NEW OPPORTUNITIES FOR FACILITIES MANAGEMENT

Enhancing Decision-making Processes in the AECO Industry with the Use of Virtual Reality

Aalborg University

School of Engineering and Science

MSc in Management in the Building Industry

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Synopsis:
The following thesis is based on the necessity to build long-lasting, high quality facilities that are adaptable and flexible in their nature. The thesis includes a study of the use of fully immersive 3D as a tool for decision-making, in order for construction clients to choose the best design proposals more effectively.

Firstly, an extensive secondary research is done on several subjects in order to clarify the existing situation in the building industry regarding the use of post construction knowledge in the design stages of new buildings.

Furthermore, a case study organization, which has a great interest in state of the art IT solutions for building design and facilities management, is introduced.

Based on the interest of the case study organization, the research team and the state of the art literature analysis performed, integration of virtual reality for decision-making purposes in the organization is proposed and the tools and procedures necessary for such integration are discussed. Best options for practicing the use of fully immersive 3D are suggested.

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Preface

This Masterôs thesis is written as a compulsory
in Management in the Building Industry, School of Engineering and Science, Department of Civil Engineering, Aalborg University, Denmark.

The subject of this thesis has been chosen as a consequence of the common interests of the authors, the potential of the subject in the construction industry, as well as the general technological inclination of the organization used as a case study.

The research team referred to in this project consists of Laura Eglite and Artur Tsapenko.

The subject has been researched by the authors in the time span from September 2015 ï December 2015.

Acknowledgements

The research group would like to express the most sincere gratitude to supervisor Kjeld Svidt, for the encouragement and deep interest shown during the research process, as well as the help provided with the use of hardware necessary to conclude the project and the never-ending enthusiasm regarding the subject and its presentation to involved parties.

Additionally, the authors would like to thank Rasmus Lund Jensen for his supervision of the research project.

The authors would also like to express gratitude to Arebjdernes Andels Boligforening in Aarhus, especially Leif Kruse, Arne Tollaksen, Elizabeta Lahu and Carina Hedevang for giving us the opportunity to examine the organization and its internal processes regarding the utilized technologies and for their open-mindedness and patience.

In addition, the research team would like to thank Mai Birk-Rasmussen for all the help and guidance in connection with her work with Aalborg University and extensive software knowledge.

Reading Guide

The current chapter outlines the key points of the entire report, as presented in *Figure 0.1.* The Phase overview shows the main purpose of the selected chapters. Chapter section shows the main chapters of this report and the right column gives the outcomes that have been expressed or found by analysing the academic literature and collecting empirical data.

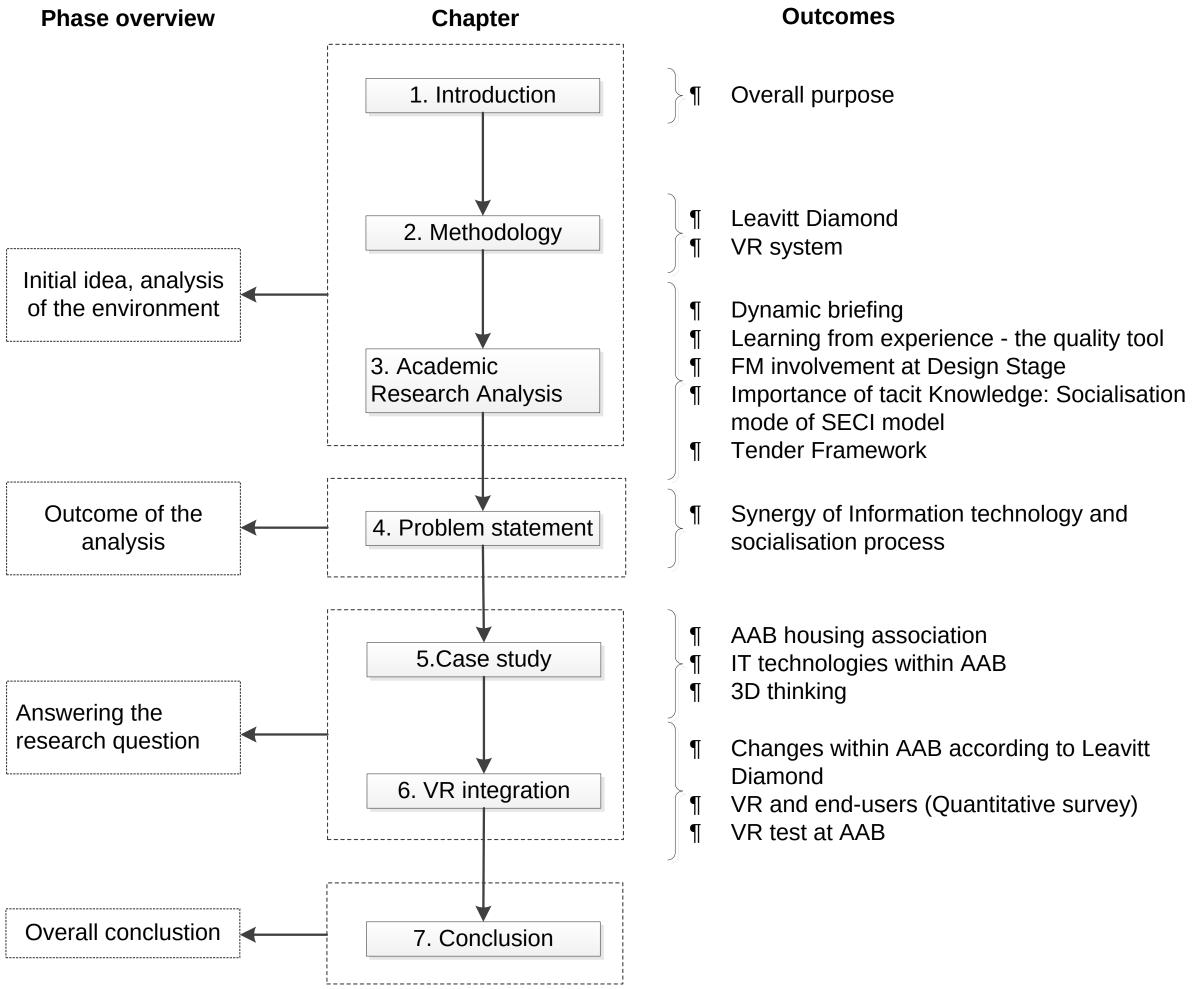

Figure 0.1 Reading guide, adapted from Dimitrov, et al. (2015)

Abbreviations

AECO	Architecture, Engineering, Construction, Operations
AAB	Arbejdernes Andels Boligforening
IT	Information Technologies
ICT	Information and Communication Technologies
FM	Facilities Management
O&M	Operations and Maintenance
POE	Post-occupancy Evaluation
PPP	Public-Private Partnership
VR	Virtual Reality
VE	Virtual Environment
HMD	Head-mounted Device
EMAT	Economically Most Advantageous Tender

Table 0.1 Abbreviations

Abstract

This study has two major purposes ï (1) to investigate the situation in the building industry regarding the use of post construction knowledge and (2) to evaluate the possibilities of the use of fully immersive virtual reality for decision-making purposes at a construction organization.

On the basis of the overall situation in the building industry regarding the quality of constructed buildings, an initial problem is formulated, in order to clarify, what knowledge is necessary for understanding the existing situation: ***What prevents the construction industry from transferring the post construction knowledge from existing buildings to the design phase of a new building?***

The State of the Art presented in the thesis serves as the foundation for the development of the report. The most important variables that prevent the integration of post construction knowledge in designing new buildings are analysed, in order to enable the statement of the problem dealt with in this study: ***How can immersive 3D tools help to provide tacit knowledge during the decision-making process in an organization oriented towards state of the art IT solution integration?***

A case study is presented and analysed, in order to facilitate the solution of the problem stated previously. Finally, areas, which the proposed integration of immersive virtual reality tools would have an impact on, are specified and elaborated. The technological processes AAB would have to go through are described and best practices are suggested.

The thesis concludes with the observation of the authors that in the current stage of technological development immersive 3D might not be the most helpful tool in decision making during tender procedures in AAB, due to their small-scale projects. However, the tool might prove very useful in other instances within the same organization, such as communication with tenants, where AAB would gain the chance to use virtual reality as a highly effective presentation tool, where decisions regarding renovation projects can be made and the consequences of these decisions can be instantly presented to the interested parties. Nevertheless, the authors are of the opinion that virtual reality shall become an important part of the future of AECO industry and shall be used across different disciplines and sectors in near future.

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Table of Contents

1. Introduction

It is widely accepted that the planet Earth is currently facing an environmental crisis caused by human-centred activity that has resulted in reduc from which serious consequences of social and environmental character are starting to emerge. The significance of the issue has given rise to worldwide discussions and international agreements in order to seek balance between the forces of society, economy and environment. The importance of this relationship is most evident in the built environment. (Langston & Ding, 2001)

Constructed facilities are the most important economic, social and environmental investment of the human kind (Langston & Ding, 2001). The built environment is t biggest asset, since it is where the nation's According to Newton, et al. (2009), in advanced industrial societies 95 percent of population works in the built environment and approximately 80 percent of GDP is generated within it. The design, planning, construction and operation of the built environment is fundamental to the productivity and competitiveness of the economy, the quality of life of the citizens, and the ecological sustainability of the continent and planet as such.

The world is undergoing a constant development and the built environment plays a major role in it. The economic development of a country calls for increased construction of factories, office buildings and residential buildings. As the economic position of the society continues to increase, the demand for architectural resources in the form of land, buildings or building products, energy and other resources for building operation also increases. (Haghighat & Kim, 2009) However, new construction projects involve resource consumption and site modification, which generally diminishes environmental wealth and increases capital wealth (Langston & Ding, 2001).

Hence, the concept of sustainable development is introduced. Its most popular definition, given by the Brundtland Report in 1987 runs as follows: ñ*[Sustainable development is] development that meets the needs of the present without compromising the ability of future generations to meet* (Langston & Ding, 2001, p. xiii) This concept has motivated the search for construction solutions that still improve living standards without diminishing the importance of environmental protection. Therefore, the main challenges for the industry are defined as follows:

- The construction industry must re-engineer its entire production process,
- Current economic approaches to project evaluation need to be re-examined,
- The integration of economic, environmental and social aspects of sustainability needs to be further developed,
- Awareness and understanding of sustainability issues at all levels in the community needs to be increased.
  (Langston & Ding, 2001)

ñ*Transforming buildings and infrastructure to become more sustainable elements of our built environment is a key challenge for the property, construction, planning, design and facilities management industry, as well as governments at all levels*ò (Newton, et al., 2009, p. 3). However, the construction flow involves many actors, processes, various types of information, different stages and a myriad of areas that can and must be improved in order to take steps towards sustainable development in the built environment. Additionally, the subject of sustainability within the construction industry is very broad and complex and is continuously being tackled from many perspectives by countless researchers and construction professionals around the world.

“A building is part of the global ecosystem. There is a continuous flow of resources, natural and manufactured, into and out of a building. This flow begins with construction and continues throughout the building’s lifespan to human well-being and (Haghighat & Kim, 2009)*”*

Nevertheless, the building industry is responsible for enormous amounts of waste created. According to the European Commission, “*construction and demolition waste is one of the heaviest and most voluminous waste streams generated in the EU. It accounts for approximately 25% - 30% of all waste generated in the EU and consists of numerous materials, including concrete, bricks, gypsum, wood, glass, metals, plastic, solvents, asbestos and excavated soil.*” (European Commission, 2015)

Demolition of buildings can be regarded as an activity that creates great amounts of waste and pollution, but is not always necessary. Demolition of a building is usually undertaken in case the structure is in a poor state and cannot be used for future activities. Hence, to minimize the extent of demolition in the future and to achieve a sustainable built environment, it is necessary to construct buildings of high quality and durability, not structures that are designed to deteriorate after 10 years. This requires a paradigm shift of the entire industry, where the mantra of producing more with a lower quality in order to keep the industry going has to be dismissed (Newton, et al., 2009).

The Danish law, however, states, that the construction and demolition waste has to be sorted to the highest extent possible (Miljøministeriet, 2012). Nevertheless, it is only the physical waste that can be recycled – the energy used for constructing the buildings, which are demolished, cannot be recycled. With this in mind, the authors of this thesis would like to emphasize the need for designing durable and adaptable buildings and avoid demolition waste in general. Due to the broad scope of the subject, the report will concentrate on the briefing and preliminary design stage of buildings, where the construction client and its representatives have a very important role to play in the future building, its lifespan and its environmental impact in both the construction and operation phase.

1.1. Initial Research Question

The building industry has always been considered a conservative industry, which is historically slow to development (Christian, 2001). Hence, the industry faces many different issues that result in higher procurement price for construction clients.

According to Jensen (2009, p. 124) “*One of the problems in the building industry is a limited degree of learning from experiences of use and operation of existing buildings*”. Moreover, the idea of knowledge transfer from the operation experience of buildings is not a new phenomenon. Brøch (1996) has undertaken the investigation regarding utilisation of accumulated knowledge at the design phase from the operation and maintenance phase. The results were not positive and the author believed that the future technologies would help to fill the gap in bringing the post operation knowledge to the design process. However, the technologies only serve as an additional aid to achieve the desired objectives. The main driving-force of change is oriented towards the participants of the construction industry. Hence, the initial question of this project is a follows:

What prevents the construction industry from transferring the post construction knowledge from existing buildings to the design phase of a new building?

The research team believes that the above-mentioned problem is preventing the construction industry from achieving high operational efficiency, which would reduce the total cost for construction clients. However, many factors are involved in the knowledge transfer process, thus, the following chapter aims at analysing the academic literature of particular areas. The review of the state of the art might present more factors that negatively affect the continuous development of the industry. The continuous development in the construction industry could be achieved by evaluating the feedback from each constructed building and applying the gained knowledge in the design phase of a new procurement. This procedure creates a loop learning, where the construction participants capture the mistakes from the constructed buildings and avoid them in the next building project.

However, the analysis of current academic literature has to be delimited, because the area of concern is very wide; hence, covering the whole spectrum would go beyond the limitations of the authors.

2. Methodology

2.1. Research Strategy

The research strategy for this thesis was conducting an analysis of the current situation in the construction industry from the academic perspective and, with the use of a case study, solving a small-scale issue that has the potential of expanding throughout the building industry.

Initially, an overall area of interest is stated by the authors, in order to provide a frame for the further research. Subsequently the state of the art is analysed regarding the current situation and proceedings in the construction industry with the help of an extensive literature review that covers many areas of interest, in order to gain an understanding of the current affairs and issues of the sector and to clarify a detailed problem statement.

Furthermore, a case study, social housing association AAB, is used in order to attempt solving the proposed problem in a small-scale before suggesting a larger-scale change in the industry. The case study is supplemented with attendance of events organized by Aalborg University, which provides answers and important information regarding the specific tools the authors wish to implement in the industry.

2.2. Data Collection

Two main types of data collection have been used in this research project, namely qualitative and quantitative research.

Qualitative data has been collected from the case study in the form of interviews, e-mail communication, phone conversations and data exchange between the involved parties.

Both the interviews and the phone-interviews were conducted in a semi-structured manner. The subject of the interviews and direction-creating questions were prepared by the research team and delivered to the interviewees prior to the scheduled meetings. Furthermore, during the interviews, additional questions were addressed towards the interviewees if deemed necessary. In total three interviews with the case study organization have taken place ï 2 personal meetings and one phone conversation. In addition to that, the research team held a presentation of a prototype of the proposed technological tool in order to learn the organizationôs opinion in the matter. Furthermor
conducted in order to support the information received from the case study company. Most of the conversations have been recorded for future reference.

Additionally, e-mail communication took place between the organization in question and the research team. In some cases, questions were directed towards the organization, which were answered in a written manner. Nevertheless, in some situations data in the form of written documents or computer-generated building models was forwarded to the research team.

Furthermore, the research team participated as observers in a number of events related to the research subject, in order to gain a more practical insight in the matter.

In addition to the qualitative data collection method, a quantitative survey was performed as a part of the second case study. In this case, a questionnaire with 14 questions was created and distributed among the persons of interest. Subsequently, the gathered empirical data was analysed with the help of diagrams and charts, in order to gain an overall understanding of the situation in question.

2.2.1. Source Criticism

The main sources used in this report are academic research papers and books. These sources are evaluated by the research team as fully reliable. Additionally, materials such as laws and regulations are used, which are also deemed highly reliable. Materials and information provided by AAB are also viewed as trustworthy, since AAB is the only possible source of particular types of information regarding the organization. Furthermore, a number of internet sources are used, whose reliability might be questioned. However, internet sources only from well-known organizations and established firms are used, hence deeming them trustworthy.

2.3. Solution Strategy

Within the pages of this report, a change is suggested in the case-study company. Leavitt Diamond is used in order to address and analyse the possible consequences of this change in four main areas of the organization, namely technology, task, structure and people. Hence, this serves as the foundation for the solution chapter.

2.3.1. Leavitt Diamond

Any change within an organisation has to be analysed and controlled to ensure its successful integration into the business process chain. In 1964, Harold J. Leavitt proposed a conceptual view of an organisation, which is the most recognised by the academic world. Leavitt argues that rarely any change takes place in an isolated environment. (Nograġek & Vintar, 2011) The change in one component has an impact on other components of the organisation. Thus, all components within the proposed frame are interconnected. However, the level of impact is not likely to be distributed equally among components, therefore each component has to be analysed in order to identify the magnitude of occurring change.

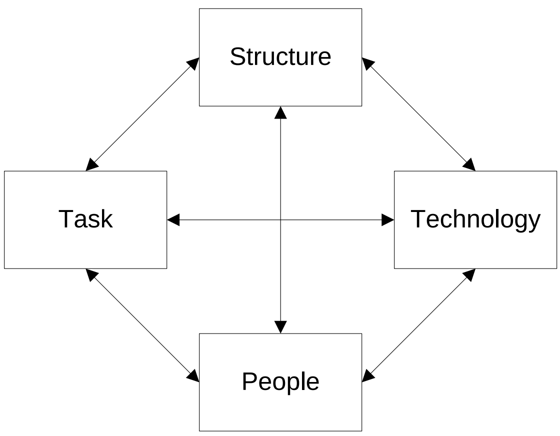

Figure 2.1 Leavitt Diamond adopted from Leavitt (1965)

The four areas and their interconnection of Leavitt Diamond are shown in *Figure 2.1*. “*Any of these changes could presumably be consciously intended, or they could occur as* *unforeseen and often costly outcomes of efforts of change only one or two of variables*ò (Leavitt, 1965, p. 1145). Meaning, by ignoring other variables (components) and only focusing on the desired component would cause costly outcome that each organisation is willing to avoid. The report is aiming at integrating virtual reality system in AAB as an aid for their decision-making process. The integration of a VR system would influence those four variables; hence, it is valuable to evaluate the impact of the change on those variables. A short introduction is given to each area that was proposed by Leavitt. (Leavitt, 1965)

Structure: Structure component consists of many different aspects: hierarchy, communication line, departments, management structure, level of authorities, and system of workflow. The structure is to be significantly changed if a radical modification is made within one of the remaining components and vice-versa. (Leavitt, 1965)

People: This component refers to people, but from t knowledge or according to Leavitt that is the area, which is exclusively remaining in human domain. (Leavitt, 1965)

Task: It refers to process chain of goods and services. It also covers operational subtasks that are normally found in complex organisations. The main area of interest is the new processes that must be introduced due to change. The question is how the reengineering procedure needs to take place in order to integrate the change within the current business processes and what is the value to be produced by doing those tasks. (Leavitt, 1965)

Technology: Under this component, the technology is considered as the computer aided system that would drive the process in case it is a source of the change. In case of the change in another component, the technology component serves as supporting activity to sustain the change and make it a part of the business process. Additionally, as part of technology, it includes machineries that might be introduced within the organisation to increase operational efficiency. (Leavitt, 1965)

An example, where the Leavitt diamond and the interconnections between its elements are demonstrated is presented in *Appendix* A.

2.4. Virtual Reality System

The report includes the use of virtual reality systems for testing and presenting virtual reality environment at AAB. Hence, a short description of the setup is given. The software that was used for conversion of the 3D model is Autodesk Revit, Autodesk 3Ds Max and Unity3D. The hardware was provided by Aalborg University, which includes:

- 4 gaming computers: ASUS ROG G20AJ-NR042S,
- 27inch touchscreen: Liyama ProLite T2735MSC-B2,
- 3 sets of Head mounted displays: Oculus Rift Development Kit 2,
- Joystick: Logitech Extreme 3D Pro,
- Joypad: Xbox wireless controllers,
- Motion-sensing controller: Leap Motion.

Evokon Aps has developed an application programming interface for Unity3D. The developed package insures compatibility with all mentioned controller devices. Moreover, it provides an access to a specific server, which is used for virtual environment. Four computers connect to the server when Unity3D application is launched. This is made in order to have several people in one virtual environment at the same time. The particular system allows having three participants in immersive 3D environment and additional few people could be engaged in non-immersive 3D environment by means of the touchscreen.

2.5. Limitations

During the processing of this report, several limitations were met by the research team. Firstly, a language barrier was encountered, due to the international nature of the project team. This obstacle was dealt with in the most effective manner possible, however some uncertainties still remain in connection with data translation and understanding.

Secondly, the case study has a rather extraordinary position in the construction industry. The housing association considers facilities management and leasing business as their two core activities. Hence, in construction procurements AAB acts as a construction client with an integrated FM function.

Thirdly, the quantitative research performed in connection with this report was done amongst a very limited amount of respondents due to the low number of workshop participants. Hence, even though the data gives an overall idea of the matter, it cannot be extensively generalized to the level of all the interested parties.

