of FM in building projects

'The role of facility management in building projects' (JENSEN, et al., 2009)

The conference paper of this research focused on the theoretical knowledge transfer to implement facility management in the building process. The result of observation from building project of Danish broadcast corporation and FM best practice in European countries with 36 case studies (JENSEN, et al., 2009)

The author proposed a theoretical study of knowledge transfer in the front end and back end of the project to find various requirements during the design process and fulfilling needs after construction. The difference in knowledge transfer is further analyzed by applying the concept of continuous briefing and continuous commissioning.

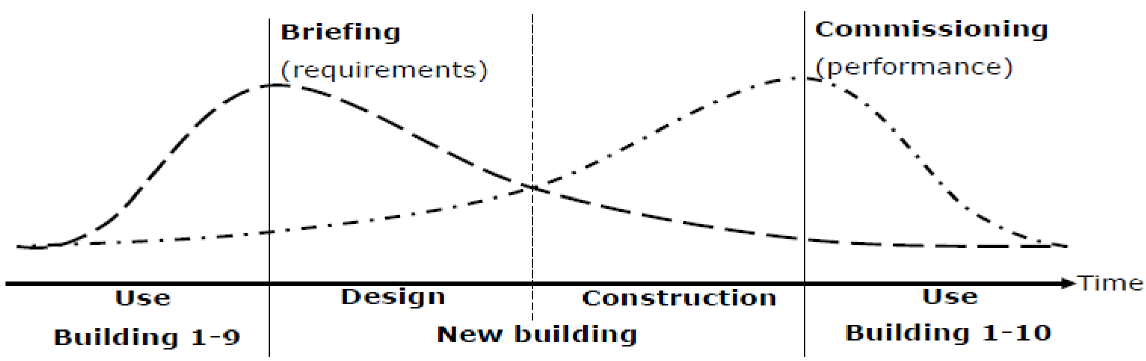


Figure 10 The pincer movement of FM on the building process (JENSEN, et al., 2009)

The difference in the briefing (requirements) and commissioning (performance) lead to predicting the barriers to carrying the requirements until the end of projects life (Figure 10). The major findings in obstacles are Project related, legislative and structural, competence-related and sociological barriers. Form the barriers author projected the solutions for project related obstacles and best practice, the participation of clients and facility manager and life cycle costing. On engaging in these solutions, there can be a complete information transfer from the front end to the back end of the project process.

The author concluded using the LCC approach FM and maintenance practice can be implemented in building projects. Although the implementation of LCC is to select low-cost alternative design process without approving for excess budget incurred. However, in several cases, there is a partition in facility management and construction phase responsibility causes conflicts and difficulties in the financial plan. Nevertheless, it can be integrated into public-private partnership projects considering maintenance manager as a part of client association. Jensen et.al also suggested that visualizing O&M costs separately for material and installation provides a better understanding to other stakeholders in relation to choose of implementing FM in design (JENSEN, et al., 2009).

4.3.4 Case 4: Promotion campaign of LCC by Davis Langdon

Development of a promotion campaign for Lifecycle costing in construction (Davis Langdon, 2010)

In this report, the author tried to exhibit projects of European countries to understand the complete detail of LCC and how it is employed in different countries. Here four of case studies are reviewed out of 15 case study from 11 different European countries to relate with research goal.

Building 1: LCC is implemented in the project Kuopio Taxation House Finland for refurbishment work. Life cycle assessment of HVAC system integration to choose the most economical and efficient system. The various costs included here are investment cost, heating, cooling, and electrical energy costs (over 15 years) and maintenance cost over 5 years (due to owner's restriction to process new tender after 5years). 2.3 million euros budgeted for renewal of HVAC system out of 8.6 million euros total budget. Two alternative cost analysis of the integrated systems are proposed in comparison with the traditional system. The detail of analysis is given below in table 6:

Table 6 Kuopio taxation house LCC for refurbishment -2009

Description	Traditional A	Integrated B	Integrated C
Investment cost	1 535 000	1 605 000	1 815 200
Maintenance cost (5yrs)	147 500	135 000	136 800
Energy costs	748 900	684900	726600
Total LCC	2 431 400	2 424 900	2 678 600

The integrated system is considered to ensure the low energy consumption options. As per that, the estimated amount for alternative B is minimal compared to the traditional cost of about 10% and energy consumption in case B is also less. Moreover, operation cost and energy cost obtained is less. This examination enables the client to decide the suitable system to adopt. Furthermore, the approach assists to evaluate the possibilities of both cost and life cycle effective solutions.

Building 2: Rikshospitalet project in Norway

Large hospital project started construction in 1988 and completed in 1998 but in operation about 10years and finalized in 2000. However, the first 6 years endured to numerous refurbishments. The building was already been built using LCC assessment in the beginning. The current study is to compare the old evaluation with the real-time operation costs. The client interest is to assign management, operation, maintenance (MOM) over LCC to measure the difference. Therefore, all the stakeholders were involved. The calculations of LCC is drawn from three level version with service period of 60years. Firstly, the concept stage is a general review of building cost and factors. Secondly, by standard requirements of Key Performance Indicators (KPI) and finally using different alternatives of building components.

The initial investment cost in 1988 was 334 million euro and estimated operation cost as per NPV is 84 million euros operational cost per year of 100000 m^2 area (Total area available 140000m^2). The calculation is done according to three levels and final counted budget for entire lifecycle is 670 million euros. There is a drastic difference of 40% from initial LCC due to the extension of two year of service period from 1998 to 2000 and additional cost incurred for the extension of building in remaining 40000 m^2. The running costs are mostly accounted on assumptions from the deducted amount which don't have an exact prediction.

In the ten years of service, initial 6 years undergone many refurbishments because of increasing the floor area which had a huge impact on business as well. The maintenance and operational costs are financed from the sinking fund that was budgeted on an assumption which resulted in massive variation in costs.

Building 3: Uppsala Entrance, Sweden

The project is a residential type consists of 7 buildings with 90 apartments and around 15 million euro is the budget for the development of the element. The purpose of the building is to design in the view of the green housing, hence the life cycle cost of renewable sources are predicted over district energy cost for the period of 30years. The below table gives the complete LCC of different energy sources:

Table 7 Life Cycle Cost of energy generation – Heating and electricity

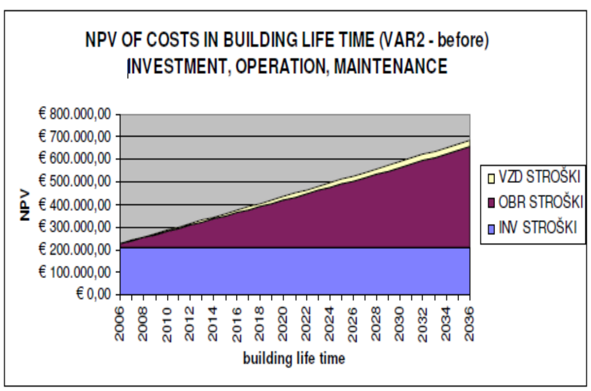
	District Heating	Pellets (2 sup.)	Air thermal solar collect (1 lev.)	Flat therm. solar collect (1 lev.)	Combined solar collector/ suncells (1 lev.)	HAWT (1 lev.)	VAWT (1 lev.)	Silicon Suncells (2 lev.)
Investment cost	150 000	1 050 000 (200 kW)	428 000 (41 kW)	462 000 (110 kvm)	630 000 (100 kvm)	665 000 (25 kW)	600 000 (25 kW)	540 000 (200 kvm)
Annual maintenance cost	5000	11 000	9100	9100	7000	10000	9000	9000
New investment cost	0	525 000 kr (20 år)	278 000 kr (12 år) 139 000 kr (24 år)	312 000 kr (15 år)	96 000 (25 år)	258 000 kr (20 år)	90 000 kr (25 år)	0
Technical lifespan/ calculationperiod (year)	30	20/30	12/30	15/30	25/30	20/30	25/30	30
Produced heat (kWh/year)	0	361 000	61 000	49 000	24 300	0	0	0
Purch. värme (kWh/year)	361 000	0	300 000	312 000	336 700	361 000	361 000	361 000
Produced electricity for internal use (kWh/year)	0	0	0	0	6000	20 000	20 000	22 000
Produced elecricity sold ext. (kWh/year)	0	0	0	0	0	10 000	5 000	0
Köpt el (kWh/år)	32 000	32 000	32 000	32 000	26 000	12 000	12 000	10 000
Total present cost (kr)	5 121 000	6 075 000	5 045 000	5 139 000	5 254 000	5 239 000	5 121 000	5 028 000
Energycost per produced/bought kWh (kr/kWh)	0,63 (0,63)	2,34 (0,63)	**0,57 (0,63)**	0,65 (0,63)	0,83 (0,63)	0,75 (0,63)	0,63 (0,63)	**0,53 (0,63)**