3. State of the Art

The research group has outlined five research areas in which a state of the art academic literature review is performed in order to find the issues regarding the use of post construction knowledge in new building design that have been identified by scholars. The research areas in question are expressed in *Figure 3.1*. The area of end product is present solely to provide a connection between *Briefing stage* and *Learning from experience.*

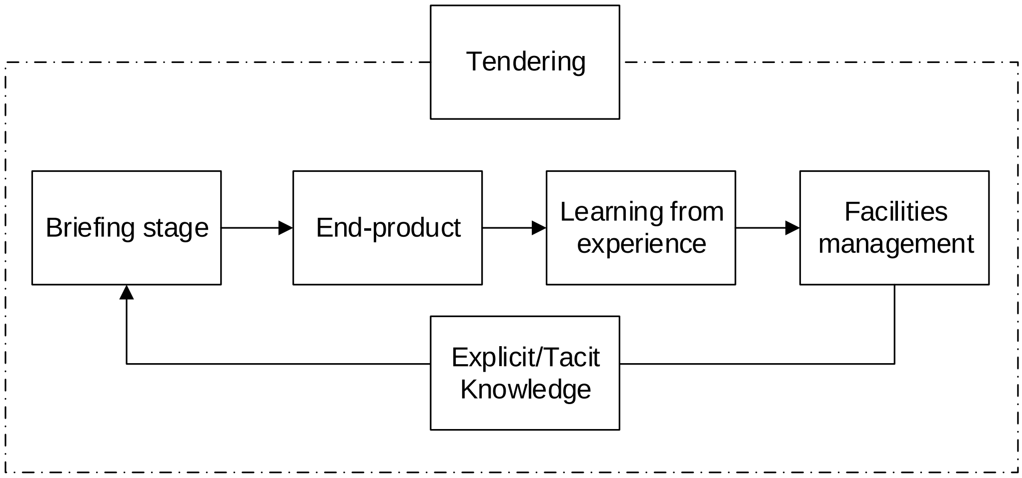

Figure 3.1 Research areas

The *Briefing stage* is one of the stages that have to be undertaken to initiate a construction procurement. The construction procurement solely depends on the outcomes of the briefing phase. (Blyth & Worthington, 2010) Hence, the briefing stage is the first and possibly the most vital part of the construction procurement. The outcome of the construction process is a built facility that is considered to be the end product of the procurement process.

The chapter *Learning from O&M experience* is the area where the need for gathering data during the post construction operations and maintenance is analysed. Furthermore, a question is raised regarding the particular entity that shall perform the post occupancy duties and the evaluation of the building performance. According to the state of the art literature analysis, the facilities manager is the key person to evaluate the performance of constructed facilities and bring the gained knowledge to the building design stage.

Facilities manager is a new actor within the construction industry: hence, many issues are identified in involving this professional in the design stage. The involvement of FM brings mutual benefits for construction projects as well as post-construction activities.

Moreover, the knowledge is stored in different ways, namely as explicit knowledge, which can be codified and as tacit knowledge, which is hard to codify. The knowledge transfer from O&M enhances the quality of the designed product.

The *Tender* area creates framework conditions, which affect the other mentioned areas. The research focus in *Tender* area is based on analysing public tender, which implies utilisation of Danish Tender Act and EU directives on public procurement. Moreover, the evaluation of award criteria is discussed, which could have its influence on design choice.

These five areas are analysed prior to the case study to outline issues that are discussed in the academic world. The organisation might face similar concerns regarding efficient knowledge utilisation within its operations.

3.1. Briefing Stage

In order to get a building built, the client needs to interact with the industry. This requires communicating with a diverse group of professionals and enterprises that each represent a different part of the industry and engaging in legal relationship with them. This process is what is normally referred to as procurement. Procurement is the framework within which construction is created or procured. Traditionally, the client decides what his wishes and needs are, appoints and instructs a designer, who drafts the building and makes a selection of a contractor, who then constructs what has been designed. In this, the client faces many problems that are widespread within the industry. (Boyd & Chinyio, 2008)

ñClients of the construction industry worldwide have long believed that the industry is inefficient and untrustworthy, particularly when it comes to the timely delivery of projects within agreed budgets.ò(Morledge & Smith, 2013, p. 92)

3.1.1. Clients and their Characteristics

Commonly, the industry tends to excuse poor performance by blaming clients for not knowing what they want, for being slow in approving the proposed designs and for making significant changes throughout the realization processes (Fellows, et al., 2004). However, clients are rarely the same.

There are different categories of clients that require different solutions to their problems and that present very different opportunities. It is therefore essential to identify the client accurately before addressing the project as such. (Masterman, 1992) Masterman (1992) therefore proposes a definition of a client in order to avoid misunderstandings:

ñ[A client is] the organization, or individual, who commissions the activities necessary to implement and complete a project in order to satisfy its/his needs and then enters into a contract with the commissioned parties.ò(Masterman, 1992, p. 6)

The construction industry has many client types. There are highly experienced clients, who build regularly and understand the industry well, as well as very small, inexperienced clients, who might build only once in their lives, and the entire broad spectrum in between them. Naturally, the clientôs level of experience and
and procurement process. Inexperienced clients require a lot of guidance on each aspect of the process, where the experienced clients might feel comfortable driving the entire process themselves. (Morledge & Smith, 2013)

Masterman (1992) proposes four characteristics of construction clients that are the most relevant and affect the choice of a procurement method. Description of procurement routes is given in *Appendix* B.

1. Whether the clientôs organization is private

Public clients have many constraints that limit the choice of the procurement process, since they need to ensure the best possible use of th adapt rather conservative risk management strategies (Masterman, 1992). Additionally, the public clients have severe legal restrictions and they tend to seek functional projects with verifiable value for money (Morledge & Smith, 2013). Private clients, on the other hand, are generally concerned with maximizing their profits and are therefore more prepared to adopt aggressive risk management tactics in order to achieve their goals (Masterman, 1992).

2. The level of experience with building projects

Furthermore, the level of experience with building projects plays a crucial role in terms of client behaviour when dealing with issues within the construction industry. According to Masterman (1992), the clientôs attitude towards different aspects of the construction activities differs greatly with the levels of experience. The experienced clients generally have detailed knowledge and understanding of the construction industry and its procedures and tend to be involved in the industry regularly. Additionally, these clients tend to show desire to be continuously involved in the project. Inexperienced clients, on the other hand, lack knowledge about the construction industry, are easily influenced in construction matters by external parties and have no desire to be involved in the project on a consistent basis.

However, most of the construction industry clients are inexperienced since they build only when it is needed to improve their main operations, so they build infrequently and depend heavily upon professional advice. Relatively few clients are frequent purchasers of construction and consequently are more experienced and can use their buying power to demand exactly what they need. (Morledge & Smith, 2013)

3. The future use of the procured building ï leasing/selling (primary client) or own activities (secondary client)

The reason for procuring a building is very important when trying to distinguish between different clients. Primary clients procure buildings as their primary source of income, to use them for sale, lease, investment etc. Secondary clients procure their buildings in order to enable them to undertake their main operations. The construction expenses represent a small portion of their annual turnover. (Masterman, 1992)

Depending on the clientôs type, their interest
energy consumption and overall quality can vary greatly. Typically, a primary client would be interested to procure the building for the lowest possible price, in case he intends to sell the property, and would not concern himself with life-cycle costs of the facility. The secondary client, on the contrary, would have a higher interest in the long-term expenses, hence choosing solutions and materials that are the best choice in the long run. Nevertheless, in case a primary client intends to lease his property, his interest in the long-term expenses rises.

4. The main operations of the organization (Masterman, 1992)

The main activities of the clientôs company, th
by it and business activities it is engaged in tell a lot about the company and the type, size and scope of the procured building.

The procurement route depends on clientôs charact
building procurement etc. The analysis of different variables that might affect the

construction has to be made in the clientôs or procurement route. This analytical process takes place during the strategic briefing, which is discussed further. The applicable procurement route reduces the probability of mistake occurrence during the construction project. However, the well thought out choice of contract type does not guarantee the successful outcome of the construction project.

3.1.2. Briefing Process

Briefing process is the first stage of the construction procurement in all contract types used in the construction industry. Blyth & Worthington define briefing as ñ*an evolutionary process of understanding needs and resources, and matching these to its objectives and its mission*ò(Blyth & Worthington, 2010, p. 3).

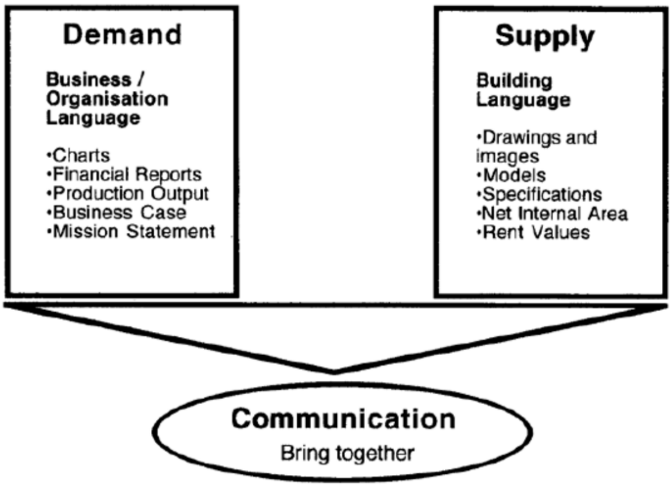

Figure 3.2 Communication between demand and supply (Blyth & Worthington, 2010, p. 57)

According to Blyth & Worthington (2010), briefing is aimed at formulation of the clientôs problem and finding the best solution for it. As shown in *Figure 3.2*, the briefing process has a demand and supply side. These sides are used to very different ways of communication, i.e. the client usually uses charts and reports to express his information, whereas the consultants use drawings and models to do so. Therefore, it is very important to bring these two parties together with effective communication to avoid misunderstandings in the briefing process. Effective briefing should begin without having a ready solution in mind in order to review the available options and articulate requirements. Furthermore, briefing is also about managing change, since ideas evolve, are tested and progressively developed into specific sets of requirements. The degree of understanding of clientôs was proposed and articulated to a designer (Kamara, et al., 1999). The briefing is considered the most important process, where the future outcome of a facility is based on the input that is contributed through the stage (Blyth & Worthington, 2010). The degree of understanding of the clientôs proposal depends (Kamara, et al., 1999). Briefing is considered the most important process, where the future outcome of the design is based on the input that is contributed throughout the stage.

There are two levels of briefing ï the strategic and project briefing:

ñ*Strategic briefing is the identification of the overall mission or goal of the project discovered before the decision to build.*ò(Kelly, et al., 2002, p. 38) *ñProject briefing involves gathering facts concerning the building project, comprehending the context within which to design for optimum use and aesthetic expressionò* (Kelly, et al., 2002, p. 38).

Strategic briefing is a process where the client is identifying the needs of future procurement, consultancy services. The construction initiative comes from demands that have emerged in the clientôs organisation. The construction pr carefully analysed to make sure that the investment would be returned. When the consultancy (designer/engineer) is appointed, the next step is to gather the information regarding construction characteristics. The requirements of end-users are mainly represented in a data source, e.g. text and diagrams, interviews, questionnaires and meetings with building or design professionals, (Jensen & Pedersen, 2009). The designer, based on the accumulated documentation of the building characteristics, creates a project brief, which includes drawings, images, models, specifications etc. (Blyth & Worthington, 2010). The project brief is the main document that forms a framework upon which the design of the building is created (Designing Buildings Ltd, 2015).

Historically the briefing process, according to Morledge & Smith (2013), has been regarded as not worthy of any serious attention. In the mid-20th century, the architects were aware that the information from the client needs to be collected, but no time was spent to learn how to practically carry out the process. In the 1970s, it was already noted that the brief was lacking essential information but it was still viewed as fairly unimportant. The 1980s came with significant critical reviews of the briefing process and in the 1990s, the importance of the brief and the clientôs role in it was at last ac

However, such briefing approach is static, because the procedures that are to be followed do not have a loop to reflect upon the previous steps. Nutt (1993) stresses the inefficiency of traditional briefing due to limitation in the logic of its process. The limitations are regarding the inability to forecast future requirements of organization with confidence. Therefore, there is a need for change in the traditional procedure by introducing dynamic briefing process (Jensen & Pedersen, 2009).

3.1.3. Dynamic Briefing

The implication of dynamic briefing is that briefing must be seen as a process, not an event. Additionally, it should be a process, which starts early and continues throughout the entire project. Continuous interaction with the client is essential to this process. The underlying principle is to decide as little as possible at each stage, which means identifying the critical decisions and addressing them, but leaving flexibility on other issues for later consideration as more information becomes available. (Barret & Stanley, 1999)

As discussed earlier, clients are usually the least experienced members of the design process. Their knowledge and understanding of the processes of the construction industry increase with time and involvement in the exact possibilities of a design unfold and an ongoing dialogue with the design team takes place. Adhering to the detailed early brief prohibits this dialogue from taking place. (Othman, et al., 2004)

Dynamic briefing implies continuous interaction the design team (Jensen, 2011). The stakeholders in this case are end-users, facilities manager and the organisation's executive managers that ensure alignment of the proposed solution with the organisation's strategy. All a areas of focus and interest when they look at the proposed solution. As a result of dynamic briefing, the interests of each stakeholder must be taken into consideration. Thereby, the initial focus throughout the interaction might be changed due to proposed solutions and stakeholde dynamic briefing presents the opportunity of being heard to all actors involved in the process.

Consequentially, it is believed that the dynamic briefing process would:

- Enable client organisations to achieve their expectations,
- Facilitate an innovative response to the drivers that may develop the project brief by unfolding, growing, progressing or changing its content for the benefit of the project,
- Manage project change orders minimising their impact on project cost, time and quality.
(Othman, et al., 2004)

Prins (2006), in his research work, concluded that both static and dynamic approach should be used in different steps of briefing when one method is more feasible than the other is. Therefore, it is important to note that briefing is not only a static stage of the design process, but in fact, also a dynamic process that should involve stakeholder cooperation (Jensen & Pedersen, 2009).

A client is the initiator of a construction process; therefore, he has the most power as a stakeholder. "*The construction client is often a unit that monitors the interest of many different stakeholders*" (Ryd, 2014, p. 88). The client's empowerment c momentum of keeping the briefing static or dynamic. The new briefing characteristics ensure the consideration of future operation and maintenance and ensure alignment with the organisational strategy. As it could be observed, dynamic briefing is a continuous interaction with the construction client throughout the whole construction process to ensure the alignment between the demand and supply. The main aim of dynamic briefing should be "*process of feedback, and dialogue with all stakeholders*" regardless of the construction stage (Jensen, 2011, p. 39). However, the scope of this report only covers the briefing and tendering framework, where the importance of providing feedback is identified.

3.2. Learning from O&M Experience

Existing buildings have undergone design, construction and O&M processes, which are similar from building to building, hence, the existing structures have the potential to serve as examples to the parties involved in the construction industry. The examples can be both positive and negative; however, it is mostly important to emphasize the mistakes made previously in order to avoid them in future. Therefore, this chapter highlights the need for continuous development in the building design process and the necessity to evaluate the existing buildings with the help of Post-occupancy Evaluation and integrate the gained knowledge in the design of new facilities.

3.2.1. Continuous Development in the Procurement Process

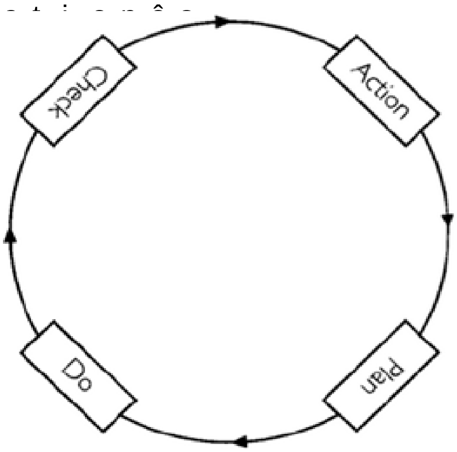

Figure 3.3 Deming Cycle (Blyth & Worthington, 2010, p. 72)

In order to improve the quality of an organization's operations, there is a need to evaluate the performed activities against the initial objectives that are set during the strategic briefing (Blyth & Worthington, 2010). Deming, one of the pioneers in quality management, has proposed the Deming cycle, *Figure 3.3*, which prompts the enhancement of the quality of a product by learning by doing. According to Evans & Lindsay (2005, p. 92) *“The Deming philosophy continually improvements in product and service quality by reducing uncertainty and variability in design, manufacturing, and service processes, driven by the leadership of top management.”*

- The *plan* stage consists of identifying current situation and outlining the processes within the situation,
- The *do* stage includes a pilot version, which helps to evaluation the outcome of the planned proposal,
- The *check* stage summarises if the proposal is feasible and positive and negative outcomes are learnt,
- The last stage, *Act*, is the process is standardized and become a current best practice.

  (Evans & Lindsay, 2005)

In construction, e.g. in the design process, the stages expressed in the Deming cycle have their place of existence. However, in the *do* stage the pilot version has a small chance of appearing due to the nature of the construction product. However, the do stage is possible if the project scope implies several buildings with the same characteristics that must be constructed by one at the time. In this case, the first project serves as a pilot one, whereas the rest would not face the mistakes that were made in the pilot building. Otherwise, the pilot evaluation could be formed from the experience of participants in the construction industry to achieve continuous improvement of the end product. Additionally, the need of capturing the knowledge identified during the process is vital to prevent the solution failures in the next construction project. The concept of *action, plan, do* and *check* is well established in industries like manufacturing, but the cycle of learning from experience is barely considered in the construction industry. The incentives to imply the knowledge from the past is to enhance the quality of constructed buildings that are traditionally considered to have insufficient quality.

One of the possible reasons for a “how knowledge” implication in the new briefing stage of the construction process is the organizational structure of construction projects, which has a project-based approach. The framework of knowledge accumulation has to take place in order to gain access to the needed information at the right time to eliminate doubts during the decision-making process. *Figure 3.4* shows the area of concerns; the past/current building performance needs to be taken into account during the design of a new procurement. The newly procured building would also form a part of the building performance, which is summarised and considered during the design stage of a new construction project. Thereby, the feedback loop with the current asset should be structured in order to achieve continuous improvement in the construction supply chain within an organization. The question is how the construction industry could use their past projects, experience and best practices to enhance the quality of the facility performance once it is constructed.

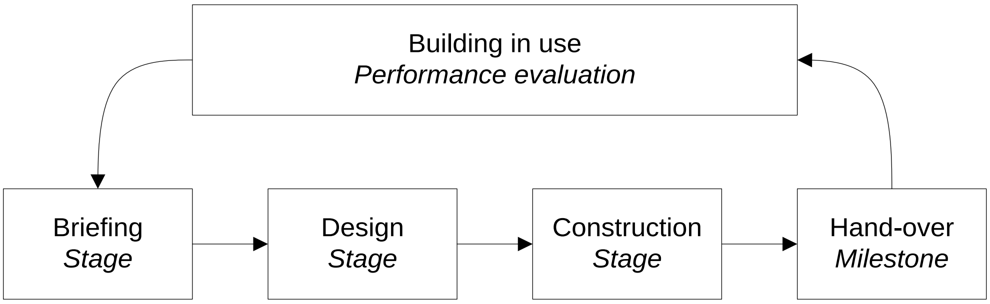

Figure 3.4 closed loop of continuous development, adapted from Bordass (2014)

However, not all experience accumulated throughout the daily operations should be considered relevant. For example, some construction solutions that have proven to be reliable may not be feasible due to e.g. the current building legislation. *Figure 3.5* shows the balance between the proven solutions (prescriptive) and innovation (performance). The idea is that the reliable solutions that have been used in the past are applicable for new constructions. However, the locked-in solutions, which are solely based on good practices, prompt to significantly reduce the innovation in design. Hence, the continuous development is degraded and in long-term leads to low building performance, because some solutions might be inefficient. Whereas, an overwhelming amount of Innovative solutions increases the chances of failure in different parts of a building. This causes high maintenance costs and reactive solutions that may have negative influence on the budgeting of post-construction activities and overall building performance. (Blyth & Worthington, 2010)

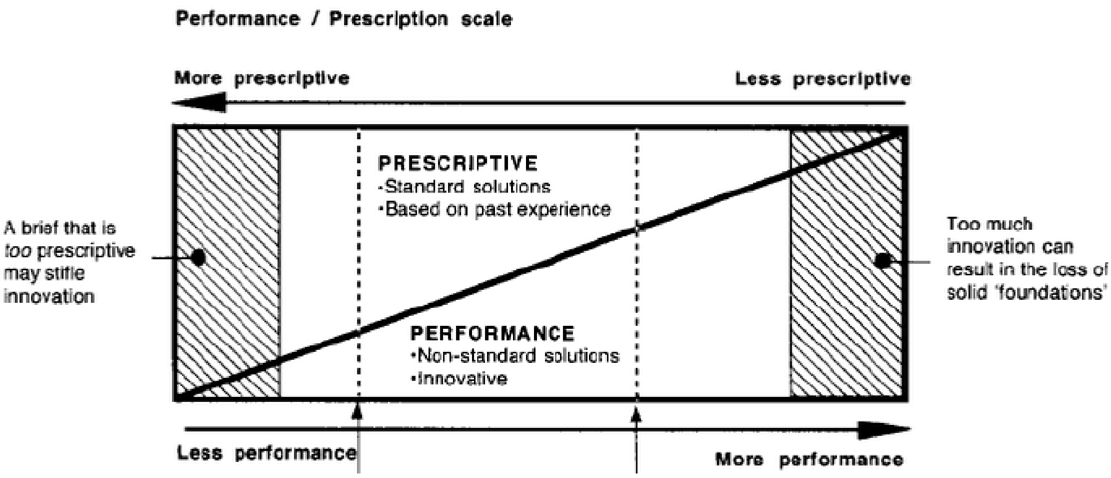

Figure 3.5 Briefing process with a mixture of new and proven solutions (Blyth & Worthington, 2010, p. 65)

The performance (innovation) knowledge could be contributed by a designer or another external stakeholder involved in the design process. This knowledge is not likely to be contributed by the internal capabilities of an organisation that procures the construction project. Whereas, the prescriptive knowledge (experience) shall be provided by the organisation that evaluates the current assets in regards to its performance. Thereby, there is a need for a system that captures the information of assets in use to form a qualitative and quantitative database that could be used for better decision-making in the briefing process. (Blyth & Worthington, 2010)

3.2.2. Post-Occupancy Evaluation

Evaluation of current assets in the organisation helps to identify the problems and successful solutions in existing buildings and forward the findings to the design phase of a new procurement. Learning from experience reduces the possibility of making the same mistakes in a new building, which would cause higher maintenance and operation costs. The aim of an evaluating mechanism in asset maintenance and operations is to provide a better foundation for a decision-making process that would enhance the quality of a newly procured building and overall real estate performance within an organisation (Mallory-Hill, et al., 2012).

The performance expectations of the future facilities have to be expressed and documented. In this case, the participants would have a clear picture of what needs to be delivered to the client (Preiser, 1995).

This would help to improve the quality of the construction project by delivering what is requested and within the agreed time. In 1960s, Post-occupancy term was introduced due to inadequate experience in public building performance from the perspective of the building occupants. The areas of concern were health and safety, indoor environment and security issues. (Preiser, 1995)

The definition of the term was proposed by Preiser in 1988: *ñPost Occupancy Eva (POE) is the process of evaluating buildings in a systematic and rigorous manner after they have been built and occupied for some timeò* (Federal Facilities Council, 2002, p. 9).

According to Preiser (1995), the term Post-occupancy Evaluation is misleading and some experts claim that post-occupancy takes place when a building is constructed and occupied, thereby the process has a milestone that evaluation takes place once the building is occupied. However, the POE is a continuous process of capturing the information during the asset operation. Therefore, another term has appeared in the construction industry, namely building pathology, which is gaining creditability in Europe, especially in UK.

Purpose of POE

POE has several purposes, which solely depend o normally represented in goals and objectives. According to Federal Facilities Council (2002), the information gathered by POE provides several positive outcomes that are shown in *Appendix* C. Due to the scope of the report, the purposes of POE regarding new construction are only expressed with the following list:

- To measure functionality and appropriateness of design,
- To adjust the programs for repetitive facilities,
- To test the application of new concept.

The first purpose of POE is evaluating the proposed design against the requirements and characteristics that were stated by the client evaluated in a future facility in order to ensure the alignment of demand and supply. POE consists of the information from experience in explicit data that forms a base for evaluating the proposed solutions concerning objectives set by the client. (Federal Facilities Council, 2002)

Another purpose is to standardize the briefing for the future facilities. In some types of organisations, the requirements for new buildings are identical. Therefore, the programming should not contain bias information that causes the same issues every time a new facility is produced. POE identifies the failures in the program by evaluating the previous areas of failure, which can be improved in the next programming and design activities. (Federal Facilities Council, 2002)

Furthermore, the third purpose of implicating POE is to evaluate innovative approaches in the built facilities concerning feasibility, reliability and maintenance. Today, the technologies are developing rapidly, which naturally has an influence on the building industry. The buildings become more intelligent in energy management, security solutions etc. However, it is possible that the new solutions show their feasibility only after some period. In this case, POE helps to monitor that the characteristics of the proposed solution remain the same as intended at the design stage. (Federal Facilities Council, 2002)

The most recognized reason for implementing the evaluation loops is to learn by reflecting the performance and continuous development that was discussed earlier in this chapter. (Blyth & Worthington, 2010)

The common foundation of previously discussed purposes is the evaluation process that helps to identify the potential flaws that must be omitted in the next building procurement. The evaluation loop supports the continuous development that aiming at providing synergy between demand and supply side, which enhance the quality of buildings. The concept of POE that was proposed by Preiser (1995) is given in *Appendix* D.

Facilities Management and Post-occupancy Evaluation

Yu, et al. (2008) undertook interviewee studies regarding the variables in construction programming from three different regions: UK, USA and Hong Kong. According to them, the professionals participating in the research agreed that consultancy with facilities management benefits the briefing process in regards to sharing their experience with the design team. Additionally, POE, according Yu, et al. (2008), ensures that the objectives identified by the client are fulfilled.

Eley (2001) investigated how the post-occupancy evaluation approach meets the facilities management business. The author argues that FM becomes a key player in the assessment of post-construction activities, once *"the performance-based building and regulations are accepted as the norm"* (Eley, 2001, p.167)

FM has all rights to become a key player, because of a full access to the building elements once the building is commissioned. Additionally, FM is the one contacted by the users if the building does not meet its design expectations; therefore, it is in his own interest to make sure that the newly procured building meets the O&M expectation. However, Eley (2001) is concerned about the current systemised evaluation and feedback system within the FM that does not reach all the relevant parties, including the cases with involvement in design process. (Eley, 2001) Furthermore, Jensen (2002) argues that one of the most FM-specific tasks in design process is the transfer of experiences from existing buildings.

To sum up, FM is the person that should perform POE activities, whereas including POE would positively influence the design stage of new construction procurement. Therefore, the research team believes that the facilities management team should expand their duties and become a member of the design process. However, there are many factors concerning the question: why the knowledge of facility manager is still overlooked in the building design. The following chapter attempts to outline the variables that prevent the involvement of FM.

3.3. Facilities Management

The construction industry collaboration chain has been relatively unchanged for many centuries. The usual parties involved in the design and construction of buildings, namely the client, consultant and contractor, overall seem to be functioning just fine. However, the world is in constant change and the construction industry changes with it. New research, new disciplines, software and collaboration approaches emerge on an ongoing basis, though only some are here to stay. One of the somewhat recent additions to the construction industry is facilities management (FM), i.e. the professional mainly responsible for POE discussed previously. Hence, this chapter discusses the past, present and future of FM and its contribution to the building industry.

3.3.1. History of FM

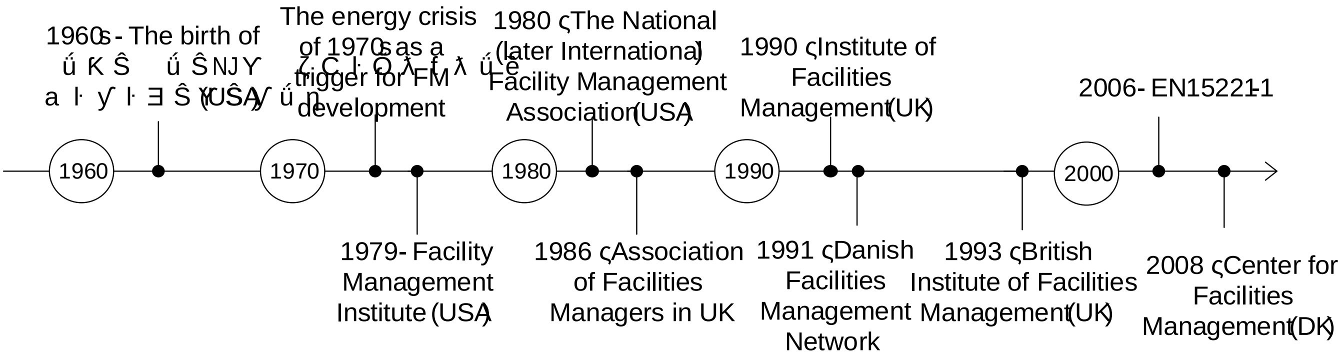

Figure 3.6 FM timeline

When hearing the term ñFacilities Managementò of
well explored comes in mind. It is rarely fully understood what FM really stands for. In the recent years, FM has been a rather popular topic among construction sector researchers, which leads many to believe that FM itself is a new discipline. However, it is not entirely true. FM was first introduced in 1960s and since then has become the fastest growing profession in the UK, according to British Institute of Facilities Management.

As shown in *Figure 3.6*, the history of FM starts in 1960s where the main incentive for the development of FM was the introduction of computers in the workplace. This was when the term ñFacilities Managementò was first introduced by Ross Perot of EDS (Electronic Data Systems) in the USA. At that time, FM was associated with the new trends in the management of IT systems and networks. However, quite soon, the scope of FM already expanded to include system/modular furniture and office design. (Wiggins, 2010)

The energy crisis of the 1970s triggered the understanding of the importance of cost-in-use and the need to manage costs associated with premises and services that support the organisationôs business better. Additionally it far ahead of office design. Therefore, an office furniture designer Herman Miller, realising that the market was being supply led, concluded that it needed to interact with clients who understood the importance of planning and value of space. He then brought together a group of would-be knowledgeable property users and various property advisers in 1979. Very quickly, this group established itself as the Facility Management Institute (FMI). (Wiggins, 2010)

A year later, in 1980, the National Facility Management Association (NFMA) was established, born of the need to create and organization independent from the furniture/space planning predecessor in order to allow FMôs full po
very quickly evolved into the IFMA (International Facility Management Association). (Wiggins, 2010)

While the birthplace of FM was the USA, the pioneer of FM in Europe was the UK. The Association of Facilities Management (AFM) was registered in 1985 and launched in 1986 by a small group of 10 facilities managers as the first such body in the UK, formed to support the professionals practising FM. The Institute of Facilities Management (IFM) was launched in June 1990. It grew out of the Facilities Management Group and Office Design Group (of the Institute of Administrative Management, IAM). The merger of these two organisations was formalised on 1 September 1993, and in January 1994, this merged organisation was named the British Institute of Facilities Management (BIFM), which is now the leading authority of FM in the UK. (Wiggins, 2010)

Development of FM as a discipline in Denmark followed straight after the example set by the UK. In 1991, the Danish Facilities Management network (DFM) was established and it currently accommodates more than 200 large Danish firms and nearly 500 independent professionals as members. The main goal of Danish Facilities Management network is to develop the subject, to broaden and share knowledge about Facilities Management, to promote interaction between practice, education and research and to be the link to the international development in the subject area. (Danish Facilities Management Network, 2015)

Additionally, the Centre for Facilities Management (CFM) was established in January 2008 in order to strengthen research within Facilities Management (FM). CFM started with financial support from Realdania in the period 2008-2016. (Center for Facilities Management, 2015)

According to the historical development of FM, it can be seen that FM has a history of more than 50 years; however, it is still considered a relatively new discipline and profession in the private sector. Nevertheless, according to Roper & Payant (2014), it has been exercised as post-engineering, public works or plant administration in the public sector for a long time. Despite the somewhat short history of FM, it has grown and changed significantly over the years.

As Price (2003, p. 30) states, *ñFM is an emerging discipline. Its roots lie in the custodial role of a building superintendent/caretaker largely concerned with operational issues of maintenance, cleaning and* [illegible] Atkin (2009, p. 4) is of the same opinion, that *ñFacilities management has traditionally been regarded as the poor relation within the real estate, architecture, engineering and construction (AEC) sector. This is because it was seen in the old-fashioned sense of care taking, cleaning, repairs and maintenanceò*

However, ñ*Nowadays, it [FM] covers real estate management, financial management, change management, human resources management, health and safety and contract management, in addition to building and engineering services maintenance, domestic services and utilities supplies*ò(Atkin, 2009, p. 4).

Additionally, Roper & Payant (2014) are of a very firm opinion that FM is an essential business function and it must be positioned at the same level as other essential executives, e.g. human resource and IT system managers. This signifies that the role of FM has evolved throughout the last decades and, as Price (2003) suggests, FM has demonstrated significant growth as a profession in its own right due to the need of specialist people who can add value to business and organizations that control infrastructure.

FM is an essential business function that affects not only income and costs but also production, employee satisfaction, workplace health and safety, work environment and to a certain extent even areas such as recruitment and employee retention. In addition to that, Roper & Payant (2014) claim that when practiced correctly, FM brings following benefits to the organization:

¶ Facility plans match the organizationôs plans,
¶ Properly outfitted space is available when and where it is needed,
¶ Capital expenditures are planned and controlled,
¶ Employee productivity is maximized,
¶ Costs are minimized, sometimes avoided, and always predicted.

Brºchner (2008) has raised the question regarding the causes of recent tendency of integrating FM service into the business spectrum of construction contractors. Additionally, Jensen (2008) claims that the consulting engineering and architect firms in Denmark have started establishing departments regarding the FM consultancy.

To sum up, it is clear that FM as a discipline has undergone many changes during its short period of existence. It has evolved from a low-end support function mainly concerned with cleaning, repairing and generally taking care of a building to a broad-range support function that requires a wide range of knowledge and skills that reach outside the boundaries of traditional disciplines. The modern FM is a mix of technical background, business management and knowledge and sense for entrepreneurship, which allows people from different backgrounds, like architecture, design, engineering, business management, property and construction to interest themselves and specialize in FM. (Price, 2003)

3.3.2. Definition of FM

As observed, FM is a very broad discipline and throughout the years of its existence, many different definitions have arisen. Some define FM as simply a more sophisticated way of referring to operations and maintenance (O&M), whereas some see it as a lawful member of leadership and management disciplines. Since, as mentioned before, FM is highly flexible and allows use of single sections of the discipline, one definition cannot be offered as the main, best or most precise one. Hence, three most commonly used definitions of FM are stated in this report.

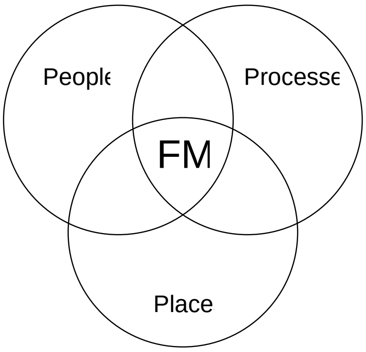

Figure 3.7 FM definition, adapted from FMI

One of the most common and most cited definitions of FM, credit of which goes to the former Facility Management Institute of the USA is *ñthe practice of coordina workplace with people and work of the organization; integrates the principles of business administration, architecture, and the behavioural and eng* (Cotts, 1999, p. 3) *scienc* The FMI also simplified and defined FM with three interlocking circles representing people, processes and places, as shown in *Figure 3.7.* This figure signifies the role of FM as the binder between the three Pôs and its duty well as and processes within them in order to create value and positive environment for the people.

BIFM, however, has formally adopted the definition of FM provided by CEN the European Committee for Standardisation and ratified by BSI British Standards: *ñFacilities manag is the integration of processes within an organisation to maintain and develop the agreed services which support and improve the* (British *effective* Institute of Facilities Management, 2015)

IFMA defines FM as *a profession that encompasses multiple disciplines to ensure functionality of the built environment by integrating people, place, process and technology.* (International Facility Management Association, 2015)

3.3.3. Proactive FM

One of the reasons facilities management should be involved in the design phase and take a pivot role in the POE is for it to change from t operating and maintaining the post-construction product. Proactive management is targeted at identifying both the existing and upcoming issues to avoid decrease of performance. Additionally, it provides better decision-making actions in different parts of the facilities management daily operations. (Franceschi, et al., 1996)

The evidence of FM ñfirefightingò strategy can example, Eley (2001) compares how FM fits with POE. The reactive approach of FM is one of the barriers that keep the FM away from having smooth daily operations.

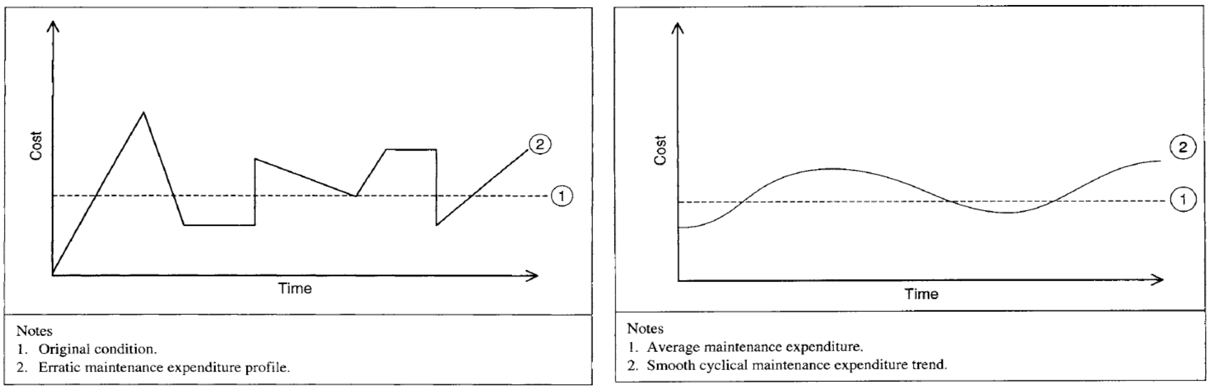

Figure 3.8(a-b) O&M expenditure in FM by using different management approaches (Douglas, 2006, pp. 551-552)

Figure 3.8a, shows the expenditure profile of facilities management that has a reactive management system. It is clearly visible that the costs appear rapid and unpredictable compared to estimated investment conditions. The internal operations of facilities management are to be destructed by sudden problem occurrence.

Figure 3.8b shows the proactive management of the maintenance and operation. The proactive approach shows that the estimated budget is more realistic and the flow is smoother compared to the reactive approach (Douglas, 2006). Predictable maintenance sessions give a better overview of the needed budget; hence, it becomes easier to justify the expenditure to the upper management. Therefore, the manager of facilities needs to understand the advantages of getting to know the procured building starting from the design stage. Hence, to increase the efficiency of internal operations, the facilities management has to consider the activities that have taken place before receiving the building, to avoid reactive actions in his operations. One of the ways to avoid this is sharing their expert knowledge by being involved in the design stage.

3.3.4. Knowledge Management in FM

As discussed earlier, to avoid operational issues in FM, the knowledge has to be shared with the design team. Knowledge management is important in any kind of business. In the case of facilities management collaboration with the building industry, the principle of knowledge push and pull works the following way: the knowledge can be pushed from the FM to other parties involved in the building process or the knowledge can be pulled from the FM by the other actors. When referring to a knowledge push, the FM is the party most interested in sharing experiences and getting through to the industry. In the case of knowledge pull, the information is found important by the industry and is requested from the FM. (Jensen, 2002)

Additionally, the knowledge can be transferred either in explicit or in personalized form. The codified knowledge is usually found in paper-based or digital form and is therefore easily transferrable from person to person or from party to party. The personalized knowledge, on the other hand, is in the form of competences and capabilities of people, which makes the knowledge transfer more complicated. This implies that the knowledge from the FM to the design and construction team can be pushed either via data of different formats or via involvement of a person with specific competences. (Jensen, 2002)

Nevertheless, even though the knowledge is pushed from the FM in either personalized or codified form, it does not mean that it is exploited to the utmost extent. In order for this knowledge to be used efficiently, a pull action is needed from the design and construction team. It is necessary for both the client and other involved actors to acknowledge the need for the FM information. Generally this means that the knowledge can be pulled either by force, where the client uses his power, or with an understanding of needs and benefits FM can bring to the project and proper attention towards it. (Jensen, 2002)

Figure 3.9 illustrates the mechanisms that can be used for transferring knowledge between FM and other parties involved. The left side of the matrix refers to the objective to raise awareness about FM in the building design, whereas the right side refers to the objective to validate the performance of the building.

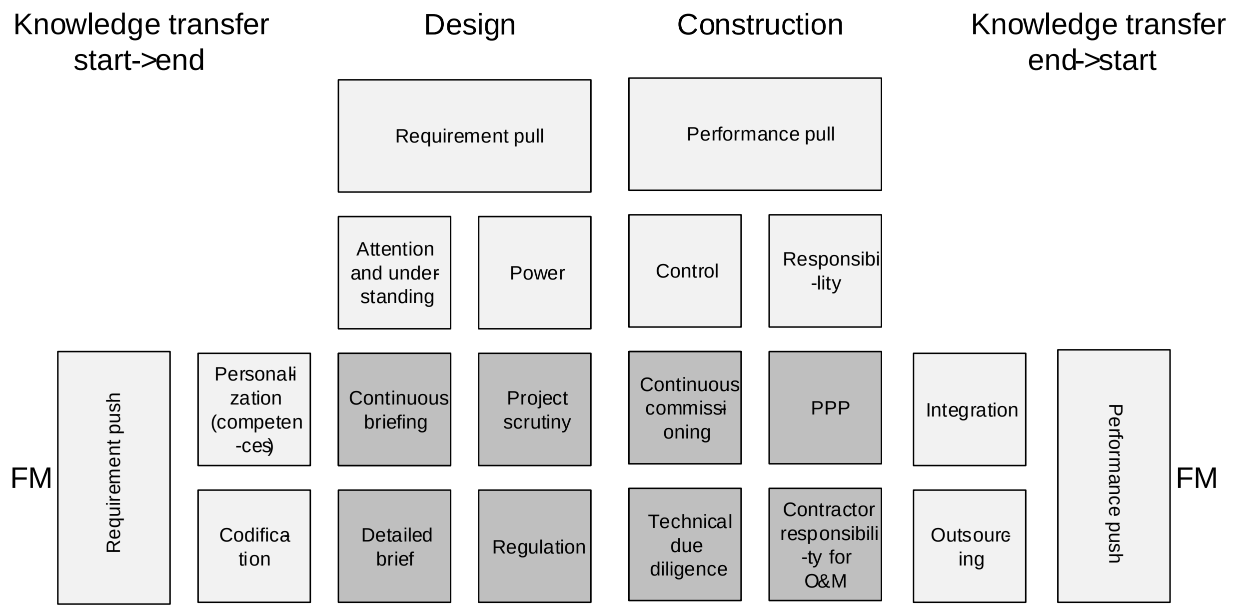

Figure 3.9 Knowledge transfer from FM to construction projects, adapted from Jensen (2002)

As shown on the left side of the matrix, when the design team pulls the knowledge from FM by genuinely paying attention to the FM knowledge and the FM shares their tacit knowledge, the dynamic (continuous) briefing, as discussed in *Chapter 3.1.3 Dynamic Briefing*, can be used. In case the FM shares the knowledge in a codified manner, detailed briefing, which specifies all the clientôs requirements to the s
the client uses his power and enforces the use of FM information and the FM uses personalized knowledge, the client can request scrutiny of project phase documents from the perspective of FM. If the FM knowledge is codified, requirements are set through governmental regulations for fulfilling specific requirements, e.g. assessment of total economy.