Note: Orange columns- Heat generation, Green – heat and electricity, Blue-electricity
VAWT – Vertical axed wind turbines HAWT – Horizontal axed wind turbines

The net present value of all the different components are evaluated as shown in the table. The annual maintenance cost for district heating is the cheapest following combined solar collector and it includes all kind of energy. But from the results, solar panels, installation and air silicon solar panels and cells look cheaper with the available subsidies than district heating and buying electricity (Davis Langdon, 2010). Wind turbines HAWT, combined solar collector, and pellets are also expensive. The feasibility study provided diverse alternatives to select the suitable one in line with cost.

Building 4: Steletova Social Housing Refurbishment, Slovenia

The building consists of 8 blocks in the net floor area of 3800 m^2 and 60 apartments in total. Construction of building completed in 1977. Because of excess, operational cost owner decided to refurbish the building to save maximum energy. Thus, to decide low-cost low energy performance, LCC is applied for feasible analysis. The analysis is taken place in two service period 30years and 60years. Various alternatives are measure with existing and refurbishment, changing window and ventilation, refurbishment of advanced version, or renovation and replacement etc. The energy consumed for heating for before (var 2A) i.e. existing condition with maintenance (replaced windows and façade), no thermal improvement with actual energy consumption (before in 2006/2007) and after refurbishment (var 5a) i.e. renovation with low energy allowed windows and wall, mechanical ventilation with actual energy consumption data (after in 2008/2009) are evaluated. The results of energy consumption and carbon emission in the primary case are 244,990 KWh/a and 127,738 Kg CO2/a respectively. Whereas in lateral case 181,150 KWh/ a of energy consumption and 94,452 Kg /a of carbon emission. The operation and maintenance cost for suitable refurbishing method was analyzed and shown in Figure 11 the cost NPV of the difference of variables are calculated.



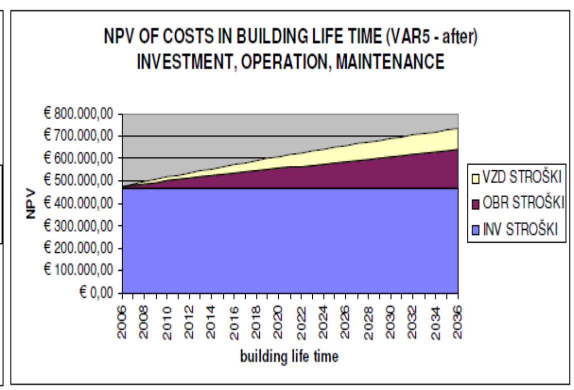


Figure 11 Net present value building lifetime of two variables before and after (Davis Langdon, 2010)

Investment cost is shown in blue color and violet shows operational costs and yellow to maintenance cost. In the second case after renovation, the investment cost is the high and operational cost is low with regular maintenance of slightly higher cost. The net present value (NPV) for 30 years before refurbishment and after refurbishment are €676,847 and €1,071,713 respectively. NPV for 60 years would be €1,110,974 for before and €1,427,608 after renovation. In case of improper heat recovery from mechanical ventilation and/or not installed in all parts of building the NPV of renovation for 60 years is €1,172,425 which is almost equal to the previous variable. Although the cost is high in case of renovation, the importance is given to reduce energy consumption with low carbon emission so as to reduce operational cost. The study provides the several variables to make a feasible decision considering all the aspects of social, ecological and economical.

4.3.5 Analysis of case studies

To start with the analysis, a concise note will act as a support. The analysis of cases is initiated with a brief note of all the case studies in a table. The description of the study, the concluded result as per the authors' statements are mentioned in table 8. Further analysis is illustrated later as per the given description.

Table 8 Description of case studies relating LCC

Sl. No.	Case studies	Title	Description of the study	Results
	Case 1	'Life cycle costing as an important contribution to the feasibility study in construction projects' by Renata Scheiderova Heralova		
1	Building 1	Supreme Audit Office (SAO) in the Czech Republic	Feasibility study between purchasing the old building and new construction	Feasibility studies to find the most cost-efficient solution, design to determine an in-service budget for the owner, the most economical bid proposal, or to choose the optimum operation and maintenance strategy
2	Building 2	Depository building for Náprstek Museum of Asian, African and American Cultures	Feasibility study for the economic sustainability of construction project	
3	Case 2	'Suitability of life cycle cost analysis (LCCA) as asset management tools for institutional buildings' by Kshirsagar, et al.	Estimated versus actual cost	suitable to compare alternate building systems and types than predicting facility performance

4	Case 3	'The role of facility management in building projects' by JENSEN, et al.	Theoretical knowledge transfer to implement facility management in the building process	Using LCC approach, FM and maintenance practice can be implemented in building projects
	Case 4	'Development of a promotion campaign for Lifecycle costing in construction' by Davis Langdon		
5	Building 1	LCC is implemented in the project Kuopio Taxation House Finland for refurbishment work	Life cycle assessment of HVAC system integration to choose the most economical and efficient system	the approach assist to evaluate the possibilities of both cost and life cycle effective solutions
6	Building 2	Rikshospitalet project in Norway - Large hospital project	Comparison of old evaluation with the real-time operation costs	There is a drastic difference between initial LCC and real-time cost
7	Building 3	Uppsala Entrance, Sweden - Residential building	Life Cycle Cost of renewable sources	The feasibility study provides diverse alternatives to select the suitable one in line with cost.
8	Building 4	Steletova Social Housing Refurbishment, Slovenia	refurbish the building to save maximum energy	Low energy consumption with low carbon emission so as to reduce operational cost.

The case studies opted here are related to Life Cycle Cost and its application in different scenarios. Most of them are applied for a feasibility study as the LCC analysis is to provide substitutes for making feasibility decisions. Two of them are focused on the comparison of estimated cost with actual costs.

In the first two cases of the feasibility study, the results obtained from analysis created a way to decide the suitable option in terms of budget. There is a difference of more than 10% of the total amount of the two alternatives in the first case. In the second example, for determining the LCC of the economically sustainable project, the three alternatives provided having a difference in cost about 15% from maximum to average and minimum to average. The study presented the most economical choices minimum, maximum and average costs to select a suitable one. In the third example case, there was a drastic difference between the estimated cost and the actual costs.

The four case examples from Davis Langdon gave a diverse conclusion about LCC. In the case of Kuopio taxation house refurbishment work, there was a variation of 10% between traditional and integrated choices which concluded to select integrated model B of less operational cost as well as low energy consumption. The feasibility study of LCC gave an appropriate result to carry out the work.

In the 6th case for the hospital building, the old evaluated cost is completely varied from the actual cost. The cost expenditure during the lifetime was totally high which could not justify the Life Cycle Cost prediction made during construction. The evaluation was compared for the 10years lifetime of the building. During the 10year period, there were numerous refurbishments works took place. The additional expansion of the building, reconstruction, and maintenance of the current building at the time of floor expansion was the primary reason to show this excess operational cost.