In case the objective is to validate the performance of the building, the FM can push the knowledge by either integrating the facilities manager of the future building in its design process or by outsourcing the FM function to a specific contractor. The design team can pull the FM knowledge by increasing control or increasing responsibility.

As the right side of the matrix illustrates, increasing the responsibility and integrating the future FM in the design process suggests the use of Public Private Partnership (PPP), described in *Appendix* E, which is a long-lasting way of procuring capital projects. In PPPs, the FM is a part of the consortium responsible for design, construction, financing and operating the building; therefore, the FM has a high authority.

When the responsibility is increased and outsourcing of FM is chosen, an arrangement is made to extend the service of one of the contractors involved in the construction process to post-construction activities. In case the level of control is increased and FM is integrated, the continuous commissioning can be used. In this situation, the FM function or an O&M consultant is involved in the design process from the very beginning in order to continuously validate the construction design and solutions. When control is increased and FM is outsourced, technical due diligence can be used. This suggests a technical assessment of the buildingôs conditions when transferring the

This matrix shows how various methods of integrating the FM knowledge in the building design and construction can be used. The different methods signify that regardless of the situation, the FM knowledge can be transferred to the team and eventually to the building in order for all the involved parties to benefit from it.

3.3.5. Benefits of Involving FM

ñBeing responsible for the running cost, O&M, energy consumption, adaptation and development of the buildings belonging to an organization, facilities managers have the daily contact with users and obtain an in depth knowledge about the special needs for facilities that support the processes and culture of that particular organization. This knowledge can be a very valuable source to be used in the planning of new buildings if it is put into play in an appropriate wayò(Jensen, 2008, p. 3).

FM is the eyes and ears of the clients. When handing over of a building takes place, the eyes and ears of the client also assume the role of his hands and feet. (Enoma, 2005)This metaphor signifies the importance of FM both in the design and in O&M stage. FM is a force that could safeguard clientôs objectives, evalu
contract point with end-users.

There are many benefits that each involved party could profit from. The British Institute of Facilities Management (BIFM) initiated a research about bringing FM knowledge into the design process. The research conducted by Jaunzens, et al. (2001) identified several positive outcomes of FM involvement. According to Jaunzens, et al. (2001), a building designed and constructed with the involvement of FM is:

¶ Better suited to meeting business needs,
¶ More attractive to clients,
¶ Easier to commission and maintain,
¶ Easier to control and manage,
¶ More cost effective to operate,
¶ Better able to respond to the needs of the occupants.

Moreover, Meng (2013) outlines positive outcomes from different perspectives that could take place if the design team included facilities management discipline. The benefits are illustrated in *Table 3.1.*

Actor	Benefits of involving FM
Client	Å Reduction in operating and maintenance costs because of the achievement of a better building, which can be operated and maintained more efficiently and effectively, Å More emphasis on the whole life cost rather than focus on the capital cost, especially when a client is the end client, Å Identification and avoidance of potential problems in advance, Å More likelihood to meet the clientôs
FM	Å Making it easier to operate and maintain facilities and provide services by selecting appropriate materials, equipment, and technical solutions, Å Better knowing whether the FM contract can be fulfilled successfully in the future and what the FM performance outcome will be, Å Minimizing or avoiding residual risks, e.g., the risk in relation to cleaning windows where access is extremely difficult, Å Collaborating with client and designer and bringing the project team together.
Designer	Å Identify design flaws in advance, Å Achieve more accurate results during design, Å Improve the operability, maintainability, and serviceability of designed facilities, Å Encourage sustainable practice, e.g., energy saving.
End user	Å Reflecting their concerns and expectations during design, Å Providing a safer, healthier, and more attractive working environment, Å Supporting productivity and improving work efficiency, Å Providing more flexibility for changing requirements.

Table 3.1 Benefits of involving FM, adapted from Meng (2013)

Everyone involved in a construction project can benefit from early FM involvement. The client has the biggest advantage in this situation, since the FM professional is able to significantly lower the O&M costs of the building and ensure that possible problems encountered in O&M phase are eliminated already in the design stage. Moreover, the chance that the clientôs requirements are met i
when an FM professional works together with the client.

The FM itself benefits greatly from this scheme by making the facility much easier to operate and maintain and by influencing its design in a way that reduces unnecessary risks, as discussed in *Chapter 3.3.3. Proactive FM.* Additionally, the designer of the building, with the help of FM, is able to design a facility with significantly reduced amount of flaws and improved maintainability and serviceability. It also creates the opportunity to concentrate on more sustainable practice.

Moreover, the end user of the building is able to receive a much more attractive working environment that supports productivity, since his concerns and expectations are heard early in the design phase.

Furthermore, Jensen has specified the incorporation of consideration for operation, sustainability and user needs as the most important task for FM in design, which covers the entire life cycle of the future construction. (Jensen, 2008)

3.3.6. Barriers of FM Involvement in the Design Process

The traditional design and construction process as shown in *Appendix* B generally consists of the client, consultant (architect and/or engineer) and the contractor. The FM is very rarely considered a part of these processes.

According to Jensen (2008) , there have been attempts to include FMs with a background of building O&M in the building design process, mainly by participation in design meetings. Moreover, Jensen (2008) argues that one of the reasons why the attempts to include FMs in the design stage have not borne fruit is the lack of competences of the FM staff. These professionals mainly have a very technical background and a practical education and they often lack theoretical knowledge and understanding. Their ability to transfer knowledge from their experience with existing buildings to the new building being designed is quite limited. Furthermore, their understanding of the design process is also limited, which leads to misunderstandings and arguments during the design meetings. Additionally, it is believed by actors in the AEC industry that the professionals of FM simply lack prestige to be fully integrated in the design stage. (Jensen, 2008)

Another study done by Meng (2013), has investigated involvement of FM through series of specialist interviews conducted in the UK. The author has observed two different viewpoints by interviewees from facilities management and designer perspective. The FM side claims a high importance of their involvement due to high probability of failure occurrence in design solutions. The design flaws are normally identified at the post-construction phase, when the building is under FMs common belief is that buildings are not just a shelter with aesthetic appearance and that the design of a building should include such aspects as functionality, practicability, O&M and serviceability to ensure satisfaction of end-users and achieve the value for money. The bottom line is that if FM role is ignored, design flaws are likely to occur and be identified only after the construction is built. (Meng, 2013)

Opposing the FMs was the designer team. According to Meng (2013), these interviewees are not against early FM involvement. However, they are a quite sceptical about the input of facilities managers in the design phase. Half of the interviewees agreed that FM could enhance the design robustness; however, they argue that a high quality design can easily be produced without the involvement of FM. The design flaws could be identified with the experience of other stakeholders in the design team. Several interviewees from the design team pointed out that involving an additional party in the team could create conflicts of interest, which prolong the design duration and administration costs. (Meng, 2013)

Tay & Ooi (2001) argue that the cause of not involving FM in the construction industry is the overlapping of FM with other disciplines within the traditional construction industry. For example, FM takes over the workplace assessment from the architect or designer. Generally, the architect is capable of performing such task with a high level of quality without additional assistance. The ability for other actors to undertake the FM role undermines the facilities manager's professionalism and presti
interviewees of the design team described above. Both sides have their own perspective on the matter due to their business and interests. Therefore, they see the role of FM involvement in the building design stage differently. According to FM interviewees, the architects still see the facilities management role as a post-construction service without seeing the benefits it could contribute to the design. It appears that each of the interviewed sides does not have a clear pict (Meng, 2013). The each ot

conflicts regarding the professionalism of FM could be reduced by clearly identifying the discipline and role of FM within the construction process. (Tay & Ooi, 2001)

To increase the value of the facilities manager, a radical organisational change in design stage is necessary. Nutt (1993) states that too much attention is paid to the design aspect of the brief. He believes that more time has to be spent on other parts of the brief: organisational, management, construction, to make sure that there is balance in the whole brief. A more balanced briefing process would bring more value to the design with regards to future requirements, consideration of post-occupation issues and possible risk (Kelly, et al., 2005). The facilities manager would have his niche in such decision-making processes due to his post-construction duties. Reorganisation and re-evaluation of values in the design process would increase the power of facilities management to influence a construction project. (Kelly, et al., 2005)

Furthermore, Bröchner (1996) conducted a research about Swedish construction in 1960, the result of which is that there is a poor connection between evaluation of proposed design and future O&M. Bröchner c[illegible] the future development of information technologies would help to create a bridge between the building design and O&M. Hence, todays technologies in the construction industry might potentially involve FM in the design stage.

Furthermore, Jensen (2008) has grouped the barriers facilities management is facing within different aspects of the construction project, which are summarized in *Table 3.2.*

Type of barriers	**Barriers**
Project related	• Temporary and project based staff – new participants, • Innovative projects provide more know-how challenges than standard projects, • The client is considered to be the only responsible part to place focus on operational phase, • It is difficult to allocate responsibility for focus.
Structural	• Solely focus on the costs in the construction phase, • A short sighted focus, • The parties have different areas of focus and very few are focusing on the operational phase, • Short-term relationships due to tender rules and legislation.
Legislative	• Legislative regulations limit the recruitment of participants, • Lack of legislation within certain areas.
Competence related	• FM staff lack know-how and communication skills, • FM is not considered a strategic issue, • The client's consultants lack know-how, • The end users lack know-how, • The clients lack competences, • The participants lack knowledge about FM.
Sociological	• Power struggle between the participants, • The client's attitude towards FM, • Low status of FM, • FM staff are reluctant to participate in the construction phase, • Short-term relationship due to tender rules and legislation.

Table 3.2 Barriers for FM integration, adapted from Jensen (2008)

One of the fundamental issues in this case is the project-related organisation within the construction sector. With this organization style, the staff changes with each project, hence making it more difficult for FM to integrate in the design teams. However, with the client being the highest authority, FM is still likely to be both integrated and accepted in the project teams. This suggests the high importance of the client being informed of the benefits of FM involvement in building design.

The structural barriers of FM involvement refer to the shortsightedness of construction project actors. In the usual building design process, mainly the costs related to design and construction are focused on, hence ignoring the O&M costs, which are easily capable of turning the cost tables.

Additionally, the involved party competences, or rather lack of them are also significant barriers. The end users, clients and even their consultants lack knowledge about FM in general and its possible useful contributions to the entire project. The client attitude towards FM, that seems to postpone it until the project is finished, also creates a barrier. However, the FMs themselves also lack the necessary competences and communication skills to fully integrate in the process and prove that FM has evolved to being a strategic, rather that purely technical issue.

All these issues contribute to the sociological barriers of FM involvement, namely the low status of FM and the power struggle between other actors, in which FM seems not to be able to position itself.

The quantitative research done by Meng (2013) has shown that 80.6% of interviewees have had experience with early involvement of facilities manager in the design process, whereas 19.4% did not have a practice of having FM entity in the design stage. This clearly shows that the need of additional party is recognized. However, the author cannot claim that having FM in the design team is a common practice. Moreover, the interviews were conducted in the UK, which is considered a pioneer in FM early involvement in Europe.

As discussed above, there are many reasons of various scale and importance that seem to hinder the integration of FM activities in the early design stage of buildings. However, this research tackles the concern regarding limited ability of FM to evaluate design proposals due to his technical background as it is manifested by Jensen (2008).

3.4. Knowledge Asset

The knowledge within an organisation is normally codified and stored in local servers. However, not all knowledge can be articulated and hence, expressed in a codified manner. As Polanyi (1967, p. 4) says, ñ*We can know more that we can tell*ò. It clearly give
that the most knowledge within a company is distributed among the individuals, and not stored in documents. This non-codified expert knowledge of FM could bring a lot of value in a decision-making process with many variables involved.

Knowledge, according to its ttrruaedibtelolineaflò.defThe
epistemology of knowledge definition is ñbeing
question has to be first believed by an individual owning that particular knowledge and he/she has to be able to justify that knowledge (Nonaka, 1994).

The term ñknowledgeò and ñinformationò are ofte distinction between both terms. *ñThe information is a flow of mes created and organized by the very flow of information, anchored on the commitment and beliefs of its holder* (Nonaka, 1994, p. 15). Moreover, Davenport & Prusak (1998) argue that data has to be also included in the knowledge context, which incorporate objective facts about the eventsò. Thereby, the data and information, which derives from minds at work.

According to Nonaka, et al. (2008), knowledge asset is accumulation of knowledge within an organisation that arises from the knowledge creation process. Knowledge asset consists of intellectual capital, e.g. patents, databases, documents, skills, capabilities, organisational structure etc. In other words, knowledge asset is accumulation of explicit and tacit knowledge that is produced by doing the business. Nonaka, et al. (2008) argue that knowledge creation is solely linked to the individuals employed in the company. Hence, the knowledge asset helps in making better decisions, which leads to positive outcomes, creating a better business environment within the organisation.

Polanyi (1967) divided human knowledge into two categories: explicit knowledge, which is transferrable between human beings, and tacit knowledge ï a type of knowledge that is hard to articulate and formal *deeply rooted in action, commitment,* knowled *and involvement in a specific context*ò (Nonaka, 1994, p. 16). *Figure 3.10* illustrates the different knowledge types.

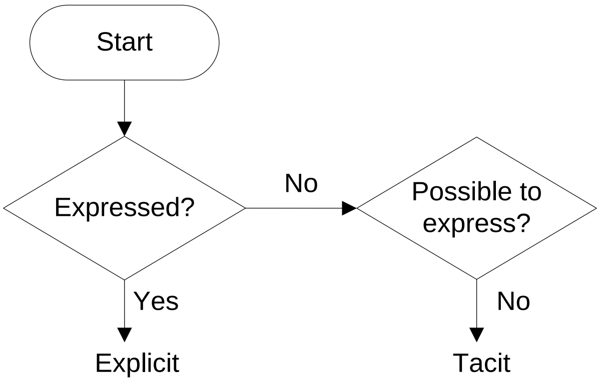

Figure 3.10 Explicit and tacit knowledge, adapted from Woods & Cortada (2000)

3.4.1. Explicit Knowledge

Explicit knowledge is the type of knowledge that ñ*can be articulated in formal language, including grammatical statements, mathematical expressions, specifications, manuals, and so forth*ò (Nonaka & Takeuchi, 1995, p. viii). If the knowledge can be articulated and expressed, then the knowledge is explicit (Nonaka & Von Krogh, 2009). An example of explicit knowledge is a best practice procedure that is used within the organisation. The knowledge of best practice is transferred from one employee to another by means of written documents, orally, etc. Another example is ISO standards that structure different kinds of procedures within the company.

As discussed earlier, there is a vital need to utilize post occupancy knowledge when the organisation aims to create standardized briefing and evaluate a prototype of future facility. Part of the post occupancy evaluation comes from explicit knowledge. Thus, the information regarding a similar building that is stored in the software is accessed to familiarize the employees with the bad and good practices what were introduced in the previous design solutions. Thus, it helps to avoid making the same mistakes by making use of the failed solutions that were earlier identified by post construction evaluation.

Nonaka & Von Krogh (2009) argues that the knowledge is created by individuals. An individual is a driving force to convert the information/data into knowledge that can be utilised within the company. This kind of new knowledge is discussed between the individuals by face-to-face conversation, meetings, phone conversation etc. Thus, the information is transferred to different employees within the organisation, which converts it into explicit knowledge that could be articulated in writing. The information captured in the organisation regarding operation and maintenance is not the only source of knowledge creation. The companyôs policy, behaviour and co
knowledge that is expressed or is possible to
boundaries. However, over time, the employees are absorbing the explicit knowledge and gaining the knowledge by performing their duties. This knowledge converts into experience of each individual, which sometimes is hard to share further. Hence, another form of knowledge is collected simultaneously within the organisation. This type of knowledge is based on experience, intuition and principles taken for granted. (Nonaka & Takeuchi, 1995)

3.4.2. Tacit Knowledge

Tacit knowledge is the type of knowledge that is hard to express or explain. It refers to the knowledge that is obtained through experience; hence, difficult to share by set of instructions, pocketbooks etc. (Ribeiro, 2013). Most researchers admit that most of the knowledge within an organisation is accumulated in form of tacit knowledge (Suppiah & Singh, 2011). Polanyi (1967, p. 4) has stated the need of reconsideration of human knowledge: ñ*We can know more that we can tell*ò. Around 90% of all knowledge gained within the organisation is accum(Smith, 2001). Winter (2004)ployeeô claims that tacit knowledge, along with a combination of other assets, is an essential part of competitive advantage. According to Nonaka & Von Krogh (2009), tacit knowledge is the foundation of knowledge creation theory, because it covers the knowledge that is intangible. Therefore, trying to use and retain the knowledge within the organisation is a vital strategic step that has to be undertaken in each organisation. Tacit knowledge is defined as personal, context specific knowledge that is hard to express and communicate (Suppiah & Singh, 2011) (Polanyi, 1967) (Nonaka & Takeuchi, 1995).

According to Collins (2007), there is a need to distinguish different types of tacit knowledge, because they have different level of codification.

Two types of tacit knowledge are distinguished regarding their ability to be codified: somatic-limit tacit knowledge and collective tacit knowledge (Collins, 2007).

Somatic-limit tacit knowledge refers to human body. It supports or enables an individual to perform an action and to interact with the physical world (Ribeiro, 2013). Collins (2007) argues with the Polanyi (1967) example of riding a bike. The latter argues that the human kind can articulate the knowledge of riding a bicycle, but it would not give another individual an aid in learning to ride the bicycle. However, Collins (2007) suggests that the knowledge of riding the bicycle still could be codified in the robotic digital computer, where the robot could ride the bike. The idea here is that some parts of somatic-limit tactic knowledge could be codified, thus, the knowledge can be converted into explicit rules, and another individual could obtain the knowledge by following those rules (Collins, 2007).

Collective tacit knowledge refers to the ability of an individual to perform an action with the understanding of its social context. The collective knowledge is crucial to understand in order to make a proper action (Collins, 2007). Collins (2007) refers again to riding the bicycle, but in this case, he also considers the traffic conditions. Thus, the knowledge of knowing-how to ride a bike is not enough to perform an action; it requires additional knowledge within traffic management e.g. knowing how to make an eye contract with the traffic participants at the junction to ensure a safe passage. Therefore, the second type of tacit knowledge is not a matter of individual knowledge, but it requires to be known tacitly, because this knowledge represents a collective knowledge that is not a property of any specific individual. (Collins, 2007)

ñ*The right way to think of collective tacit knowledge is as something that human individuals, and only human individuals, can acquire, because of their special and continual access to the location of the knowledge ð which is the social collectively*ò(Collins, 2007, p. 261).

This knowledge has a small chance to be codified into a system, unless machineries would have the ability to socialize with human beings (Ribeiro, 2013). However, individuals can obtain the knowledge by being within the same environment as the person with some specific tacit knowledge.

Both tacit knowledge types are vital to consider in case of evaluation of new construction procurement at the organisation. The somatic-limit tacit knowledge helps in extracting the knowledge that has been accumulated throughout the professional life experience of FM and express it at the meetings regarding specific matters. An example could be experience that is gained by doing POE of existing facilities. Where a facilities manager knows of certain solutions that are used in the buildings and causing extra expenses. This type of knowledge can be forwarded to the decision-making team to ensure avoidance of choosing the potentially inappropriate solution. The collective tacit knowledge looks at the evaluation from the points of social framework within the organisation. This kind of knowledge could be e.g. unspoken strategy or the organisational behaviour. When an evaluation of design takes place, it is important to weight the design from different aspects including the tacit knowledge. As it was stated earlier, 90% of the knowledge is hidd heads; hence, taking the knowledge out in terms of design criticism would contribute a non-controversial input to a better decision-making process. Therefore, there is a lot to gain by trying to use the combination of tacit and explicit knowledge to evaluate the prototypes of future facilities, especially putting the emphasis on employeeôs experience, w tacit knowledge.

Explicit knowledge is always grounded in tacit knowledge. Before the knowledge can be articulated, it has to be created in oneôs head formatted tacit knowledge that has appeared by beliefs and justification of an individual. (Nonaka & Takeuchi, 1995) Moreover, the interaction between explicit and tacit knowledge is the driving force for creating new knowledge within the organisation (Nonaka & Von Krogh, 2009), (Nonaka & Takeuchi, 1995) (Nonaka, et al., 2008). The employees that do post occupancy evaluation can contribute a lot of value in regards to design evaluation of a new building. The model of knowledge creation process was proposed by Nonaka & Takeuchi (1995), which is called the SECI model.

3.4.3. Knowledge Creation Process

Knowledge sharing is defined as the process of transferring tacit and explicit knowledge to other individuals (Wang, 2011). Tacit knowledge is a complex knowledge based on feeling and experience; thereby it is hard to codify in order to make it shareable. One of the schools regarding sharing of tacit knowledge is the belief that tacit knowledge must be converted into explicit knowledge in order to make the knowledge available to other employees. (Haldin-Herrgard, 2000) (Nonaka & Takeuchi, 1995) Tacit and explicit knowledge have to be diffused (Knowledge Conversion) in order to be used and shared within the organization.

Nonaka (1994) has proposed a model of knowledge creation - SECI, which is shown *in Figure 3.11.* The description of the model is based on Nonaka (1994) and Nonaka, et al. (2008), since the main author of the sources is the creator of the model. SECI is a process model, which is based on four modes with according sequence:

- From tacit knowledge to tacit knowledge,
- From tacit knowledge to explicit knowledge,
- From explicit knowledge to explicit knowledge,
- From explicit knowledge to tacit knowledge.

From \ *To*	Tacit Knowledge	Explicit Knowledge
Tacit Knowledge	Socialization	Externalization
Explicit Knowledge	Internalization	Combination

Figure 3.11 SECI model, adapted from Nonaka (1994)

The first mode is called *socialization*, which stands for sharing the tacit knowledge throughout the interaction process between individuals. The important observation is that ñ*an individual can acquire tacit knowledge directly from others without using language*ò (Nonaka & Takeuchi, 1995, p. 62). For example, a technique of artistry shown by a teacher is learnt by an individual throughout observation, imitation and practice. One of the key drivers to enable the tacit knowledge sharing is experience. (Nonaka & Takeuchi, 1995) Without the experience, it is difficult to shar living in the same environment individuals share and receive tacit knowledge about the surrounding environment. ñ*In socialization, individuals embr fighting them, absorbing knowledge in their social environment through action and perception*" (Nonaka, et al., 2008, p. 20). As the result, it helps to reach new viewpoints regarding the environment the individuals are surrounded by. Nonaka, et al. (2008) provide the example of Honda car manufacturing company, where the product development team had visited Europe to understand the environment for which the car prototype is designed. The idea was to avoid getting tacit knowledge from the Europe Honda division regarding the location but instead, to introduce the environment by being there. Hence, receive collective tacit knowledge, before developing a product for that specific environment.

The second mode is externalisation, which is converting tacit knowledge into explicit knowledge. Example of such process is an R&D team trying to explain a new product concept (Nonaka, et al., 2008). ñ*Tacit knowledge of individuals i* -way *dialogue and further c* (Nonaka, et al., 2008, p. 22). Dialogue and *defined* observations are effective tools to transfer the tacit knowledge that could be further articulated and expressed on paper. Furthermore, the key drivers of externalisation are metaphor and analogy (Nonaka & Takeuchi, 1995). For example, Honda R&D team used the metaphor of the falcon to design a prototype of van. (Nonaka, et al., 2008)

The third mode of knowledge conversion is combining different explicit knowledge into a system, where the knowledge is grouped, sorted and categorized. (Nonaka & Takeuchi, 1995) This mode is called *combination*. The new source of explicit knowledge combined with the existing explicit knowledge forms a new knowledge creation.

Internalization is connected with organisational learning. However, the tacit knowledge in this case is mostly referred to an individual, questioning how the person could convert explicit knowledge into experience by e.g. learning by doing or exercising (Haldin-Herrgard, 2000). The practise is a vital process to absorb explicit knowledge by an individual and create tacit knowledge with alignment to oneôs own beliefs virtual simulations might help to gain the experience, where the on-the-job training is not possible due to e.g. working environment.

The process within SECI is continuous, because new knowledge comes from the internal and external environment. In the internal environment, new knowledge appears due to interaction of tacit and explicit knowledge. The external environment provides tacit and explicit knowledge, e.g. new government directives, changes in the market, new competitors etc. The interaction between tacit and explicit knowledge results in innovation thinking/design. (Nonaka & Takeuchi, 1995)

Todayôs technologies help to bring explicit kno driving simulators. In case of a driving simulator, an individual learns the driving regulations by attending courses regarding driving techniques, which is a representation of explicit knowledge. Whereas, bringing the individual into a driving environment with help of the driving simulator allows him to acquire the tacit knowledge of driving a car. As it was discussed earlier, most of the employeeôs knowl interest of using the knowledge of post construction activities to the design process means that the most focus has to be put on *socialization* mode of SECI model. The expert knowledge of facilities management has to be expressed and captured by the participants, where later the knowledge could be possibly codified. In order to perform socialization process, a participant should be integrated in the environment in question. The technologies provide a significant aid to support our daily activities. Hence, the concern is whether the technologies could help to share tacit knowledge or not.

3.4.4. IT Systems for Knowledge Asset

Many research studies have been conducted to prove the importance of using IT technologies for enhancing the knowledge management within organisations. Short descriptions of several studies are presented further.

An investigation on IT support within knowledge asset has been performed by Davison, et al. (2013) within two companies in China. One of the aims of the research paper was to investigate the IT contribution to knowledge sharing. The communication tools that were referred to in the academic paper are communication based IT platforms such as MSN messenger. It was observed that the communication tools play a vital role in sharing knowledge among the individuals (Davison, et al., 2013).

Furthermore, Ġarkiĩnaitė & (2005) have outlined several linkages of IT based tools with socialization of SECI model. In the socialization part, the IT tools that could be used are the following:

- Online meetings,
- Online Chat,
- Online Community of practice (Interaction with particular individual with particular knowledge),
- Groupware application systems (application that helps in interpersonal interaction),
- Knowledge Mail product (email analyser: individual profile with capabilities, ôs level and area of expertise).

Additionally, Ġarkiĩnaitė & (2005) argue that a high level of IT usage positively affects the knowledge transformation within the SECI model. Moreover, Lopez-Nicolas & Soto-Acosta (2010) conducted a qualitative research of 300 Spanish small-medium enterprises. The research group has observed a strong IT tool utilisation, which provides a significant aid for knowledge creation. However, they have identified a low usage of IT technologies within *socialisation* mode of knowledge-creation process.

Furthermore, Haase, et al. (2013) have performed a case study in understanding if technology based learning environment, namely non-immersive virtual reality helps in externalisation mode (tacit knowledge to explicit knowledge). The reason for performing the case study was exploring less expensive learning techniques to help to sustain expert knowledge within an organisation. The authors claim that non-immersive virtual reality has shown a high potential in sustaining the expert (tacit) knowledge within the company by making an effort of sharing it.

Besides, Watanuki & Kojima (2007) proposed a framework of using Virtual reality-based knowledge acquisition in combination with traditional educational methodologies to help educate young engineers and employees. This approach implies acquisition of explicit and tacit knowledge (*internalisation* mode). In internalisation process, a virtual on-job-training session is performed, where a person enters a virtual environment simulation. In such environment, it is easier to teach a participant to obtain the needed work experience. A benefit of implementing VR into the learning process is to allow the user who has obtained explicit knowledge to acquire the technique and skills of experts (tacit knowledge) in the virtual environment. Thereby VR has a great potential in *internalization* mode according to SECI model.

By analysing several academic research works, it is clearly shown that IT technologies play a significant role in the knowledge creating process. Moreover, Ġarkiĺnaitā & Krikġ (2005) have outlined possible tools that could be utilized in socialization process. Further, the main investigation of IT technologies in this report has been focused primarily on finding the evidence of using virtual environment as part of knowledge creation process. According to two researched cases, the virtual environment has its potentials in learning process within organisations. According to the SECI model, the part of the learning process is located in the internalization area, where the explicit knowledge, e.g. documents and handbooks is converted into tacit knowledge of an individual. Watanuki & Kojima (2007) believe that immersive virtual reality is showing its full benefits in supporting the internalization process. Whereas, Haase, et al. (2013) argue that virtual reality is useful in externalisation to sustain the expert knowledge within the organisation. However, VR could be potentially used in other modes of SECI model. For example, in socialisation mode tacit knowledge is shared among participants. Virtual reality provides the environment in which the participant in question can express his thoughts on particular matter by judging from his experience. Additionally, tacit knowledge is hard to share among participants; therefore, placing the facilities manager in virtual environment would help him to express his expert opinion.

Based on the small-scale investigation, it is possible to assume that IT tools, namely virtual reality, could be the enablers of enhancing the sharing process of tacit knowledge during design evaluation. There is a high potential for implication of virtual reality within the organisation:

1. Providing an immersive feeling during an arrangement regarding a new retrofitting of a building when tenants are involved,
2. Potentially providing better understanding of an object, hence extracting more tacit knowledge of the participants, which aids at having a good decision-making session.

3.5. Tender Evaluation

The tender competition is the process in which briefing meets decision-making. I.e. the brief prepared by the client or its representative serves as the foundation for the bids offered by bidders in the tender. Therefore, it is vital that the briefing is done in the most effective manner and all the wishes and requirements, also regarding the previous experiences, are explicitly stated. Nevertheless, the tender evaluation is the process in which the decision regarding the best proposal will be made and the contract awarded. The following chapter, therefore, introduces the legal requirements for the tender process.

The tender competition takes place both in public and private procurements. The reason for performing an extra action in the building procurement route is to secure the project scope against overpriced solutions.

A client and his team set up the requirements of the scope of works. This process takes place at a regular project briefing. The outcome of the project briefing is tender documents that form a foundation for further tendering process. The deadline for a bid submission is stated in the tender documents. Participants perform scrutiny of the received documents to prepare bids and send back to the client. The r team by comparing them against the initial tendering documents. The bid that aligns with the requirements the most wins the competition.

The tender appraisal and selection of the right candidate continues to be a vital area, which determines the future procurement outcomes in terms of quality, budget, and project duration. Hence, the role of the client and his team in undertaking the decision-making regarding the right choice of candidate is the most critical (Watt, et al., 2010). Another reason why the tendering is an important chain within the building procurement is due to legislation.

The difference between a public and a private client is in the legislation that must be followed. The private client has no obligation to create a fair competition environment for the bidders, because the investment in a new procurement is not financed by public entities. However, the private client must follow the same tendering rules as the public client if any amount of public capital is involved in the procurement at any stage of the project. This capital could also be expressed in terms of subsidy. Moreover, the case study of this report is in a situation, where the organization is partly financed by Aarhus municipality; hence, it must use the public tender in case of new procurements or renovation projects.

3.5.1. Public Tender

Since the research takes place in Denmark, the report is based on the Danish legislation. The Danish Tender Act is the act that applies to the public tendering.

The main purposes of the Danish Tender Act are:

- To enhance the competition among the bidders,
- To ensure equality and transparency.
(Erhvervs- og VÞkstministeriet, 2007)

The Danish Tender Act is applied when certain characteristics are involved in the tendering. Moreover, it covers services in several procurement areas such as construction works, design or execution; combinations of the work provisions are also possible. When the procurement value is over 500 000 DKK, the procurer must apply the rules under the tender act. Additionally, if the procurement is below the financial threshold of EU, the Danish tender act applies. If the value of procurement exceeds the threshold, EU procurement directives must be used. The EU financial threshold is 5 186 000 EUR in 2015 (EUR-Lex, 2013).

There are several types of tendering routes allowed by the Danish Tender Act, namely:

- Public Tender,
- Restricted without pre-qualification,
- Restricted with pre-qualification,
- Confidential tender,
- Frame agreements.

A short description of these types is given further. The public tender allows an unlimited amount of participants. The restricted tender without pre-qualification limits amount of participants by inviting them to the tender, instead of allowing any interested contractor to participate. This helps to reduce the transaction cost that arises during the tendering evaluation. Restricted tender with pre-qualification has similar characteristics with the latter. The difference is that the invited contractors also receive set of criteria to fulfil in order to participate in the competition. However, the prequalification criteria must not discriminate nor create unfair competitive environment. (Erhvervs- og VÞkstministeriet, 2007)

A confidential tender allows the developer to invite specific contractors to the tender; however, not more than three or four in case one of the bidders is from outside the local area. Unlike previous tendering types, in confidential tender bids do not have to be opened at the same time, all bidders do not have to be informed of the bids of others and there is no restriction regarding negotiations. However, there is a threshold - if the contract sum is above 3 000 000 DKK, the confidential tendering type is not allowed. (Konkurrence- og Forbrugerstyrelsen, 2005)

A frame agreement is an agreement between a developer and a firm, which has the goal to determine the conditions of contracts awarded during a given period. This contract form creates the opportunity to choose a firm that shall perform a specific type of works on an ongoing basis, e.g. repainting apartments after tenants have moved out. (Konkurrence- og Forbrugerstyrelsen, 2005)

If the prices economic threshold, only two types of tender are available:

- Open Tender,
- Restricted tender with pre-qualification.
  (EUR-Lex, 2015)

These tender types are not different from those provided by the Danish Tender act. However, some differences are present e.g. time for a tender submission etc.

3.5.2. Award Criteria

Tendering is a traditional method for procuring the major constructions and civil works. As it was discussed earlier, there is a significant emphasis on ensuring the transparency of competition and equality among the bidders. Criteria by which each contractor is measured against has to be known to the bidders beforehand. Under the public tendering, there are only two types of award criteria, namely Lowest Price and Economically Most Advantageous Tender, as illustrated in *Figure 3.12*.

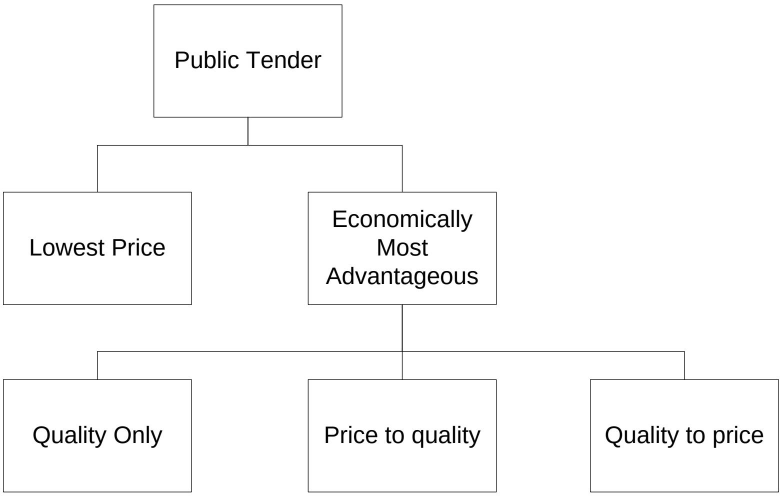

Figure 3.12 Different possibilities of selection criteria (Bergman & Lundberg, 2013, p.75)

Lowest Price

The simplest way of evaluating the submitted bids is by using the conventional method of tender evaluation, namely the contract is awarded to the bidder with the lowest proposed price (Wang, et al., 2006). Within this criteria frame Bajari & Tadelis (2001) argue that it ensures the motivation for higher competition and as the result of significant cost reduction. Although this method is still used frequently, the lowest bid criterion is considered troublesome (Williams, 2003). The reason is that the lowest bids might contain bias information e.g. low quality materials or underestimated level of risk that contractor is taking by proposing such bid. As the result, the construction project could face disputes that normally lead to extra expenses and extension of time. Both of these factors influence the final cost of the procurement, which would differ from the price agreed in the contract. Therefore, the lowest bid might not be the best in term of total price (Ballesteros-Pérez, et. al., 2015)

According to Ballesteros-Pérez, et al. (2015), the award criterion of lowest price is considered as a ranking procedure. The ranking method allows ordering the bids in sequence from the highest price to the lowest and vice-versa.

However, making a decision solely based on this ranking could be misleading due to the chance of experiencing abnormally low bids criteria (ALBC) (Ballesteros-Pérez, et, al., 2 which would influence the client's procurement. Ballesteros-Pérez, et al. (2015) have outlined the ranking rules proposed by other academic researchers, the intention of which is to avoid the ALBC phenomenon, ensuring best value for money. The ranking methods are expressed in *Appendix* F.

Larsen, et al. (2013) have made a quantitative research regarding what kind of criteria is used by the Danish public authorities that have been published in the European tender in period of January 2010 to March 2013. 157 cases were found during that period. The result is illustrated in *Figure 3.13. 118* cases have used the lowest price as the award criteria, whereas the Economically Most Advantageous Offer has been used in 30 cases.

Furthermore, Dini, et al. (2006) and Bergman & Lundberg (2013) argue that the lowest bid criterion is the most suitable when the work specifications of the construction works are clear to the client or the entity responsible for the tendering and acts on cl

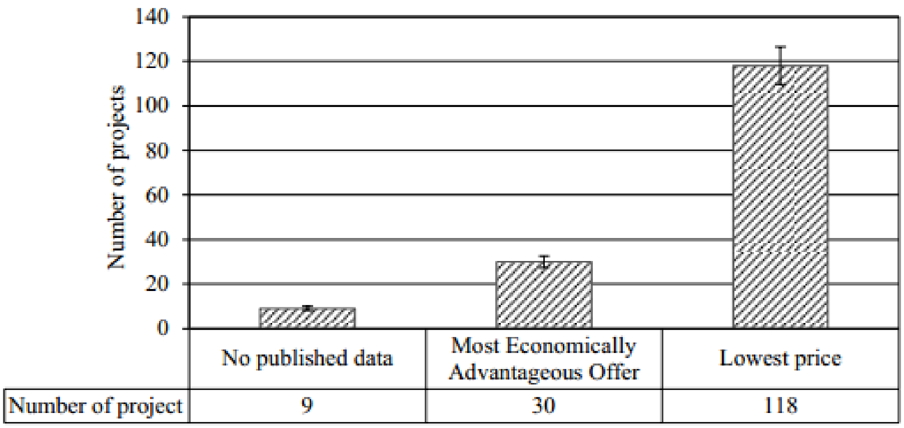

Figure 3.13 Selection criteria for 157 cases (Larsen, et al., 2013, p. 22)

Economically Most Advantageous

The concept of economically most advantageous tender (EMAT) (Bergman & Lundberg, 2013) is not that new in the construction market. According to Ballesteros-P®rez, et al (2015) the price-quality bidder proposal is tracing back to 1968. It also involves considering non-price parameters to choose the most optimal solution in terms of quality and price. To implement this type of evaluation approach, the need to be scored and weighed and respectively ranked to estimate the EMAT bid that archives the best value for money. According to the previous quantitative research that has been performed by Larsen, et al. (2013), only 30 (19%) cases out of 157 are evaluated by most economically advantageous criteria. However, Wong, et al. (2001) have conducted an imperial survey in UK regarding the clientôs ev that there is a clear trend in moving towards the EMAT criteria that, in fact, should bring more value for money.

The implementation of this awarding criterion requires the technical/quality and economic proposals of bidders to be scored and weighed to allow the auctioneer to rank them and identify the most economically advantageous tender.

Furthermore, Bergman & Lundberg (2013) outline two methods that are used for EMAT.

Quality to price is one of the proposed methods. The idea is to achieve the best quality within a certain price range. The bidder proposing the higher quality for the same money shall be chosen. This method is more appropriate when an expected quality level is easily achievable, but there is a sense that superb quality requires a high price to pay. (Bergman & Lundberg, 2013)

Price to Quality: In the following method, the price needs to be converted into a score that is addable to quality in order to rank the competitive bidders.

The *Quality* in this case is the sum of all criteria that are not expressed by price. These criteria are experience, life cycle, buildability, maintenance concerns etc. Hence, two different approaches are given to evaluate participated bidders.

The authors argue that the current technique of converting price into a score that later is combined with the quality is inefficient due to lack of transparency, making it difficult to evaluate the real preferences of the client. (Bergman & Lundberg, 2013) Additionally, Bergman & Lundberg (2013) are proposing that the second alternative of quality to price is a better choice due to human nature of evaluating the price from the quality perspective. However, these two approaches are only needed where there is a moderate level of uncertainty, which renders it inefficient to use the lowest price criterion.

Both of the proposed methods are facing a complexity in regards to combining two factors as quality and price into a ranking figure that can be easily evaluated. Additionally, in order to establish the theoretically best return on investment the combination of price and quality criteria has to be considered by a construction client (Ballesteros-P®rz,æt al., 2015). The information that strengthens the weighting and scoring criteria should come from experience of the tendering team. Some participants of the tendering team should be a group of people that perform O&M in the similar buildings. Hence, a lot of explicit and tacit knowledge could be forwarded to the briefing team, which would help to choose a contractor with the right set of characteristics. The right contractor choice secures the construction against cost and time overruns. Additionally, as it has been discussed, the lowest price criterion is still widely used in Danish tender advertisements published in the European public procurement journal. Additionally, the lowest price is the most appropriate when the scope of works is clear for the briefing team. Hence, there is a possibility to establish an approximate price for the service. However, the price estimation still requires the inclusion of post-construction expenditure to make sure that the procurement is economically reasonable in a long term. Once again, this information could be provided by facilities management team by means of explicit and tacit knowledge, gathered by post-construction evaluation.

3.6. Chapter Summary

In this chapter, five research areas have been outlined and analysed in order to identify the issues that have been recognized by scholars.

Firstly, the chapter *Briefing Stage* explained that briefing implies two separate phases, namely strategic briefing and project briefing. The strategic briefing covers the aspects of pre-briefing evaluation of consultant services, requirements for new procurements and contracting types. The project briefing includes cooperation with consultants to articulate the requirements in question. The outcome of the project briefing is tender documents, upon which the design of a new procurement is based. In the state of the art, several scholars claim that the traditional briefing is static, which means that there no feedback is given upon the previous decision-making milestones. Hence, the briefing process does not include findings that might be discovered during the continuous interaction between the end-user, construction client and consultants. The dynamic briefing approach aims to close this gap by introducing a capturing mechanism, namely feedback evaluation. The feedback evaluation has similar characteristics as loop learning, where the current situation is evaluated against the previous proposal and newly emerged knowledge or findings are identified. The identified information is provided to the construction client to make sure that information aligns with the clientôs objectives and expectat -users.

Furthermore, the chapter *Learning from Operation and Maintenance Experience* shows that learning from past experiences is a vital a step towards enhancing the quality of future buildings. By learning from the existing buildings several design flaws could be avoided, which would in turn increase the clientôs value
the procedure where the design flaws of constructed facilities are identified and codified. However, experience of the entity that performs such evaluation shall be taken into consideration, because not all knowledge can be codified and hence remains known only to this entity as tacit knowledge.

Facilities management is the entity responsible for post construction operation and maintenance. There is evidence that FM has increased its importance from being only responsible for O&M, to having a more strategic function. Moreover, FM is the entity responsible for POE, whose knowledge within this area could help to create a good briefing documentation and choose the most appropriate design proposal that would avoid budget overruns in long term. However, according to the state of the art literature, several issues prevent involvement of FM. One of the most impor
that reduces his ability to evaluate the design proposal due to limited visualisation capabilities. However, expert knowledge of FM must be pushed to influence the decision-making process during tender bid evaluation.

Knowledge asset is the combination of explicit and tacit knowledge that is accumulated during post construction evaluation. Some researches claim that around 90% of all knowledge within the company stays in human resources (Smith, 2001). Hence, knowledge creation shall take place in a company to effectively sustain and utilise that knowledge. Nonaka & Takeuchi (1995) propose the SECI model, which aims that sharing explicit and tacit knowledge. Evidences of using virtual reality (VR) tools in SECI model have been found in the state of the art research. The areas of VR usage are (1) sustaining the expert knowledge (externalisation mode) and (2) educational purpose (internalisation mode). However, the question of utilising VR in socialisation mode (sharing tacit knowledge) has not been discovered in the research. As it was mentioned earlier, it is important to utilise expert knowledge in design phase to ensure alignment wi
achieve the ultimate value for money. However, the biggest concern is to share tacit knowledge that is hard to codify.