Another case study is to determine the LCC of energy source from the perspective of creating a greenhouse. Comparison of low energy low-cost renewable source over the district energy. Operational cost for solar flat panels and cells found cheaper than conventional energy. In the last case of social housing refurbishment, the owner's aim is to reduce energy consumption as well as carbon emission. Analyzing the economical alternative for the refurbishment, different approaches were studied and LCC was evaluated for all the proposed variables to choose the appropriate one.

The LCC analysis grants various substitutes according to the financial circumstance that allows the owner to choose the appropriate proposal. However, in the case studies represented, the LCC evaluated at an early stage of construction did not have proper backup or data to predict accurate budget. Even though the predicted net present value provided a way to make decisions, the actual cost or operated estimations are not determined yet to confirm the optimization level of Lifecycle costing in facility management phase.

The studies which determined life cycle cost in later stages for refurbishment or renovation resulted in the most predicted value which showed that Life Cycle Cost has enormous benefits during the operation and maintenance phase. Due to the lack of information, and less amount of standard procedure to track the estimated budget in the later stage of the building's life, it is not giving a way to justify LCC advantages. However, the LCC evaluated for the refurbishment work ensued to optimize the operational cost. Thus, LCC has a greater impact during a running time of building.

The benefit of Lifecycle cost analysis is not only for the economic purpose but also to support sustainable building practices. The whole evaluation of financial consideration at the decision phase results in Life Cycle Cost whereas to calculate the strict budget to match the future expenses is always difficult. However, LCA (Life-cycle cost analysis provide a way to examine the system, raw materials, and cost incurred in each system in its useful life and also the cost for external methods. External methods basically relate to additional cost to procure material such as transportation or shipping charges. Thus, the analysis for the feasibility study provides a more detailed financial account which can meet the actual costs (Cotts, et al., 2010).

Two steps can be followed for the analysis; primarily to set a time frame to do analysis which can be done during the contract stage for the selection of product or system. In the second step, cost-oriented analysis can be performed considering the cost from acquisition to operation and maintenance of any system (Cotts, et al., 2010).

The most necessary requirement for building's service is energy in different forms. The consumption of energy in the form of heat and electricity in the construction industry is typically high which characterize about 30% of the building's operational expenses of the building. It is noticed that in California decreasing energy usage of about 30% can proportionate to reduce of building functioning cost up to $25,000 per annum for managing every 50,000 square feet. Financing $1 for energy efficiency will apparently raise the estimated asset value of the building by $3 (Cotts, et al., 2010).

The analysis of building system, materials or equipment in beforehand facilitates to minimize operational cost to the maximum extent. The major expenses in building use are caused by energy consumption, although, the other miscellaneous expenses are comparatively less. Driving down the energy consumptions can reduce the operational cost of about 10-30 percent depending on the type of usage. Therefore, opting suitable building components, examining their duration and quality, verifying the components lifetime budget instead of an initial low price is imperative. Because the lifetime of building components reflect the duration of building use. It is important to adopt Lifecycle Cost Analysis and Life Cycle Costing during design phase which leads to find the sustainable economic alternative.

We have found a lot of benefits from Life cycle costing and analysis. Even though the study or examination is not only limited to early stage, it is necessary to know the later impact and analyze whether the predicted cost is matching with actual running cost. There are very few studies exhibited the comparison. In most of the researches, the major limitation found was the available information and lack of data storage and transferring of as-built information to facility management.

There is a gap between pre and post construction to transfer data. Due to the lack of data transfer and lack of availability of completed projects after implementing LCC, the conclusion of the percentage benefits was hard to determine. Most of the projects which carried by integrating LCC are needed to preserve data and relate the evaluation with actual performance to show the overall result of LCC.

In case of further development or changes in the building during the useful life, many a times information of building and design were vanished or insufficiently available of data. For this reason, it is difficult to carry the maintenance work, require additional effort and pay for the maintenance and operation activity. Hence building information modeling can be adopted to minimize these risks in construction projects.

The literature study brought about immense advantages of integrating BIM not only at the design and construction phase but also at the time of the operational phase. The further study of BIM in facility management phase, how this can be incorporated and its benefits to decline facilities costs are discussed in the next chapter.

5 Adopting Building Information Modeling

BIM is noted with different abbreviations Building Information Model, Building Information Modeling, or Building Information management. It is used in the form of tools called BIM tools, BIM technology, BIM software, BIM system, or BIM modeling tools (Jaspers, 2016).

It can generate a database of building assets information in digital form and encourage virtual collaboration among facilities and construction (Chen, et al., 2018).

From the BIM Handbook, “We use BIM as a verb or an adjective phrase to describe tools, processes, and technologies that are facilitated by digital, machine-readable documentation about a building, its performance, it's planning, its construction and later its operation. To describe the result of the modeling activity, we use the term ‘building information model,’ or more simply ‘building model’ in full.”[13]

The definition of BIM as per National Building Information Modeling Standards (NBIMS)- “an improved planning, design, construction, operation, and maintenance process using a standardized machine-readable information model for each facility, new or old, which contains all appropriate information created or gathered about that facility in a format useable by all throughout its lifecycle. (Eastman, et al., 2011)

According to NBIMS – three kinds of BIM models, (a) product, (b) ability to deliver open electronic standards, an IT aided and an integrated process, (c) a need of life-cycle facility management.

Concisely the significant view of BIM practice are:

- Reducing project duration, Collaboration
- Minimize costs, quick identification of quality concerns
- Associating end to end design and construction process i.e. lean principles (Jaspers, 2016)

[13] Eastman, et al., 2011

There are enormous advantages of BIM in project construction is a known factor. However, what is it after construction when in use? The BIM facilitates to provide vital possibilities for adopting (Figure 12).

Commissioning; to transfer information and asset data for the purpose of operation in detail without missing any documents.

Early participation of FM during project design is possible due to the collaboration and accessibility for all the members. This helps facility managers to analyze adopted systems, components details and an opportunity for them to suggest quality materials, affordable price to use in the perspective of operation and maintenance. FMs have the opportunity to keep track the bills in CAFM (Computer-aided Facility Management) or IWMS (Integrated Workplace Management System) systems and estimate the O&M cost prior to design period.

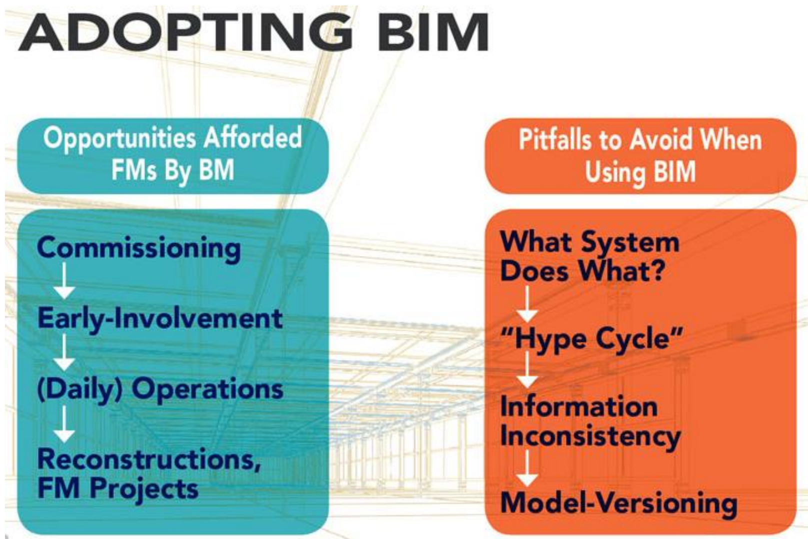


Figure 12 What is BIM for FM? (Source: (Jaspers, 2016))

Daily operation; requirements of distinct equipment and risks involved can be predicted early. Building design and Bill of quantities are available for FMs with all data. It is effortless while Reconstructing or modifying the building use when there is a track of all details available. Proper maintenance of the BIM system of a project, eases the projects run, reduce time and cost.