Tender chapter focuses on public procurement, which must be performed according to Danish Tender Act, must be performed in cases such as the Case study discussed in the following chapter. Moreover, different types of tendering under Danish Tender Act are explained. Additionally, discussion is provided regarding different types of award criteria that are available for the public entities. The public tendering has a specific framework upon which the public organisation procures its facilities.

Overall, this state of the art has presented the current situation in the building industry regarding the use of prior FM experience in new facility design. Furthermore, the chapter has created the foundation for the problem statement presented in the following chapter.

4. Problem Statement

As the *State of the Art* presents, there are many different factors that prevent the construction industry from transferring the post construction knowledge from existing buildings to the design phase of a new facility. Having this in mind, the research team believes that the construction client has a very large influence on the quality of future constructions. The developers have the authority to request buildings, in which the previously gained post-construction knowledge is taken into consideration.

However, the developer cannot and does not act alone. Therefore, the areas analysed in the preceding chapter suggest a strong necessity for more advanced knowledge sharing amongst different professions and disciplines in the industry. This knowledge sharing would facilitate the involvement of disciplines such as facilities management in the decision making process, since FM is responsible for gathering the information in POE of existing buildings, hereby expressing extensive amounts of both explicit and tacit knowledge for use in the briefs of new buildings. Dynamic briefing would enable continuous development of the new construction projects and, in theory, lead to more suitable design proposals in the tendering phase.

When construction clients are faced with the choice of the best design proposal during a tender competition, the presence of tacit knowledge from disciplines such as FM can have a very great impact on the result of the tender and hence the future quality of the built environment. However, it might prove difficult to extract this tacit knowledge from the FM with the traditional design visualisation methods due to the nature of the profession, as well as other essential decision-making personnel in the developerôs therefore that the effectiveness of the design proposal evaluation is increased in order to ensure the best possible long-term outcome.

One of the tools that can be used in order to attempt this increase of effectiveness in building design evaluation is virtual reality. It is assumed by the research team that enhancing the visualisation experience might bring valuable expert knowledge in filtering design proposals, as well as improve the general understanding of building design for individuals usually not involved in the industry. Nevertheless, the case study of this thesis covers an organization highly interested in the use of the latest 3D technology for improving their daily operations. Consequentially the research statement has been formulated as follows:

How can immersive 3D tools help to provide tacit knowledge during decision-making processes in an organization oriented towards state of the art IT solution integration?

5. Case Study

AAB ï Arbejdernes Andels Boligforening - Workers Cooperative Housing Association is the oldest social housing association in Aarhus, Denmark. It was established in 1919, when the initiative was taken to solve the growing problem of lack of apartments in the city. Nowadays AAB is administering around 8500 apartments in 57 housing departments. Each of these departments has their own economy. (Arbejdernes Andels Boligforening, 2015)

AAB is a non-profit organization, which means that no income from the rented apartments is withdrawn from the organization. All the income is dedicated towards operation and maintenance of the buildings owned by the organization, as well as new housing developments. (Arbejdernes Andels Boligforening, 2015)

In addition, AAB takes pride in providing the cheapest rentals in the city ï their housing solutions are approximately 20% cheaper than the ones offered by their competitors. This price difference is achieved by efficiently understanding and employing the various IT systems in the organization. The rent of each apartment generally depends on the sum of money necessary to maintain the apartment, the building and its surroundings. Some of the apartments provided by AAB have circa 3000 people on the waiting list, easily making AAB one of the most popular housing associations in the city. (L. Kruse & A. Tollaksen 2015, *Interview 1, 21 September.)*

AAB is closely connected with Aarhus municipality, which has to approve every important decision of AAB regarding both new building developments and existing structures. Furthermore, the municipality supports the organization by covering 10% of construction costs for all the new buildings. (L. Kruse & A. Tollaksen 2015, *Interview 1, 21 September.)* In return, every fourth apartment is given to the municipality that assigns the apartments to tenants with special social housing needs (Arbejdernes Andels Boligforening, 2015).

5.1. Values, Mission, Goals and Strategy

AAB has three core values ï honesty, community and movement. These values expresses their expectations and attitude towards themselves, their partners and their customers and show the way to their employees. (Arbejdernes Andels Boligforening, 2015)

The mission of AAB is to maintain, develop and create safe neighbourhoods and provide high quality housing. They strive to ensure that attractive and contemporary rental housing is accessible for everyone in the Aarhus area in the future. (Arbejdernes Andels Boligforening, 2015)

The goal of the organization is to be the best social housing association in Aarhus. AAB wishes to be the preferred housing association by both the people in search of a new home and their existing tenants. They want to be known as the association with the most attractive and modern rentals, as well as the providers of the best customer service in the area. (Arbejdernes Andels Boligforening, 2015)

Strategically, AAB currently focuses on two main areas:

¶ Proximity ï the connection between the staff and residents as the key to their high-level service. Their goal is to adapt their services in order for the contact between the staff and their clients to take place with the most possible understanding for the individual's needs and wishes. To enhance this, AAB is planning to create new service initiatives that facilitate personal contact with the residents.

¶ Responsibility ï Their goal is to, in addition to the high-level service, to be conscious with regard to people, environment, quality and economy. On everyday basis, they shall emphasize sustainability and energy efficiency and strive to reflect it in all of their projects.
(Arbejdernes Andels Boligforening, 2015)

5.2. Organization Structure

AAB as a housing association is rather dependent on its residents. The internal organization of AAB, as shown in *Figure* 5.1, is formed in such a way that all the tenants are able to have a say in the proceedings and situation within the association. Each of the 57 housing departments hold department meetings on frequent intervals where the small scale, local department decisions are made. Every year, at least 4 months before the next fiscal year, a compulsory department meeting is held, as stated in AAB statutes, *Annex 1*. Each of the departments has a board that consists of minimum three members. All tenants have the opportunity to become a board member if willing to dedicate their time and efforts for the good of the housing department. Additionally, the department board has to elect a member/s to be a part of the board of representatives, otherwise called the presidency. Members of the presidency can also be elected directly by the main board. This is decided in the specific housing department meetings. (Arbejdernes Andels Boligforening, 2015)

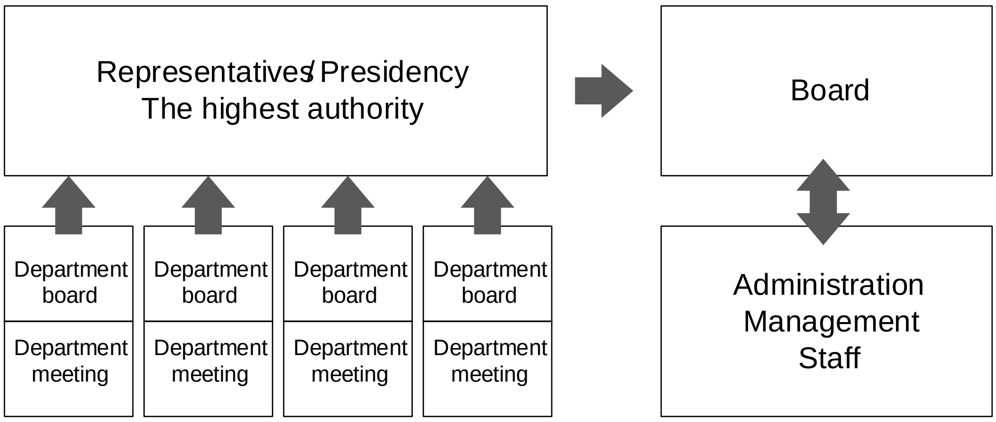

Figure 5.1 Organizational structure, adapted from AAB, original *Annex 2*

The presidency, which is the highest authority of AAB, consists of both tenants from every department board ï 1 representative from each housing department with up to 50 households and one additional representative for each started 75 households ï and members of the main board. The chairperson of the main board is also the chairperson for the presidency, according to AAB statutes, *Annex 1*. Presidency meetings take place biannually. During these meetings, the main board presents the annual report and the presidency approves the financial statements. Additionally, any incoming proposals can be voted on and new members of the main board can be elected. (Arbejdernes Andels Boligforening, 2015) Additionally decisions are made in the following matters:

¶ Choice of director,
¶ Choice of accountant,
¶ The organizationô,s construction policy
¶ Land acquisitions,
¶ New construction,
¶ Acquisitions or sale of the organizationôs es
¶ Significant changes in the organizationôs est
¶ Changes in the statutes.
(AAB Statutes, *Annex 1)*

According to the statutes, the main board, as mentioned above, is elected by the presidency on an ongoing basis. Only tenants up to the age of 68 can be elected to the board. The main board currently consists of seven members. The board is the overall leadership of the organization. It is responsible for the operations, including ensuring that the renting, budget planning, financial reporting, fixing of the rent and the daily administration are done in line with the applicable rules. The board determines the organizati policy and strategy. It also has the legal and financial responsibility for AAB. (Arbejdernes Andels Boligforening, 2015) The board employs the director, known as the head of AAB and has an ongoing communication with the administration of the association (L .Kruse & A. Tollaksen 2015, *Interview 1, 21 September.)*

Within the administration, a more typical organizational structure is employed, as shown in *Figure 5.2.*The director, chosen by the main board employs all the other employees within AAB (L. Kruse, 2015, pers.comm., 17 September).

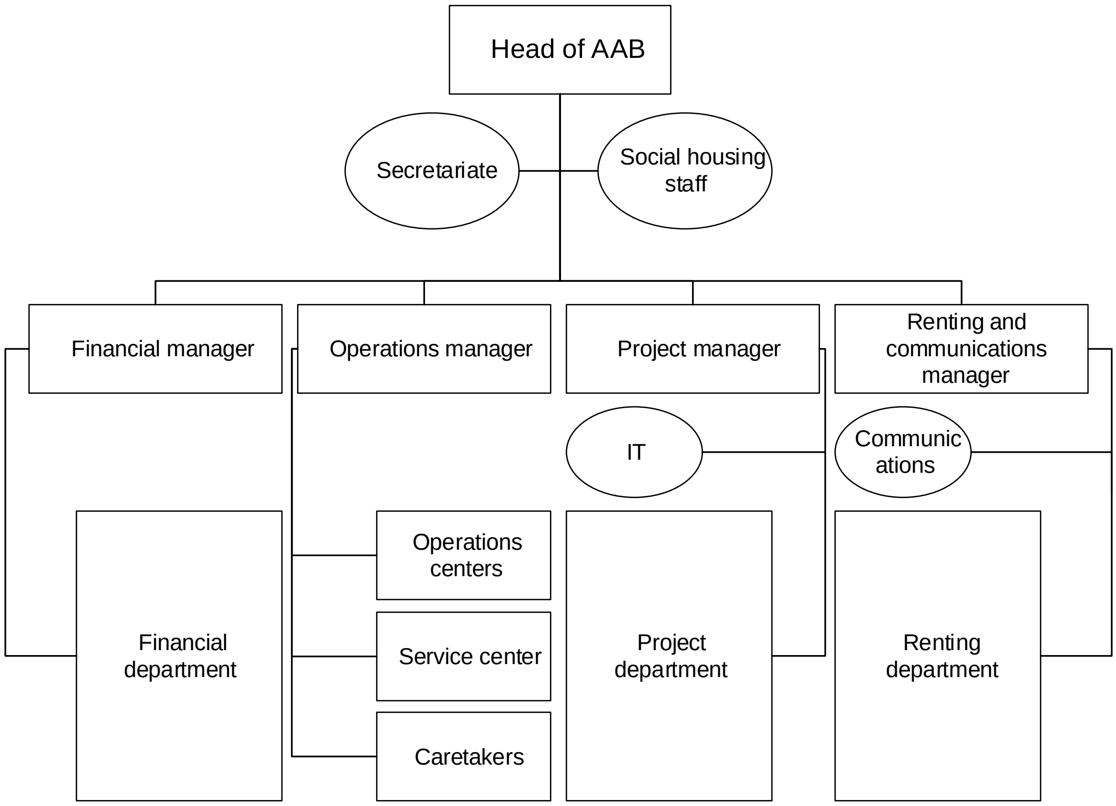

Figure 5.2 Administration structure, adapted from AAB, original *Annex 2*

The administration is divided in four departments:

- Financial, which deals with the economic matters of AAB,
- Operational, which deals with O&M of the apartments, buildings and surrounding areas,
- Project department, which is responsible for the IT system of the organization as well as the development and construction of new buildings,
- Renting and communications department, where the communication with residents takes place as well as all the matters concerning renting apartments and other housing.

5.2.1. Daily Operations

The main operations of AAB are to build, rent, administer, maintain and modernize supported housing in line with the rules and laws of general apartments (*almene boliger*), as stated in the statutes, *Annex 1.* Their daily operations include taking care of the following:

- Tenants currently occupying the dwellings,
- Administering their listings on waiting lists ï in conjuncture with Aarhusbolig.dk,
- Tenants moving in and out of the apartments ï circa 1300 households per year,
- Modernization of the dwellings every time an apartment is vacated,
- Organizing the work of caretakers ï circa 100 professionals, which take care of all the different needs in different departments.

5.3. Information Technologies within AAB

AAB characterizes the organization as innovative and up-to-date with the current technologies. AAB has always been focused on understanding IT technologies and their development to recognize the potential value they can bring to the organization. The following chapter describes the current information technologies employed within the organization, including servers, software, applications developed by AAB and information flows in different business operations.

The entire IT system of AAB is currently based on eight platforms, as shown in *Table 5.1*. Each server handles a different type of information. The software, used in the organization, communicates with the servers through a web service. Whenever a change is made in the software, it is also sent to the corresponding server. In this way all the employees are able to use the correct, updated data at all times.

<table>
<tr><th>Server</th><td rowspan="7">Web Service</td><th>Data/software</th></tr>
<tr><td>EPI-server</td><td>Homepage
Service agreements</td></tr>
<tr><td>Domino</td><td>Financial control</td></tr>
<tr><td>SharePoint</td><td>Intranet
Tenders
Web-apartment</td></tr>
<tr><td>SQL</td><td>Revit
Mdoc</td></tr>
<tr><td>Application server/400</td><td>Financial system
Apartment data</td></tr>
<tr><td>Intrasuite</td><td>Production platform
Apartment folders</td></tr>
</table>

		Inspection Construction project management Organization plan Disposal right
External		AarhusBolig renting
User web		Windows XP Energilock Techem/ Kamstrup

Table 5.1 ABB servers, adapted from AAB, *Annex 3*

This system was established in 2001, when AAB reorganized their server room and created one virtual server instead of the physical ones. Currently the organization has two virtual servers with mirrored content and a backup server. AAB has chosen to store the servers with all their data within their premises in order to increase the speed of data exchange and access. AAB have always been dedicated to improving their IT systems and the speed of data exchange, as well as saving resources by introducing new systems. Back in 2000, the organization opted for use of antennas instead of internet, which gave them the speed of 25/25 Mbit/s. By switching to antennas, AAB were able to close down 76 telephone lines and use IP telephony with just one phone for the entire organization instead. (L. Kruse & A. Tollaksen 2015, *Interview 1, 21 September.)*

5.3.1. IT Related to Construction and Maintenance

AAB, due to its legacy and continuous development, is using a variety of software and hardware to support their operations. Some key software is described in order to show its application and usage that supports AABôs obje and maintenance activities.

As the improvement of IT systems of AAB continues, new solutions are found for old problems, outdated items are replaced with newer initiatives and the overall efficiency of the IT scheme of the organization is enhanced.

The information in AAB has been represented digitally since 1976; however, there was no 3D representation of data, all information was shown two-dimensionally. Later on, 3D models of all facilities were created upon the existing 2D drawings that their buildings were provided with. The redrawing activities were performed in-house. The reason for keeping these activities in-house instead of outsourcing to external entities was to have the ability to detect information misrepresentation on the old drawings and correct them in the 3D model to have an overview of recent situation of the existing buildings. (L. Kruse & A. Tollaksen 2015, *Interview 1, 21 September.)*

During the past 5 years AAB have been working on developing an agreement between AAB and the board of each housing department called ñServicev
May 2015. Serviceviften is generally an agreement, but it is based on software developed by AAB, which the organization has chosen to make open-source. The agreement describes what is and what is not included in the responsibilities of the caretakers. The service agreement is individual for each housing department and gives the department board the chance to ñplayò with the different service par
change in other parameters at the same time. Among other reasons for introducing the system, is the purpose of creating better communication between the tenants and caretakers, as well as documenting and explaining how the rent prices in AAB are built up.

(Serviceforbundet, 2015) This development by AAB demonstrates their effort in achieving the organisationôs strategy of proximity by util

Several years ago, AAB held a brainstorming session where their IT needs and requirements were documented and the potential enhancement of productivity with the help of IT was analysed. The organization was considering creating an IT system that would fulfil the desired objectives with the help of external software developers. Additionally, a few available software solutions were analysed, e.g. Caretaker, a Danish FM system oriented towards O&M. The system is developed by consulting firm COWI in 1994 (Jensen & Scupola, 2010). COWIôs main operations are in the construction field. The interviewee claims that not being experienced in the post-construction activities, COWI has designed Caretaker to fulfil engineering needs rather than those of facilities management. Therefore, this FM system lacks the functions that FM at AAB needs to support their operations. However, a more suitable solution was found when AAB was introduced to the capabilities of MdocFM developed by NTI Cad. (L. Kruse & A. Tollaksen 2015, *Interview 1, 21 September.)*

Mdoc FM

MdocFM is a web-based platform intended for facilities management to aid the provision of agreed service. The selling point for MdocFM was its ability to be tailored to fit an individual company. (MdocFM, 2015) The software offers a variety of features both built-in and as add-ons. In case of AAB, the full potential of the software is not yet utilized due to its recent integration. Based on the information that was provided by AAB, the features that are not utilized in MdocFM are tendering function, construction project management and energy.

Moreover, the web-platform is seen as an opportunity for having a web database, where all the data can be accessed by different entities. The information stored in MdocFM is linked to the system instead of inserting various files, such as .pdf or .jpg. The reason for not storing the whole database in the FM system is decrease of performance that would slow down the overall FM system.

DOtAB

Another application that was developed by AAB is DOtAB. The intention of DOtAB is simplifying the synchronization of data regarding maintenance procedures with the main database that is operated by MdocFM. The process of full DOtAB integration in the internal organisation is, however, still under development. Due to its recent implementation, the learning curve of technical professionals hinders the full exploitation of the application.

The principle of DOtAB is based on QR codes that contain the information about a facility. The QR code is the successor of barcode, which is widely used in many industries e.g. retail and manufacturing. A QR code is located in each apartment that is owned by the organization. The code carries the information regarding each fixture mounted in the location. When a maintenance process takes place, the code is scanned by using DOtAB on a tablet computer, the ñ... is provided by accessing MdocFM ... scann and a new set of information is inserted. Hereafter, the application sends the information straight to MdocFM, where the data is automatically synchronized with the database. This procedure helps to keep the information up to date and to avoid possible bias information that might be the case in the traditional delivery procedure, namely codify the information in a document, delivering the document to the office and manually inserting the data in the IT system. The system involves less steps of getting the needed information from point A to point B. Therefore, the chance of a failure is significantly reduced. Additionally, MdocFM contains information about the financial details of maintenance of each building, occupancy of the apartments and a codified information that is linked to each object. Moreover, Mdoc FM and Autodesk Revit have a duplication feature, which allows keeping the information on both systems up to date.

Autodesk Revit

AAB has an ongoing interaction with the construction industry, owing to frequent needs for renovation, maintenance and procurement of new buildings. Therefore, a decision was made to acquire licenses for building design software, namely Autodesk Revit. Autodesk Revit is widely used in the construction industry; therefore, there are many vendors that offer systems for other disciplines like facilities management that are optimized for information exchange with Autodesk Revit via add-ons.

There are several strategic reasons for having such software on board as well as the professionals who can utilise the design software. Firstly, it helps in renovation projects, since all real estate owned by AAB has a virtual 3D copy. This means that, when new items need to be added on an existing apartment or building, the architect does not need to spend time for preparing the model of the existing conditions before adding new ideas to it. The existing 3D models are a part of the briefing program that is forwarded to the architect. Secondly, the management of AAB clearly understands the use of 3D modelling as a key tool for interaction with customers, which gives them the ability to provide better service.

ñThey [customer] want to go out and look at the they in the (A. Tollaksen 2015, *Interview 1, 21 September, 2 min.56 sec.)*. The idea is that the customer can make a better decision when he sees the object, rather than visualizing it in his mind.

ñIn Revit you can take a c[...] show a p (A. Tollaksen 2015, *Interview 1, 21 September, 3 min, 26sec.)*. The design software gives an opportunity to provide the visualization foundation for better decision-making. It can, in a way, create an illusion that the customer is in the furniture store and is choosing the kitchen.

The capability of having an overview of 3D models helps to overcome obstacles and gives extra information for effective decision-making. Thus, Autodesk Revit gives AAB such opportunity by providing the following features:

¶ **Design tools**: 3D illustration of an object to give a customer understanding of the materialized object;
¶ **Walkthrough:** gives an idea of future construction, detecting the design flaws
¶ **3D objectives**: e.g. visualization of a kitchen by means of 3D or realistic rendered images. After the customer approval, a manufacturing order can be placed. In this case, the contracting period is shorter due to well-established objectives by means of 3D modelling.