Reconstruction using BIM benefits in financial returns. All the modified design and geometry is updated again for reconstruction and alterations in a new version (Jaspers, 2016). With all these advantages and ease in transfer of data with BIM effectively can mitigate up to 98% of the time taken to update FM information details or databases.

Important BIM standards to figure out accurate exchange of information are

COBie and IFC

COBie – delivery of information

- Improves the data associated with an asset
- Organized data storage and documentation
- Enhance interoperability between FM systems and BIM

IFC – Object-oriented with geometric information

- Generic file format
- Data mapping and data integration (Chen, et al., 2018)

To fill the space from design, construction, and operation and maintenance by merging the FM process among them, COBie endeavor to make use of open electronic information standards offered by IFC (Jaspers, 2016). Whilst the design data can be operated, organized and information shared with the help of IFC. It is dense to colonize all IFC information in the project and perhaps IFC is not essentially passable for all exclusive phases of lifecycle facilities. For this reason, COBie appeared as one of the superior standards in BIM for facility management (Yalcinkaya, 2017).

Autodesk Inc. created a junction called COBie extension to link Revit with Facility management systems with the help of COBie. On updating this assemblage in Revit, COBie embedded BIM model can be obtained, meanwhile, it is also accessible to fix some factors related to equipment information like the pledge, parts record, components list, and other data related to products. Furthermore, the junction can communicate to both the parties FM and BIM model by transferring spreadsheet data among them *(Cheng, et al., 2016)*.

However, to get the high-quality model of Revit by omitting errors, to verify Revit models, another plug-in is formed called Autodesk Revit Model Checker. This helps to check the errors and adopt the change as per requirements (Cheng, et al., 2016). This is how BIM software can be integrated with facility management software.

The integration will help to retain asset information without mislay. In fact, it is easy to process maintenance work orders, track inspection details, identification of damages and prolong the building service life. In support of BIM in facility management phase and its benefits, few of case studies were analyzed and discussed in the next unit of this chapter.

5.1 BIM-FM Case studies

So far, the research showed the applications of Life cycle costing and its economic advantages to minimize O&M cost. The literature review about BIM displayed the assistance function concerning Building information modeling technology in the post-construction phase. Now the further case studies illustrate the pros of implementing BIM tool to optimize the operations and maintenance cost to the maximum extent.

5.1.1 Case 1: BIM in remodeling and LEED

Courtyard by Marriot, BIM in remodeling and LEED (Leadership in Energy and Environmental Design) Certification by Eastman et.al.

A Toronto National building was decided to renovate completely and convert it to contemporary hotel adding three extra floors to existing 13 floors building. Overall renovation, replacing façade and system to match hotel requirements. Here Revit software is used to develop the model. The feasibility decision made is to bring a new system in the existing product instead of demolition and reconstruction. This assessment encouraged to lessen the use of resources and the design is formed to reduce energy consumption and meet the sustainable goals.

Initially, the description of the building is obtained from laser scanning technique, later the interactive process carried out from the BIM models. The building of the Revit model after scanning became the main cause of data to assist LEED certification. LEED is from U.S. green building council which involves in energy consumption, water, carbon emission, impact on the environment and thus produce sustainable design framework to implement in building lifecycle. Revit model acts as a base for developing energy model formed in Trane Trace™ (for energy simulation calculation) in the event of energy savings.

Adoption of BIM in the project gave access to coordinate among various departments and incorporating LEED techniques allowed to save maximum energy and benefited in saving building's operational cost. During the first year, the cost saving in operation is $52,355 and estimated cost saving for 10 years is $676,331.

Low energy usage systems (provide high performance and efficient) and less water demand (due to dual flush toilets, low flow back of house fixtures, and low-flow faucet aerators) (Eastman, et al., 2011) leads to sustainable approach direct to a maximum saving of operational and maintenance cost from the above case.

5.1.2 Case 2: BIM implementation during handover to facility management

Building Information Modeling can be implemented at any stage of building lifecycle to ease the workflow and improve coordination among the participants.

Here is a case study picked up from BIM handbook which illustrates the BIM implementation during handover to facility management of a hospital building called Maryland General Hospital. The model using BIM designed in the later stage of construction while detecting clashes to collect data information and with documents regarding equipment. The same used for facility management by handing over to the clients. The firm worked for this project is a construction management corporation named Barton Malow Company (Eastman, et al., 2011).

To maintain accurate and proper transfer of information from construction to facility management, the company adopted BIM to deliver as-built data for efficient maintenance and management of facilities.

At the stage of construction, it was difficult to coordinate complex information of MEP system installation, thus implemented BIM to ease coordination and efficient workflow. The construction management is carried out using BIM software

Tekla Structure and for information collection CMMS system, Tiscor is used. In Tiscor system, all the required data for facility management with accurate asset information are incorporated. It helps in monitoring performance, safety, precautionary inspections, and planned time for replacement of maintenance. A barcode system is made to record all the data of equipment type, location, name, and ID using a simple barcode. The software used to produce this code is Bartender.

To access all the information in the field using a tablet, a software is used developed by Vela systems. This Vela software can be used in offline mode as well. So, the data generated in the field can be captured from this software is updated in the Tekla model when online. On running the combined connector of Vela and Tekla .xml file is created and this final .xml file is imported to Tekla (Eastman, et al., 2011). Thus, all the documentation related to the building is available in an automated format (Eastman, et al., 2011).

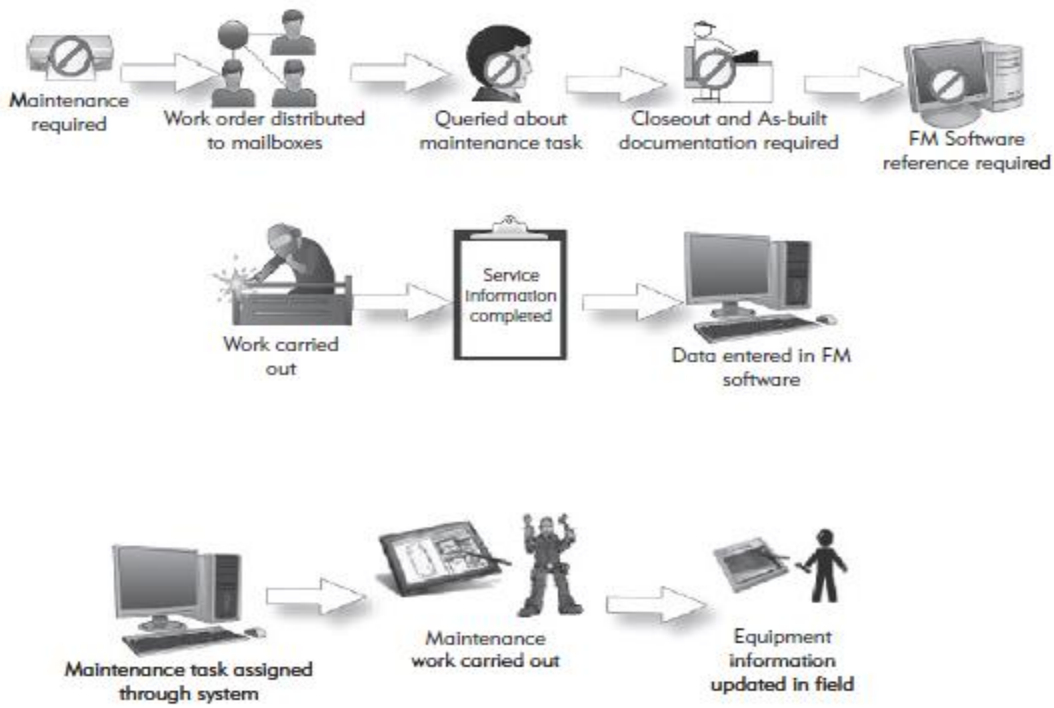


Figure 13 Maintenance workflow in the old process (First two rows) and new process (last row electronically)

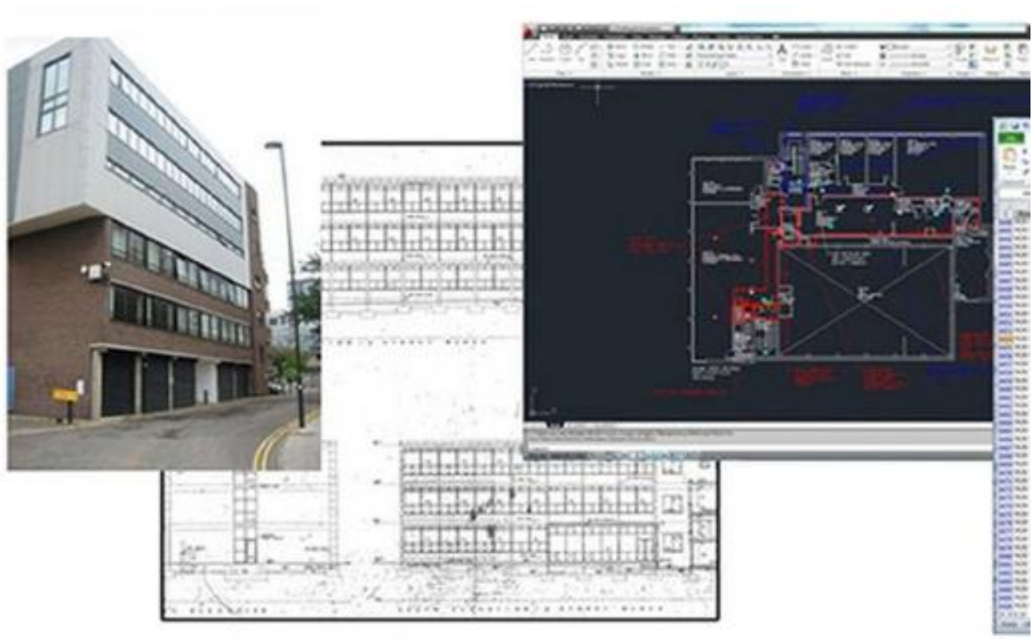
The advantage of BIM implementation in maintenance order is, easily assigning of the work orders, inspections are done electronically updating checklist, availability of all information about service calls. Thus, the workflow can eliminate some parts to save time and money from the electronic database availability (Figure 13). It is easier to pass the details electronically and save maximum information without loss which aids to save time as well as cost.

5.1.3 Case 3: BIM in facilities management applications

BIM in facilities management applications- a large university complex (Kassem, et al., 2015)

The authors demonstrated implementing BIM in FM, in the view of economic and environmental benefits taking a non-residential building as an example in Northumbria University's city campus. The research started with the literature review to examine the advantages and challenges of implementing BIM in facilities management for existing as well as new properties. To conclude this, a case study was performed to inspect how BIM can add value to FM of a university complex. The emphasis of study was on managing the space of campus (Kassem, et al., 2015).

The campus consists of 32 buildings with a gross area of about 120,000 m^2. Foremost work is to bring the drawing and information to BIM software.



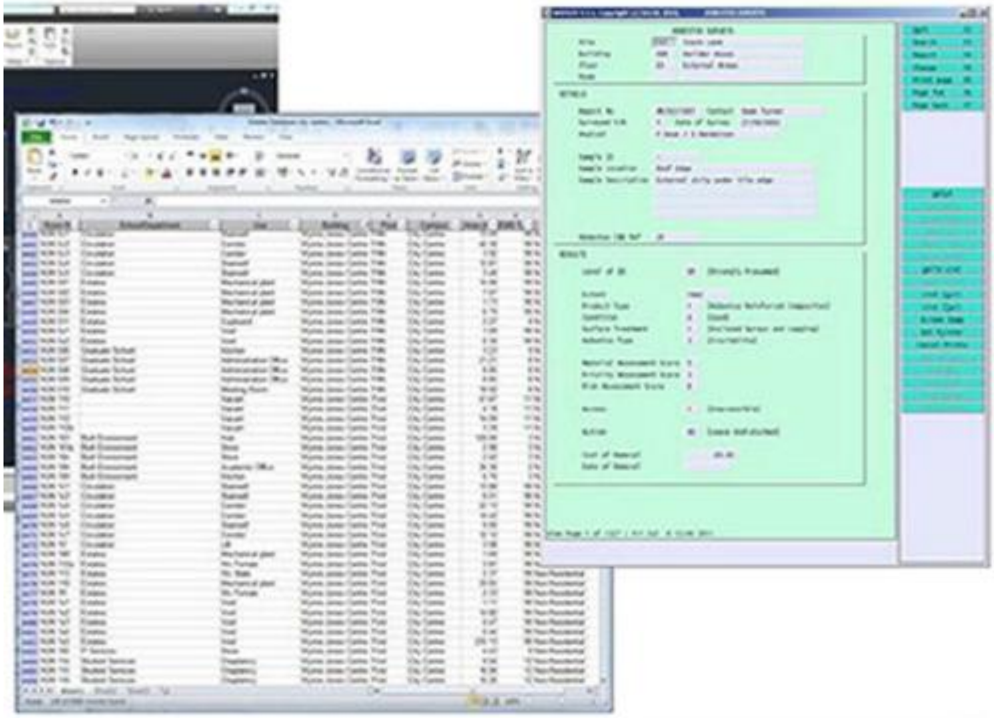


Figure 14 Existing maintenance work flow (Source: Kassem, et al., 2015))

On developing geometric data and information specification about FM in BIM software, all the other details are obtained automatically such as sections, elevations, renders, 3D visuals etc. Supplementary details like emergency tools, accessibilities, equipment, alarms were also located effortlessly and stated in agenda or schedule.

In the schedule, the information for all the equipment with their location, properties, and survey information was available so that it improves FM services. Faults can be detected easily; information of building performance and refurbishment decision creation are obtained without difficulty.

The detailed knowledge of the building is available to make any changes with each equipment detail, their time of replacement and inspection. Maintenance staffs can also check the type and nature of material and maker before replacing. It is also helpful to redevelop or refurbish in the future due to the available data and changes can be seen in the model first before executing. Moreover, it could reduce the time and cost with a precise strategic plan for decision making in future works.