Additionally, NTI Cad MdocFM web-platform has an integration with Autodesk Revit, which gives an ability to synchronize accumulated data between these programs flawlessly. MdocFM, according to AAB, is a database storage, whereas Autodesk Revit is a 3D representation of the data. Hence, it is important to have both information storages up-to-date. However, when new information is captured it is first inputted in MdocFM, which is considered the main storage. Afterwards the data is added in Autodesk Revit, when the ICT coordinator considers it appropriate to update the 3D model. There is usually a certain amount of changes until the model needs to be updated. It is considered impractical to update the model with every small change that appears during the daily operations due to high consumption of time to make a 3D modification. Moreover, not all changes that are captured and inserted in MdocFM need to be present in the 3D model, because the latter represents the information for construction alteration like plan layouts, additional windows, changes in the staircase type etc.; whereas, most of the information that is collected during the daily operations comes from the facilities management.

ñWe say every piece in MdocFM is the life insura what has to be done [é] then we can transform i need, we did not need in the Revit model to tell that the window can last for 40 years, we only tell (A. Tollaksen 2015, *Interview 1, 21 September, 6 min.8 sec.)*

Autodesk Revit has a role of virtual representation of information, which is being updated in order to have a 3D overview of the current conditions and parameters of buildings. In this case, Revit is not used as an FM software; however, the practice of using Revit as the main FM system is sometimes found at other FM organisations.

ñSome other companies use Revit as a basic [and can do it, but a personal FM system [é] (A. *give yo Tollaksen* 2015, Interview 1, *21 September*, 6 min. 50 sec.)

As an example, the interviewee refers to a simple maintenance procedure, e.g. changing of windows. He claims that providing the window manufacturer with an entire 3D model would cause misunderstandings due to the need for finding the locations of specific windows within the building layout that is not familiar to the contractor, before getting the information of the window properties. *(L. Kruse & A. Tollaksen 2015, Interview 1, 21 September.)* By using the FM system, the features like providing information about a specific component are built in the system. Therefore, the necessary information is provided without additional irrelevant data, which usually forms a basis for confusion and misunderstandings. Hence, there is a clear distinction between the roles of Revit and MdocFM. Both systems support each other in providing the needed information in the most feasible way.

5.3.2. Information Flow in AAB

AAB employs a well-established information flow, namely the way in which the information travels from one entity to the other. There are generally three different paths within the information flow supported by the IT systems that can be used depending on each specific situation.

In case of renovation of one of AAB buildings, the flow described in *Figure 5.3* is utilized. As discussed earlier, all AAB buildings have already been recreated in 3D models. In case of renovation, these 3D models are used to show the planned changes of the building. All the future changes are then inputted in the FM system, which then allows the budget to be drawn up. Further, on, the appropriate rules and regulations are examined and changes are made if necessary. In the next step, a follow-up budget is made in order to make sure that the planned works are not too expensive. Subsequently DOtAB and Byggesynsapp are used and the information is changed or added in the FM building cards in Mdoc FM.

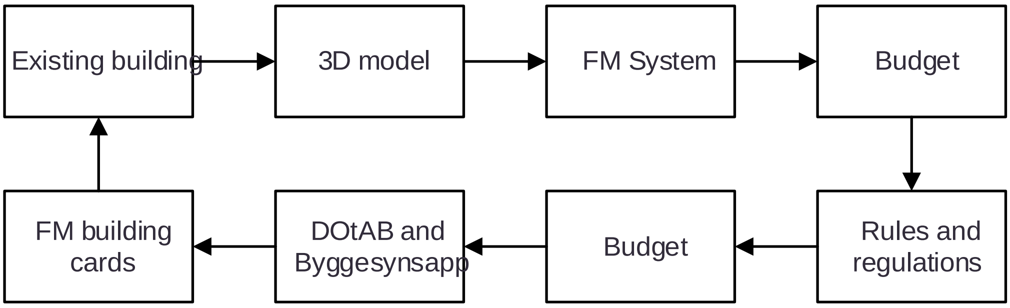

Figure 5.3 Flow 1, Adapted from *Annex 3*

When maintenance procedures need to take place in one of the apartments, another IT flow is utilized, *Figure 5.4.* The item, e.g. a plumbing fixture that requires maintenance or replacement, is first examined and relevant information is checked and inserted in the FM system. Subsequently the budget for the replacement is established, the replacement takes place and the information about the new plumbing fixture is inserted in DOtAB by scanning the QR code of the apartment and adding all relevant information. Currently DOtAB application, as it was discussed earlier, is still undergoing development, however, in the near future, it is expected that all the maintenance workers of AAB will be able to input and extract data this way.

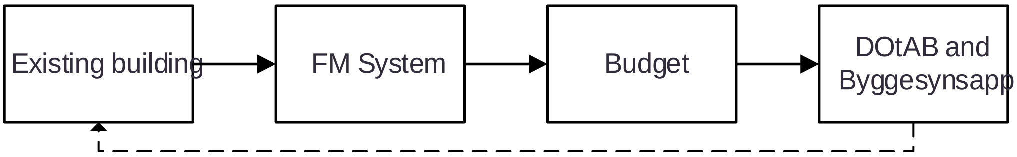

Figure 5.4 Flow 2, adapted from *Annex 3*

The tenants of AAB have the opportunity to request changes for the apartments they are currently renting. In case a tenant wishes e.g. a balcony constructed for his apartment, another flow type takes place, as illustrated in *Figure 5.45.* Firstly, a 3D model of the requested changes is prepared and when the tenant has confirmed the future changes, the information is inserted in the FM building cards in Mdoc FM software. Further, the newly created building cards are connected and stored in the AAB database on their virtual server. Eventually the budget for the upcoming changes
rent is raised for a number of years in order to finance the new balcony.

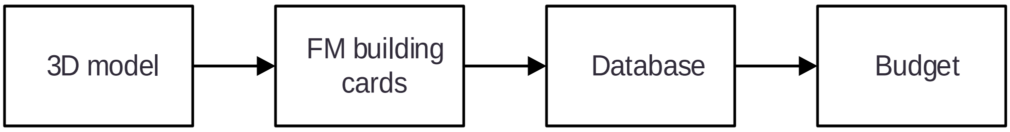

Figure 5.5 Flow 3, adapted from AAB, original *Annex 3*

5.3.3. Information Flow in New Procurement

AAB sees a strong potential in 3D modelling as a tool for interaction and communication with tenants and external parties. According to the interv *The most important is to live, to work in the model*ò *(*A. Tollaksen 2015, *Interview 1, 21 September, 2 min. 44 sec.)*, one could get many benefits from understanding the 3D working environment. When AAB decides to procure facilities, the communication and interaction with external parties is the main part of initial procurement processes. Hence, it is important to make sure that the external parties understand their requirements and objectives that are introduced to them.

Brief

The clientôs brief is outlined within the orga
consultant, e.g. an engineering firm, who then takes care of creating th
role in the brief creation is setting the basic requirements, i.e. amount of buildings, rooms, approximate area sizes, types of kitchens and bathrooms etc. When creating the brief, AAB also relies on their previous experience, hence, they might suggest a specific window or fixture type and finishes of certain materials. However, the aforementioned external consultant takes care of writing the necessary brief documents and explaining AABs needs in the most appropriate manner. This workflow is chosen both to save time for AAB and to engage a consultant that has extensive previous experience in briefing as well as engineering knowledge and can thereby specify trade-specific requirements, which AAB might not have thought necessary to add to the brief.

Moreover, AAB puts a great emphasis on understa
with the budget and future rent increase.

ñEvery time [é] new or a big restoration occurs they
system caretaker, from the those who share out, from the economy and they speak together [é] They say what peo A. Tollaksen 2015, *Interview 1, 21 September, 2h. 9min 01 sec.)*

It is important for AAB to receive such requirements and evaluate the priority of each requirement that has been laid down by the project group. Additionally, besides the current requirements, AAB evaluates future requirements that could emerge after a certain period of time, for example, the importance of the possibility to have a balcony in the living room.

The information gathered from the end-users is added on the existing 3D model in order to illustrate their wishes on the present situation, to evaluate their feasibility and receive another feedback from the customers. The interviewee states *ñall this we use in*
model to see what do peopl (A. Tollaksen 2015, *Interview 1, 21 September, 2 h. 10 min. 28 sec.)* The feedback loop used in dynamic briefing is a good tool to ensure that the tenant desires are fulfilled and representation of their wishes in the 3D model helps to evaluate the feasibility of these wishes.

According to the information captured at the interview, based on the last several experiences of collaboration with architects, it was observed that they do not emphasize the unique aesthetic part of the building, resulting in buildings having similar designs with several design flaws, mostly connected with ergonomics. The interviewee claims that the cause of such phenomenon lies in the way architects allocate time for the briefing phase, which also shows that the architects might not always see the clear distinction between the roles in design process. ñ *We do programming and then they can use, spend the time on designs* (A. Tollaksen 2015, *Interview 1, 21 September,* 2 h. 8 min. 4 sec.) The robust briefing program reduces the need of architect involvement in the briefing phase and provides more resources to focus on the aesthetic aspect of the building during the design stage. (L. Kruse & A. Tollaksen 2015, *Interview 1, 21 September.)*

Understanding of construction roles at AAB comes from their previous experience: ñ *earlier when we had total congruence on everything [é] because we spend of* (A. Tollaksen 2015, *Interview 1, 21 September, 2 h.7min. 0sec.)* Meaning that by not evidently understanding the roles of design process AAB were overlapping other disciplines, where they did not have enough experience. It caused many unforeseen expenses that pushed AAB to optimize and simplify the buildings to reduce the costs. However, it can be clearly observed that AAB pursues continuous development by aiming at innovation and identifying failures in their supply chain. Hence, the clarification of roles in the design process he duties and bring more value for money.

Collaboration with an External Architect

The collaboration with architect as discussed here takes place when AAB chooses to use trade-to-trade or general contracting types. The brief documentation is sometimes supplemented with 3D models. ñ *We send a model [...] program* (A. Tollaksen 2015, *Interview 1, 21 September, 1 h.59 m.27 sec.)* It was claimed by the interviewee that the provided 3D models have a basic detail level or, in case of a renovation project, the entire 3D model of a building, in this way understanding the roles of other actors. Mostly the brief documentation is presented in wording and sometimes, if the project nature requires strictly standardized solutions, by basic design clarification schemas. (L. Kruse & A. Tollaksen 2015, *Interview 1, 21 September.)* The requirements represented by means of 3D models provide better understanding for both parties. On the one hand, the architect sees the visual representation of the scope of work. On the other hand, the client can control that his demands are fulfilled. It is clearly observed, that AAB does not try to affect the design process by providing standardized solutions that solely come from their experience. As it was discussed earlier, design shall contain a synergy between innovation and best practices. The architectôs contribution shall al that can be further utilized by the organisation is one of the requirements of AAB.

As mentioned earlier, AAB utilise Autodesk Revit for 3D modelling purposes. However, an external architect chosen to create design for a new building initiative might use another type of CAD or BIM system to fulfil the clientôs need

ñ *Work in what you want, you can use information about the mo windows roofing [...] for FM system. If we got a view so we can open an ArchiCAD drawing and see how to maintain it, is useful for us* (A. Tollaksen 2015, *Interview 1, 21 September, 2 h. 4 min. 40 sec.)*

AAB does not try to influence the architectural workflow as long as the necessary information regarding facilities management matters is provided. There are many possibilities how 3D information can be transferred from one design system to another. IFC format must be used in public procurement due to the ICT regulations. However, if the chosen architect works in

Revit, then the best scenario is to receive .RVT format due to a high possibility of losing some information when the 3D model is exported to IFC format.

Moreover, it was suggested by AAB that the best approach is to avoid keeping highly detailed standardised 3D objects, because according to their practice, there is a small chance that they will be utilized without further modification. Workflow in 3D modelling has to start with using basic families, then adding the needed information according to the project scope. *“So we shall keep the simply in ours”* (A. Tollaksen 2015, *Interview 1, 21 September, 2h.3m. 28sec)* The method of keeping basic level of detailing comes from the experience of other parties in the construction industry. AAB have observed the behaviour of architect firms in the early implementation of *Some of them tried to make their own families - [...]. We [...] architect firms [...] stopped that”* (A. Tollaksen 2015, *Interview 1, 21 September, 2 h. 3 min.40 sec.).* The reason for ceasing the use of detailed standardized families is their rare usage in project-to-project cases. The basic families fit better for further customisation, because every construction project has its own level of uniqueness.

An interesting observation is that in case the organization has a 3D model of a building/renovation project, they provide the architect with the model. However, the architect’s updated model is not used in internal s[ystem]... model is transferred to the existing model by the internal personnel at AAB. There are several reasons for that:

Firstly, the architect might propose several solutions, whereas only the chosen one is inserted in the main model. It provides better control of safeguarding the objectives the company has set.

Secondly, the need for updating 3D objects (families) to make them usable for their internal system.

“if you think in our way it is one, a kitchen is one, in the system we got from an architect [...] 68 [pieces of objects]” (A. Tollaksen 2015, *Interview 1, 21 September, 5min. 12 sec.)*

As discussed earlier in the collaboration of Revit with MdocFM system, it is crucial to have a correct 3D model before exporting data to MdocFM. This reduces the amount of unnecessary, non-value adding information inserted in the software.

Thirdly, procurement of a facility is based on two main phases, namely the design and construction. The design phase could be accomplished a few years prior to the construction phase. Hence, the building upon which the renovation procedure would take place, is still in a normal operation and maintenance process during these years. Additional information is likely to be accumulated in the internal 3D model regarding maintenance matters, before the renovation is accomplished. Therefore, AAB claims that in order to avoid any information loss of the O&M, the best practice is to redraw the design changes in their internal 3D model.

Moreover, redrawing the external model to make a fit with the internal systems is not the only reason for keeping the model under control. When the model is sent to the organisation, AAB takes the full control of it during the whole duration of the project. The 3D model in question is called master model.

Control of the Model

AAB sees a potential in using their resources for keeping and maintaining the master model. The master model is the model that is solely controlled by AAB and all changes suggested by external parties are redrawn in this model in order to avoid insertion of bias information. *ñAll those who tell about FM system and modelling; they say when you build a new part you should make a deal with the architect, so he can keep the model for you, but in our world it* *(A. Tolladsen 2015, Interview 1, 21 September, 2 h. 0 min. 33 sec.)*

In case of renovation of a building, were several types of works need to be performed; ABB could involve different consultants, depending on the scope of the renovation. For example, renovation could be necessary for the roofing, elevators etc. Each of these parts could be taken care of by a different consultant, in which case letting the architects/engineers control each part of the 3D model separately increases the risk of data overlap, which would create a chaos in managing the information later on. Moreover, AAB does not wish to include an additional party for keeping the information *floating* in 3D, nor do they wish to keep an outsourced entity on a long-term contract, for managing their 3D models during the construction process. The reason being the inability of having a high degree of control and ensuring the use of information stored in 3D for future O&M.

AAB does not make any input in the 3D model, except adjusting activities that were mentioned before, due to resource limitation and well-defined roles in the design process. Their role is solely based on managing the model and converting the objects to make them feasible for future use in their internal sys
observations, the importance of control comes from negative experience, which AAB had when the model *floating* was performed by another party.

5.3.4. AAB Tender

As discussed in *Chapter 3.1.1. Clients and their Characteristics*, there are many different types of construction clients, which influence the procurement route chosen by these clients. According to the four characteristics, AAB is a public client with quite large experience with building projects. Additionally, AAB builds for their own use, i.e. for renting; therefore, the long-term outcome of the building project is important in this case. The main operations, namely building, renting, administering and modernizing supported housing show that AAB build for their main operations, therefore their interest in both the building procurement and the quality of the future facility is very high.

During the time of writing this report, AAB is a developer for a social housing project called ñÎblelunden.ò The project is procured in two st
2014 and is currently in use. The tender competition for the second stage was announced on October 22, 2015. The project consists of 38 apartments, with 4-5 rooms each. The contract is to be awarded in early 2016. Îblelunden is hereby used as an
processes taking place in an AAB tender procedure. *(Annex 10)*

As discussed previously, AAB creates the outline for their project briefs. However, the actual document production for the brief, as well as all the additional documentation for initiation of a tender process is outsouer, this function is represented by ase of the engineering firm Bascon A/S.

ABB uses Projektweb for their tenders, as requested in the Danish *Bekendtgßrelse o anvendelse af informations- og kommunikationsteknologi (IKT) i alment byggeri* - The order on the use of information and communication technology (ICT) in general/public construction, which is valid from 07.02.2013. (Ministeriet for By, Bolig og Landdistrikter, 2013) For the project in question AAB uploaded the following files for the contractor use, all of which were in .pdf or .docx format:

- Tender letter,
- Competition rules,
- Construction case description,
- ICT manual,
- Offer list template,
- Tender time schedule,
- General conditions 93,
- Brief,
- Appendix containing geotechnical report, area plans, archaeological research etc. *(Annex 4)*

Both in this tender and usually restricted tender with prequalification is used by AAB. A number of selected prequalification criteria are used. The information requested in the prequalification round for Îblelunden project was as follows:

- Information about the company and its consultants,
- Information about the owners of the firm and its status,
- Solemn declaration concerning public debts,
- Solemn declaration concerning Procurement Directive Article 45. 1 and 2,
- Organizational structure,
- Annual reports,
- Eventual declaration of important changes,
- References from previous work: maximum 13 in total, maximum 5 from turnkey-contractors, maximum 5 from architects, maximum 3 from engineers (preferably from work with alternative energy solutions),
- Amount of employees and their function during the past 3 years. *(Annex 5)*

According to AAB, many of these items are standard requirements for prequalification. Furthermore, previous experience in work with housing organizations is very important for AAB; hence, they requested references from previous projects. In this specific project, each participant had to present a maximum of 13 valid references, in order to qualify for the tender. References of apartment building projects were crucial. Other large-scale projects, e.g. schools etc., were not considered valid in this case. Additionally, AAB requested the information about the architects and engineers that were to be a part of the total contract, as well as their annual reports. Based on these criteria, the organization then made the choice of contractors that were allowed to participate in the next round of the tender. AAB currently does not utilize a specific ranking system for the prequalification round; hence, the choice is made simply by evaluating the part applicat and deciding upon most suitable candidates, by, e.g. eliminating those who have not provided a sufficient amount of references. For this project, 17 total contractors made the application and five of them fulfilled the prequalification criteria to full extent. However, only four contractors participated in the actual tender.

The award criterion for AAB tenders is both usually and in this case the Economically Most Advantageous tender. The sub-criteria varies from project to project, however, both the price and quality are always important factors. In Îble had four sub-criteria. Each of the four items received points from 0-10, where zero is the lowest and 10 the highest.

1. Price ï 25%
2. Functionality and architecture ï 30%
    a. In the building
    b. In connection with the dwellings
    c. In the apartments
3. Technical solutions ï 30%
    a. Construction solutions
    b. Technical installation solutions
    c. Solutions for complying with energy class
    d. Offered materials or products
4. Process and execution ï 15%
    a. Main time schedule from the turnkey contractor
    b. First-production examination
    c. Phased deployment
    d. Building commissioning process

    (Annex 6)

In this tender, AAB have introduced a new sub-criterion ï commissioning, meaning the quality assurance of the building throughout its lifecycle, in order to ensure that the building functions as it was intended (US Department of Energy, 2015). This criterion has been introduced for two reasons. Firstly, because a part of AAB main operations in managing their facilities, therefore it is very important to procure buildings of high quality, that require less attention during their operation. Secondly, AAB has the goal, in time, to acquire DGNB[1] sustainable building certifications for their buildings, where commissioning is an important part of the certification. Currently, however, AAB have requested bids from the contractors with and without the DGNB certification. I.e. the bidders have to present the difference in the price depending whether the building can or cannot be DGNB certified. The organization is therefore not bound to start their certification process just yet.

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[1] DGNB - Deutsche Gesellschaft f¿r Nachhaltiges Bauen Building Council). In Denmark, Green Building Council Denmark administers the DGNB certification.

As it could be observed, AAB evaluates the bids from *Price to Quality* approach. This approach implies converting the price of the construction into quality measures. The bidder, which has the highest quality scores within different non-price criteria, wins the competition. In *Chapter 3.5. Tender evaluation,* it was discussed that this approach is less effective due to difficulties in converting price into a quality measure. A human being is more familiar with comparing *Quality to Price*, meaning how much one could afford for the certain amount of money. However, AAB focuses on long-term perspective of procuring a facility. Therefore, higher quality ensures lower expenses on O&M, which is more important than the initial price of the building in AAB case.

The tender proposals are handed in via Projektweb and AAB in this case had 1 w to analyse the delivered materials. Afterwards the organization held a presentation session, where each of the participating contractors had the opportunity to present their design and ideas and answer questions related to them. For the Îblelunden proje team consisted of two representatives from Bascon A/S, the director of the project department Arne Tollaksen, the project engineer Carina Hedevang and the AAB building committee. After the tender participants present their projects, the evaluation team shall have two weeksô time to make th shall discuss the projects At fir together; however, the decision lies on the shoulders of Arne Tollaksen and Carina Hedevang, with the assistance from Bascon A/S representatives. Eventually, when the best project is chosen, the director of AAB, Anders Rßnnebro, contacted in order to be receive his approval of the choice.

5.3.5. Post Construction Phase

AAB have previously used the SFB classification system for naming construction elements. However, the SFB system is intended for construction use; thereby, it does not give the level of precision needed for facilities management to evaluate their expenses in regards to operation and maintenance.