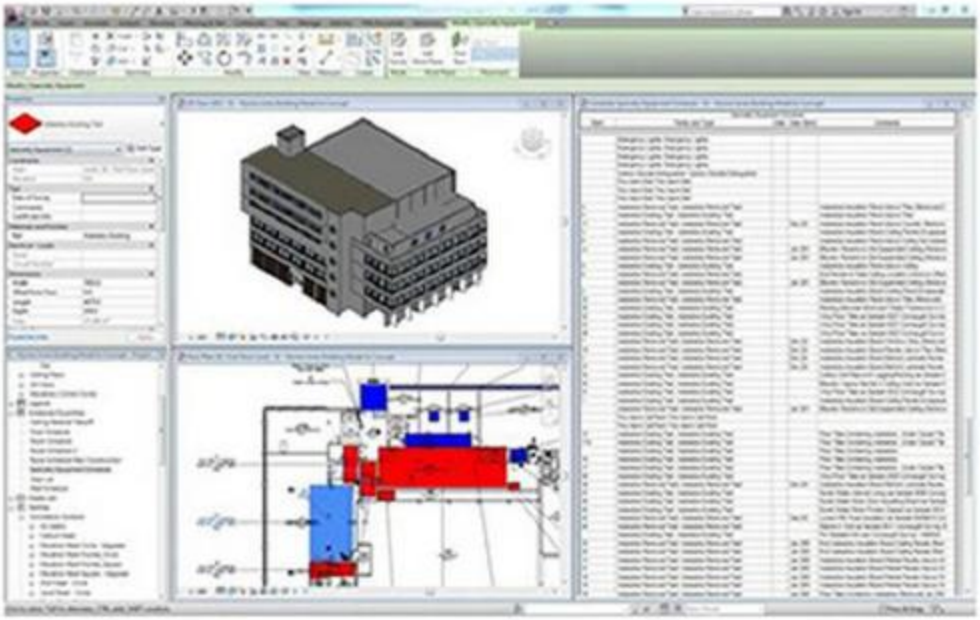


Figure 15: Integrated BIM-based Model (Source: Kassem, et al., 2015))

Despite of challenges in BIM integration like lack of skills and open electronic standard libraries to connect BIM and CAFM, there is more accurate information transfer, accessibility to all the details in the same model, effective maintenance work orders performance, ease in finding faults, capable to plan for refurbishment development and availability of related documents without losing. (Kassem, et al., 2015).

5.1.4 Case 4: BIM-Based Approach to for an Open Building Design

BIM-Based Approach to Simulate Building Adaptive Performance and Life Cycle Costs for an Open Building Design (Juan & Hsing, 2017)

Juan & Hsing determined the life cycle cost value of a collective housing adopting open building design considering three stages of life 30years, 60 years and 100 years. Traditional design is implemented for 30 years lifetime, semi-open design for 60 years and open design for 100 years lifetime. Here open design is an approach to design in such a way that they can be easily adapted to new changes and modifications or renovations in the course of the building's life.

There are two systems- 'support' and 'infill'. The outer most layer of the building can be considered as support system normally consists of columns, beams, slabs and erected pipelines. Whilst the inner components which can be included later as per the space distribution for individual rooms or parts. The components included are less durable which are drywall, windows, ceiling, doors, horizontal pipelines, and furniture (Juan & Hsing, 2017). Usually, the units of open designs consist of box units piping shafts, elevated floorboards, etc., as shown in figure 16.

Design, system of every building project differs, and it is said that BIM is more suitable for complex building and big projects. Thus, it is more useful for the buildings in use and trouble-free to manage the pipeline systems as it differs for every project and information can be generated automatically. So that regular maintenance is achievable and failure detection with immediate measures to repair is possible (Juan & Hsing, 2017).

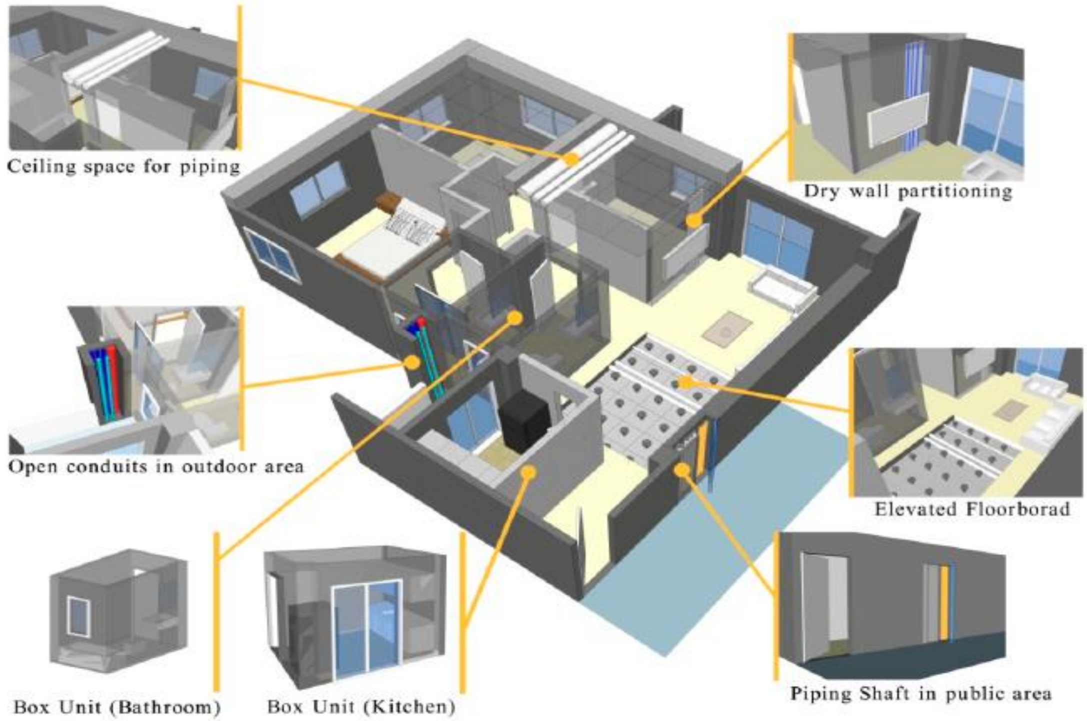


Figure 16 Open building design of the residential building (Source: (Juan & Hsing, 2017))

As mentioned at the time of analysis, the initial proposal was considered as traditional building design and construction likewise the building components are concealed pipeline, ceiling, ceramic tiles, and brick wall. The expiry of the building is targeted 30 years without any modifications. Since there is a requirement of maintenance after around 15 years and again in 30 years.

Hence, in the second scenario semi-open design the slight interior alterations and pipeline maintenance are involved after 30 years and demolition happened after the next 20 years.

Finally, in the next target, there is a complete flexibility to change the indoor structure totally, suitable pipeline maintenance, open floorboard, changing the floor design for overall modifications as decided to do a complete renovation of changing the set up to office design (Juan & Hsing, 2017).

Once the indoor adjustment completed for the 12-storey collective housing which has four 85 m^2 (pipe space and balcony are not included) houses in each floor, a model of LOD200 (Level of development) is developed in BIM is as per the conditions.

The simulation performance is conducted for ventilation, daylighting and evacuation for each proposal to examine the performance after every structure change. Each simulation performances are carried out in different software.

This simulation test is to confirm the quick performance after each adjustment of the proposed design change. All the targeted conditions and variations for the future can be analyzed instantly from the BIM concept (Juan & Hsing, 2017).

The computational fluid dynamic (CFD) simulation for wind field is integrated to check the wind speed at a third modification after 100 years and the result obtained is comfortable of speed 3.0m/s.
The daylighting examination resulted in more passable illumination at the third changes. Since it is changed to the office, some partition walls inside the house are removed that made the workspace brighter. For the evacuation simulation test, the time for evacuation was found similar among all the three variations (Juan & Hsing, 2017).

Lastly, the life cycle cost analysis is performed to determine the net present value for 100 years of building service. Slight changes made in estimation is that the modification proposed to remain the same for the three designs, but, the entire lifespan is considered 100 years in all the three variations. Also, the maintenance cost of deterioration i.e. water leakage, paint peeling repair, equipment repair works, wall cracks, etc. are added at every 15 years. The estimation resulted in the net present value for traditional design $ 6.17 million, semi-open design $5.38 and open design $4.65 million. The minimum value found in open design which is flexible in space usage, pipeline maintenance, and reduce waste Table 9.

Table 9 Life Cycle Cost Analysis for three design proposal ((Juan & Hsing, 2017)

Time (year)	Traditional design cost (NT$)	Semi-open design cost (NT$)	Open design cost (NT$)
0	3,500,000	3,850,000	4,200,000
15	353,000	282,000	200,000
30	3,562,400	692,000	440,000
45	353,000	282,000	200,000
50	-	3,650,000	-
60	3,533,800	-	365,000
65	-	282,000	-
75	353,000	-	200,000
80	-	755,000	-
90	3,510,400	-	343,000
95	-	282,000	-
100	-	100,000	100,000
Net Present Value (NPV)	6,171,000	5,358,000	4,675,000

Thus, concludes the open design concept have benefits in economic, social and environmental which have higher shock resistance and durable as well. There is also a decrease in reconstruction costs. Although the capital cost of open design is higher than traditional design about 20%, there is a reduction in the operational phase of 24% than traditional design. The study exhibited the benefit of using BIM tool in building maintenance and use to simulate potential renovation advantages in optimizing cost, to meet environmental and social demands (Juan & Hsing, 2017).

5.1.5 Case 5: COBie implementation

'COBie Case Study: Case Study & Survey Results' (Griffith & Cervenka, 2011)

In this conference proceeding the analysis determined the application of COBie to reduce work order cycle time. The study applied to the Texas A & M Health science center. The scope of work involves installation – product installation and product inspection; Commissioning – data related to warranty, maintenance, systems, and records; Operations – As-built information, supporting data for O&M needs.

The noticed information to be included the operations and maintenance data, the location of the components, equipment, and about their records and warranty details. The organization wanted to enhance the workflow efficiency by implement COBie data with CMMS software. The process to digitalize CMMS involves – Validating COBie, bring back the project team to handover phase to incorporate all data, and revising all the defined data format to create COBie file.

Once the data created in the required format all the information of delivery will be generated in COBie with recurring facilities. The strategies set in case study to implement COBie are: - integrate work terms to enable Work Order process; providing digital work order flow by tracing information and documents to COBie field.

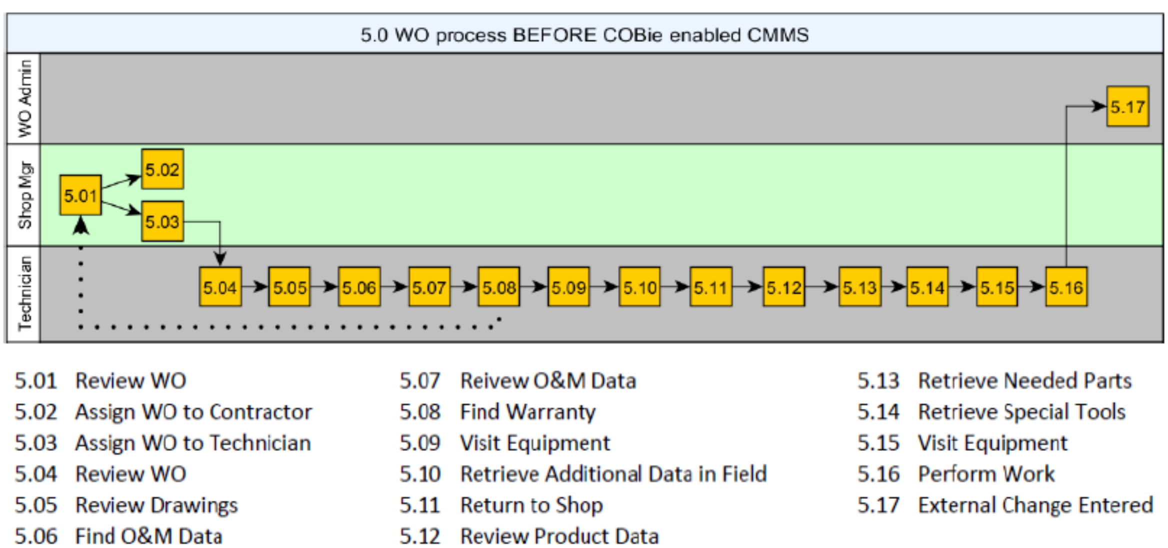


Figure 17 Old work order cycle before implementing COBie (Griffith & Cervenka, 2011)

Verifying if all the required data is available, estimating earlier work order time and details form the team, processing the new order with CMMS enabled digitally, and finally comparing the old and new sequence of work (Griffith & Cervenka, 2011). The process of work order before implementing COBie is displayed in figure 17

Each step in the work order consumes a certain amount of time to process. A survey was conducted to determine the actual time for processing the work order before integrating COBie data. The average duration for the complete cycle resulted is 130.3 minutes.
After enabling COBie data, the work order cycle compresses by eliminating certain steps. Because, the steps for finding data, reviewing, warranty details, finding equipment and retrieving additional data are available in the system without sparing additional time. All the related data is already available in the system shrinks the work order process. Thus the cycle time after integrating COBie decreases as shown in figure 18 below

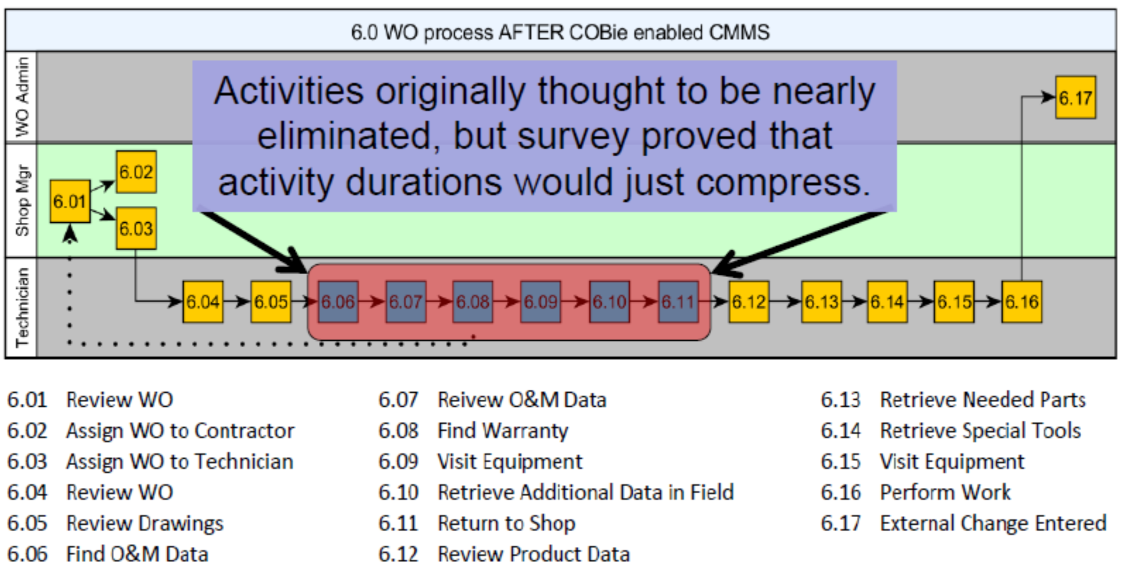


Figure 18: New work order cycle after implementing COBie (Griffith & Cervenka, 2011)

After enabling COBie data, the time required to review equipment data can be omitted which automatically lessen the duration of the work order process. The examination predicted the decrease in time taken for the process from 130.3 minutes to 118.8 minutes which is about 8.7% of time-saving. The cost saving up to 8%. This qualitative analysis concluded the benefit of implementing open standard exchange data in processing O & M work orders.

5.1.5 Analysis of BIM Case studies

A brief description of all the case studies is exhibited in table 10 below. The analysis is explained later as per the given description.

Table 10 Description of case studies relating BIM

Case Studies	Title	Description of study	Results
Case 1	Courtyard by Marriot, BIM in remodeling and LEED (Leadership in Energy and Environmental Design) Certification by Eastman et.al.	Renovation of the national building to the contemporary hotel and to assist LEED certification. Software used: Revit	Towards LEED benefited to save maximum energy. The first-year cost saving in operation is $52,355 and estimated cost saving for 10 years is $676,331
Case 2	BIM implementation during handover to facility management by Eastman et.al.	Hospital building handover to facility management. To find clashes in MEP Tekla is used and for FM CMMS system	easy assigning of the work orders, inspections are done electronically updating checklist, availability of all
Case 3	BIM in facilities management applications- a large university complex (Kassem, et al., 2015)	BIM can add value to FM of a university complex. The emphasis of study was on managing the space of campus	more accurate information transfer accessibility to all the details in the same model, effective maintenance work orders performance, ease in finding faults, capable to plan
Case 4	BIM-Based Approach to for an Open Building design (Juan & Hsing, 2017).	BIM-Based Approach to Simulate Building Adaptive Performance and Life Cycle Costs for an Open Building Design	The open design concept has benefits in economic, social and environmental. There is a reduction in the operational phase of 24% than traditional design.
Case 5	COBie Case Study: Case Study & Survey Results (Griffith & Cervenka, 2011)	Reducing Work order process by digitally enabling CMMS, implementation of COBie data	Survey and study showed that COBie integration can enhance work efficiency and reduce maintenance time and cost

The review of literature offered possible improvements in implementing BIM in operations and maintenance phase. The study of different cases in researches developed a certainty to adopt BIM tools as much as feasible.

In the case study of remodeling the building into a hotel, a renovation process involved without demolishing the existing property instead remodel the same building for hotel purpose. The administration also decided to adopt LEED techniques to reduce energy consumption as much as possible. With the integration of BIM Revit model, the project was successfully completed renovation and saved about $52,355 in the first year of building operation on meeting LEED requirement.

In the case 2, the adoption of BIM during handover to decrease the work of handing as-built data to facility management. Here BIM was adopted at the middle stage of construction to solve clashes between MEP works and structure using the Tekla model. However, this supported in later phase as well to ease the issue of work orders at the time of maintenance.

The third example illustrated the BIM implementation with FM system successfully on a university complex. The benefits found was the most accurate data transfer and effective maintenance work order process. However, there is a challenge in integrating BIM into CAFM system because of lack of available open electronic standard libraries to connect the two systems.

The approach to adopt BIM in open design provided the easy process for developing and testing different design performance, to check the simulation for ventilation, daylighting and evacuation. This integration for the purpose of future maintenance and renovation with open design system helped to reduce operational expenses.

In the last case, digitalizing CMMS system by implementing COBie data determined the improvement of work process efficiency. The study indicated the saving of 8.7% time from the old method of work orders.

The results gathered from case studies expresses the possible advantages of considering Building Information Modeling. Further, BIM can be adopted at any stage of the building lifecycle. Also demonstrated that integration of BIM in project's post-stage can enhance work efficiency of building maintenance and management and benefits in optimizing facility management costs.

After construction, all the as-built information is recorded usually in the form of paper documents which are less coordinated with the facility management team or client. BIM has the capability to fill this gap by linking the information and model to the facility management system information. This improves the maintenance process as well as to visualize the system (Maryland General Hospital had similar shortcomings). The success in integrating BIM is associated with parties' decision to systematize the building process considering both construction and facilities assess (Eastman, et al., 2011).

6 Limitations and future scope

6.1 Limitations

The difficulties faced during the process of the study was the availability of records compiling the three concepts O&M, LCC, and BIM. There were very few documents that supported all the concepts in one paper. Thus, the information related are gathered separately for each view and attempted to analyze when they are assembled.

After studying the vast profits of implementing BIM and LCC in facility management phase, the hypothetical conclusion was to adopt both at the early stages during the project design process. However, there are some limitations to the scope of work:

- ✓ Though the concept LCC is being prioritized in most of the organizations, it is not much implemented in many of developing countries. There is still a requirement to educate the owners about the purpose of including the whole lifecycle cost of building
- ✓ Deficiency in standards and strict guideline to adopt LCC. It is up to the scope of owner and contractor to include each and every expenditure of the building's lifetime. The cost assigned for facility management basically depends on the operational policy adopted by the administration
- ✓ Lack of previous data availability to show the success in implementing LCC and BIM during the operational phase. There is a requirement of factual and quantitative results. It is observed that the research showed the benefits of LCC while implementing and the results after implementing and comparisons are not found, even it is determined the results showed a huge difference. Due to the lack of information availability it is difficult to incorporate BIM at the later stages of buildings life. Success implementation cases are not available to conclude factual and quantitative results
- ✓ Improper tracking of LCC budget at each stage of building's life. Therefore, there is a notable difference found between the predicted cost and operational cost in some cases. The lack of accuracy is due to limited references
- ✓ It is also observed that application of BIM is most suitable for big and complex projects. It is expensive to implement for small projects when only consultancies involved not the large-scale firms.

- ✓ BIM provides the accurate estimation of the budget which doesn't include any percentage allowance or margin which is normally considered while evaluating. There should be an option in tools to consider the additional allowance for calculating LCC

6.2 Future scope and Recommendations

- The theoretical approach of research work provided the importance of Operations and maintenance of the building. Therefore, it is recommended in prior to considering the the post-construction phase as a crucial aspect. However, it is not yet known in many of the countries and organizations, even known it is not considered as an important feature. It is necessary to educate and show the benefits, thus Life Cycle Costing acts as a key to highlight the facilities service period of the building.
- There are not enough research papers which includes the implementation of BIM and LCC in the O&M phase. This report presented the hypothetical review and provides a path to further research considering the real case study. The implementation process is been displayed in all the papers, not the results. So a real case that has the factual outcomes after implementation could support the field to a greater extent.
- While integrating BIM with facility management systems, the the supplementary source is required to add all the data related to LCC as noticed in a case study. For the future scope and studies,, it can be a suggestion to add an LCC library in BIM tool for storing LCC inventory database that avoids additional assistance.
- The longer duration of the building operations and maintenance phase demands 60-80% of the the total budget. 40% of O&M costs is primarily due to energy consumption which is greater than the design and construction costs. Excess energy consumption in the building consumes maximum budget from the total amount. Consequently, choosing low energy consumption systems for building facilities enables savings in building use. It is recommended to take wise decisions while conducting a life cycle assessment to select low energy usage equipment and systems so as to decrease operational cost. This, in turn, meets the objective of the the sustainable building process.

7 Conclusion

The longer duration of operational and maintenance phase of the building involves maximum expenditures that require appropriate measures to reduce additional costs. Therefore, the study exhibited the role of Life Cycle Cost and BIM and their impact on reducing O&M costs.

The case studies analysis showed that LCC is applicable to select the most economical design alternative. LCC can be applied at any stage of the building to determine the overall cost of the system, product or building, however, early design decision stage influences up to 80% of buildings operational costs. Therefore, Life cycle analysis and assessment of building components are most essential to reduce the service cost. The review of literature exposed that, LCC can change the structure and usage of the building from the traditional method.

The major issue in performing maintenance work is the lack of available as-built information and documents. The theoretical analysis of different cases showed that on implementing BIM, it is easy to find the faults and process maintenance work order which leads to reducing facilities maintenance costs by eliminating additional labor costs. Thus, BIM can assist to cover this gap by allowing the continuous process of information transfer from project progress time to handover time.

BIM offers conflict-free mockup showing the real model in a visual format that is an advantage while performing renovation and refurbishment of the building. Estimation and specification of materials can be generated automatically using BIM.

The open standard electronic information integrated with facility management software can minimize maintenance process duration and cost. By digitally enabling CMMS with COBie in a health center showed an annual saving of 8% budget from maintenance cost. Effective maintenance tracking, monitor, and control on digitalizing FM system.

On incorporating both the concepts it is possible to reduce operations and maintenance costs to the maximum extent. The viable solutions for the research objectives are derived from the analysis and showed that the implementation of Life Cycle Cost and Building Information Modeling assist to decrease cost comprised in the building use. Moreover, the proper study of LCA, LCC, and application of BIM at the early design stage can facilitate to optimize not only functioning cost of building but also the entire lifetime cost.

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