In 2009, the requirement of using new classification codes was issued by Danish Ministry of Housing, Urban and Rural Affairs. All social housing associations must hereby use ñForvaltnings Klassifikationò classification s operations. In the new classification codes, 148 codes are defined for six different areas:

¶ Terrain,
¶ Outside environment of the building,
¶ Inside the building, basement area,
¶ Technical installation,
¶ Codes for materials.
(Landsbyggefonden, 2012)

MdocFM supports both classification systems, but AAB uses the new system due to the legal restriction. According to the interviewee, the reason for issuing the law to switch from the traditional construction SFB system to ñForvaltnings Klassifikationò system is the limitations of the former system in regards to annual evaluation of the work performed by the social housing organisations, because the location of e.g. windows is not specified in SFB classification system. As a result, an analysis of actions performed within a year was not clear to identify the causes of invested money. The analysis of causes of investment is the duty of facilities management. Furthermore, they are bearing the responsibilities for every financial investment made in AAB. Furthermore, AAB have linked their invoices with the "Forvaltnings Klassifikation" system to have an opportunity of tracking the money flow within the operation processes. "*What is the cause of doing system, that is not in the economic system, they can* *(*A. Tollaksen 2015, *Interview 1, 21 September, 36 min. 32 sec.)* Additionally, Danish Ministry of Housing, Urban and Rural Affairs evaluate the annual performance of social housing all over Denmark. Furthermore, they benchmark different social housing organisations to see whether the expenses are reasonable or not. In case there are any suspicions or the expenses seem irrational, the facilities management has to clarify them. Having a well-organized system helps AAB to make the daily operations more transparent for a powerful stakeholder like the government entity. *(*A. Tollaksen 2015, *Interview 1, 21 September.)*

The 3D model is, as a part of handing over procedure, forwarded to AAB from parties involved in the construction process. The organisation has to convert the objects that are linked to the SFB system into *Forvaltnings Klassifikation* classification order. According to AAB, the organization employs an ICT coordinator, who is responsible for converting one classification system to another. There is no add-on tool that is able to perform this task; therefore, the information is inserted manually. The interviewee states: "*we only do facility management […] you never need to know everything the concrete that is not facility management*" *(*A. Tollaksen 2015, *Interview 1, 21 September, 23min.59sec*). Meaning that not all information is need for FM, therefore FM classification system only applies to the components that are affected during the operations of facilities.

6. Development of 3D Thinking

As it could be observed, AAB pays a lot of attention to the recent information technologies. Furthermore, the latest area of interest at AAB is "*to live, to work in the model*" (A. Tollaksen 2015, *Interview 1, 21 September, 2 min. 44 sec.)*. Currently, the organisation utilises 3D modelling for purposes like drafting, visualisation, and walkthroughs. Therefore, the research group has decided to investigate the next possible step into 3D thinking philosophy, namely fully immersive 3D. It is therefore necessary to analyse the need and integration process of immersive 3D, in other words virtual reality, at AAB.

A change within an organisation influences all the components on which the organisation is established. Thereby, it is vital to analyse and define the changes that take place when a new procedure is implemented and to reflect it chain. The problem statement of the report raises the question of immersive 3D/VR feasibility in AAB. The VR system is a technological addition to the current technology system at AAB that aims at increasing the efficiency of the decision-making process. However, by considering VR as the only technological change, there is a high chance to fail the integration, because, as it was discussed earlier, the change does not take place in an isolated environment (Leavitt, 1965). For example, the VR could face resistance from the working personnel due to the learning curve. Moreover, the amount of adjustments within the organisation by VR might make the investment not feasible due to many changes that are required in components like people, task, and outcome that VR could potentially bring. Therefore, these aspects have to be analysed concerning the magnitude of change on each component to conclude whether immersive Virtual Reality is worth the attention at AAB. This is done with the help of Leavitt Diamond and its four aspects, namely technology, task, people and structure, as discussed in *Chapter 2.3.1 Leavitt Diamond.*

6.1. Technology

Many different types of data are used for design proposal evaluation. The design itself is usually presented in various 2D and 3D drawings and illustrations. In addition to the design, many documents in forms of spreadsheets, text files and images are presented.

Currently, 2D and 3D designs and drawings are the most commonplace representations of the design of a building. From the very history of architecture, drawings were done in 2D, whereas the 3D understanding was gained by using the triadic system – plans, elevations and sections, all done in two dimensions. (Luce, 2009) This naturally limited the understanding and sensing of the future building. Small-scale mock-ups were and still are used to recreate the overall shape and character of a building; however, that does not have a great impact on the overall understanding of the clients, users and sometimes, contractors. Only after Computer Aided Design (CAD) was introduced and widely accepted as the standard for architectural and engineering drafts, the computer aided 3D modelling was born. This greatly improved the design data representation. The architects and engineers could improve their designs and the clients and users gained the ability to visualize the future buildings, which lead to more qualified decision-making.

6.1.1. 2D Data Representation

2D drawings are still and most likely will always be an essential part of building design and hence design evaluation. Building data in two dimensions is represented in plans, elevations, sections, detail drawings etc. These 2D drawings are essential for communicating the specific dimensions, distances, areas, locations of openings, fire requirements, escape routes, connections, detail solutions and other important information, which tends to be presented in a rather technical manner. The 2D drawings contain the main essence and details of building and engineering projects. However, two dimensions are not enough for space visualisation and the information the 2D drawings represent is not always meaningful and understandable for each involved party, especially the non-professional stakeholders, e.g. the client, end users etc.

In all construction projects, before the actual building, the visualization of a proposed facility is mostly 2D paper-based CAD drawings. Throughout the building design process the project team draws, visualizes, and exchanges written and geometrical information with the help of 2D paper-based drawings. (Shiratuddin & Thabet, 2003)

The parties involved in designing and building the facility are expected to visualize all the perceived characteristics and spatial relationships between various project components. This presents a tough task and inflicts heavy burdens on the project team to make the best possible design and construction decisions (Shiratuddin, et al., 2004). Hence, if the problem is acknowledged even between the professionals of the building industry, the parties usually not dealing with this type of data are very likely to have much greater issues in dealing with this type of data representation.

2D data representation in building design evaluation is essential, since it largely covers the technical aspects of the building. This type of data is known to all members of the construction industry and is a standard when exchanging data between parties. However, due to the technical nature of these drawings, as shown in *Figure 6.1*, the clients, end-users and other stakeholders, who are not usually involved in the construction industry, often find it hard to understand. E.g., non-professionals might find it hard to visualize dimensions and areas. Therefore, a high amount of project evaluation time is used for understanding the representation and creating a general sense of the proposed project, instead of actually evaluating the proposed design.

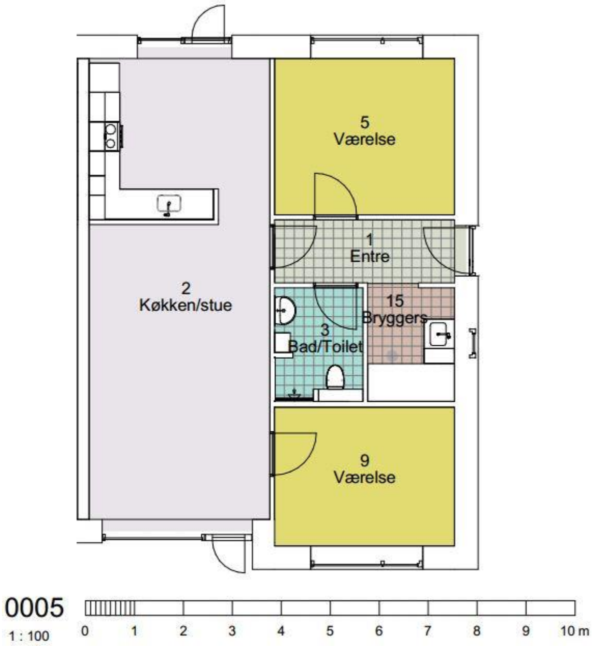

Figure 6.1 2D plan, AAB

2D data representation is used very widely in AAB. The project department, which employs architects, engineers and FM professionals, use 2D drawings on a daily basis. The use includes e.g. illustrations for their tenants in cases of renovation and use for FM purposes in the Mdoc FM software, as well as visualizing their needs for new project briefs. As in all cases, the design proposals submitted for tender for AAB also include the types of 2D drawings mentioned before.

6.1.2. Non-immersive VR

However, the 2D drawings, even with the use of mock-ups and 3D hand sketches are not enough to provide a suitable level of spatial visualisation and understanding and have proven difficult to comprehend for the clientôs

In 1981, computer graphics from Cornell University founded a 3D and graphics technology, which was a pioneer in the field (MB Solutions, 2003). Henceforward the 3D modelling techniques have been improving rapidly. 3D data representation, also known as non-immersive virtual reality, has become a crucial tool for the construction and engineering industries. At first the technology was developed for architects, designers and engineers, however the rapid technological development has enabled the construction clientôs use of the tools for design proposal evaluation. This has also greatly improved the communication between the industry and its clients, since the proposals are more comprehensive and allow for much better visualisation of buildings and designs, which in turn eases the clients and end-users in the world of architectural design and shortens the negotiation processes.

Within AAB, 3D modelling is used to a high extent in construction and renovation, as thoroughly described in *Chapter 5.3. Information Technologies within ABB.* As the representatives of the organization state, they have been using 3D models for instructing their clients with a great success. In case of renovation, for example, the architect employed by AAB had created a 3D model of the new kitchen, and with the help of a walkthrough tool presented in to their client. Only during this process it was noticed, that there are significant flaws in the design of the fixed furniture, e.g. the oven was located too high for a comfortable reach, there was no hood above the stove, some cupboards were missing handles and there were no drawers in some essential locations. (L.Kruse & A. Tollaksen 2015, *Interview 1, 21 September.)* In this case, the 3D model helped the organization to fix the mistakes before contacting the kitchen unit manufacturers and therefore saving significant amount of funds, since making changes in the further stages of the project have proven to be a costly affair.

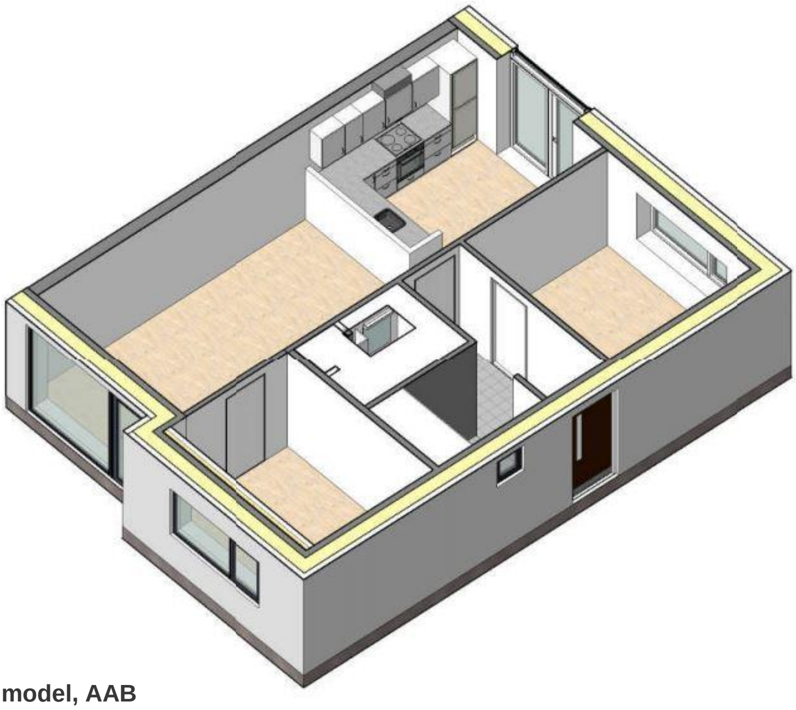

Figure 6.2 3D model, AAB

Concerning building design evaluation, 3D models, visualisations and photorealistic renders made based on the models, e.g. *Figure 6.2*, have become irreplaceable in the industry. The building models significantly reduce the time needed for the client to get accustomed to the data representation type, since the 3D world is much more familiar to the non-professional party. The model gives an almost instant understanding of the geometry and the character of the building and allows the client to explore it both internally and externally by using walkthrough tools. The 3D models bring understanding of not only the geometry of the building, but also the proposed design of its surroundings, the area dimensions and colour schemes. The option of creating photorealistic images of the models with the help of rendering brings the clients and end-users a step closer to feeling the design by providing realistic images of the future structure.

Nowadays 2D and 3D data is usually used in conjunction in order to reach the best possible result for both building design and design evaluation. However, despite the apparent benefits of non-immersive VR compared to 2D data representation, there is still room for improvement.

Currently the usual viewing method of 3D building models is through computer screens. This creates a paradox of viewing 3D models in a 2D environment, since observing such a model on a screen often creates a lack of depth perception. The 3D models often appear distorted, which once again creates difficulties for understanding and imagining the building correctly. Additionally, as Shiratuddin, et al. (2004) state in their study, which is further described in the following chapter, the computer screen has a limited field of view for use by several persons in the same time. This would prove less effective for decision-making purposes, where the c l i e nat m ônseeds t toe work simultaneously (Shiratuddin, et al., 2004). In theory, non-immersive 3D might reduce the sharing of tacit knowledge due to limited view and navigation issues within the 3D model. Additionally, AAB have been using videos made with the walkthrough tool available in Autodesk Revit for presenting the 3D renovation models to their clients, as an alternative to the usual 3D render presentation. This suggests that the organization sees the need for presenting a clear and understandable 3D model to their tenants. Consequently, the authors of this thesis believe that more immersive techniques of virtual reality can and should be used in proposed design evaluation in order to ensure the best outcome for the client.

6.1.3. Immersive 3D

One of the methods to improve the proposed design evaluation is creating a virtual prototype of a building that can be examined via virtual reality. VR brings significant value to architectural design review; it enhances spatial understanding of the design. Moreover, instant feedback of the design concept can be given by the participants of the evaluation procedure (Nikolic, 2007). The feedback is based on tacit knowledge that participants have accumulated with e.g. working experience. The virtual prototype has shown its benefits and the ability to present small/large-scale 3D spatial information compared to physical mock-up that is still used in the construction industry (Castronovo, et al., 2013).

VR often refers to an immersive system, but the degree of immersion varies depending on the characteristics of the system. Immersion is a multidimensional construct, which is formatted by specific system components (Castronovo, et al., 2013). According to Slater & Wilbur (1997) ñ*Immersion is a description of a technology, and describes the extent to which the computer displays are capable of delivering an inclusive, extensive, surrounding, and vivid illusion of reality to the senses of a human participant*ò. Where

¶ *Inclusive* specifies to which extent the physical reality is blocked out,
¶ *Extensive* is the range of sensor coverage,
¶ *Surrounding* is the boundaries of a system, which shall provide a panoramic view and
¶ *Vivid illusion* provides the visual and color resolution.
(Slater & Wilbur, 1997)

Semi-immersive VR refers to large-scale connected screens that create a medium-level of immersion CAVEÊ. Furthermore, full-Immersive technology implies a head mounted display (HMD) or immersive CAVEÊ. (Castronovo, et al., 2013) These systems are briefly described further in the chapter.

The stereoscopic technologies have been used in virtual reality for decades and are commonly defined as an expensive approach that requires many person-hours to set up the system. However, there is a tendency in the gaming industry to implement VR technologies to enhance the gaming experience. Hence, the cost of technologies and production is reduced, which results in cheaper solutions that could be used in professional industries. (Lyne, 2013)

VR features like stereoscopy, large field of view, large screen and isolation from real environment have increased level of presence in the model and spatial understanding in reviewing the construction design (Castronovo, et al., 2013) (Nikolic, 2007). VR is being progressively used in architectural design review, for it gives the ability to interact with the proposed design by being in the model. In the early design stage, VR helps to give a sense of scale, magnitude and room layout. VR provides a means for more qualitative feedback of design proposal from user ôscale 3D environment (Castronovo, by provi et al., 2013).

Shiratuddin, et al. (2004) have outlined several display technologies of virtual reality. *Table 6.1* represents these technologies and their display characteristics. However, the CAVEÊ by the author of the table is considered only semi-immersive, but it varies depending on the amount of wall displays that create the illusion of presence. Hence, the system in case of high usage of components could be also considered fully immersive. E.g., Castronovo, et al. (2013) consider CAVEÊ to be a fully immersive system.

Display	CAVEÊ	HMD	IWB
Immersive	P	P	-
Semi-immersive	P	-	P

Table 6.1 Display technology of VR adapted from (Shiratuddin, et al., 2004)

Figure 6.3 Virtual Reality CAVE (Deepak, 2014, p. 21)

The Cave Automated Virtual Environment (CAVEÊ). ñis a large surrounded screen projection of VE display that was developed to overcome the limitation of single-user VE display such as HMD. ò (Shiratuddin, et al., 2004). The system was introduced at SIGGRAPH in 1992, providing the users with a sense of being in the 3D model, when they are surrounded by three walls of screens and floor projection (Kang, et al., 2012). The system has a cube like shape, which consists of wall of screens ranging from two to six screens (Shiratuddin, et al., 2004). The screens in the system make a room of 10 feet (approx.3 meters) wide, 10 feet (approx. 3m.) long and 9 feet (approx. 2.7m) tall (Kang, et al., 2012). The system covers 270 degree of field of view, which allows providing a true sense of scale to the users (Castronovo, et al., 2013).

The projectors are responsible for displaying the images on the walls. One projector is displaying one single wall. The projectors work simultaneously on each wall and the walls are partly/fully surrounding the participants, which allows achieving the illusion of immersion (Shiratuddin, et al., 2004). Due to the size of the screens, more than one user can participate allowing brainstorming sessions and communication process while pageò.

Immersive Workbench (IWB). The IWB is a drafting display system, which allows multiple user involvement at the same time. The system supports high resolution and head tracked images and navigation such as joystick for orbiting the 3D object. (Shiratuddin, et al., 2004) *Figure 6.4* illustrates IWB system, which can be used for semi-immersive virtual reality.

Figure 6.4 Immersive workbench (Kreylos, 2005)

Headed Mounted Display (HMD). This VR system allows a user to have a fully immersive virtual reality experience. The basic system behind the HMD consists of two stereoscopic displays placed with an offset from each other and displaying the same image to each eye. The reason for keeping a gap between the images is for the interpapillary distance. The human brain has to combine those images together, thus creating consciousness of the perception of depth. (Lyne, 2013) The participant is isolated from the physical environment, allowing full absorption within the virtual environment. Therefore, the system is considered fully immersive. However, multiple user participation within this type of virtual environment is possible. Each participant wears the HMD that is fully isolated from the real environment, but each user can see other participants in the virtual environment and discuss the concerns they observe within the 3D model.

Figure 6.5 Oculus Rift HMD (Oculus Rift, 2015)

The latest consumer product that is available on the market is Oculus RiftÊ. ñ*The Oculus Rift is a hi*
(FOV), low-latency, consumer-priced virtual reality head-mounted display (Lyne, 2013, p. 557). Additionally, other vendors are introducing their HMD systems to the market as well. For example, Sony PlayStation is planning to release HMD called Project Morpheus in 2016 (Sony PlayStation, 2015). The competition on the market allows reducing the end price, which could motivate the professionals to try the systems.

As it can be observed, there are several variants of virtual reality systems that could bring different level of immersion, depending on the projectôs charact
(2004) have conducted a research regarding the efficiency of VR display in regards to reviewing construction 3D models.

- ¶ The CAVE system consisted of four display walls providing 270-degree field of view (front, bottom, left and right). The authors conclude that the system provides efficient level of realism to have a sense of being in the model. Moreover, the system is suitable for designing/planning and decision-making process and multi user interaction with the 3D object,
- ¶ Immersive Workbench (IWB) has low quality of detail, therefore, is not a well-aided tool for design/planning and decision-making process due to lack of good visualisation of details. The level of immersion is low due to lack of enclosure of the viewing, which does not take the participants away from the real environment,
- ¶ Head Mounted Display (HMD). The author argues that the system does not help in the design process due to individual participation of each user. The level of realism is high due to isolation form the real environment.

(Shiratuddin, et al., 2004)

Nevertheless, the research was conducted in 2004, where the technology level was not that developed in comparison to todayôs technological process opportunity to conduct a HMD experiment with a single participant. Today, as it was discussed earlier, there is an option to include more users to interact with the same model, which increases the level of communication during the design review and communication between the users. According to a private conversation with a representative of Evokon Aps, certain HMD systems provide the opportunity for up to 100 people to use the environment simultaneously.

Castronovo et al. (2013) have conducted a research regarding the feasibility of semi and fully immersive VR. Full immersion is more appropriate for smaller groups and the need for detailing is high. Whereas, semi-immersion, which has a larger footprint, is feasible for a large group of people that all can navigate the model on the screen, while still having a sense of being in the model. In AAB, both semi and fully immersive VR can be used in different situations. A semi-immersive system could prove beneficial for the event where the end-users need to be informed of certain design solutions. I.e. when a larger group of people should be using the environment simultaneously. The fully immersive VE, on the other hand, can be used by the leadership of AAB when making large-scale design decisions, such as choice of a design proposal in a tender competition.

The benefits of VR involvement have been demonstrated in a case study of a 16,400-m^2 building (Maldovan & Messner, 2006) and design review of operation and patient rooms (Castronovo, et al., 2013). Whereas Maldovan & Messner (2006) combined immersive display projection, namely CAVEÊ with 4D CAD[2] for performing a construction process review to enhance the scheduling process of a project that was under time delay due to unexpected reasons. Another case study shows VR importance in complex buildings such as hospitals, where the physical mock-ups play a vital role in designing a technically complex room e.g. surgery room. However, the physical mock-up has proven useful, but it requires great amount of resources to build. Hence, the virtual mock-up is a cheaper solution with a more interactive system that reduces the time for decision-making (Dunston, et al., 2011). These two case studies are examples of where VR has shown its benefits. The authors of this report believe that since the cost of ownership is decreasing and the flow of converting 3D objects into VR is becoming smoother, virtual reality could enhance the productivity of new construction throughout the design stage. VR helps to achieve such efficiency by helping at sharing tacit knowledge of the participants by putting them in fully immersive environment.

However, due to overall system cost and availability of the particular VR system, HMD VR system is used in this report. The proposed HMD system has the ability to involve many participants in the same model, which may increase the interaction and communication

[2] 4D: 3D + time planning

process. Moreover, the cost ownership is lower in comparison to CAVEÊ system. The size of HMD system is quite small, which gives a high portability comparing to another system.

6.2. Task

In order to work with HMD VR and utilize all its benefits, it is first necessary to export the 3D model from its original software to the VR engine. The main development of VR technologies currently takes place within the gaming industry; therefore, the VR tools for the AECO sector are largely developed by game development engines. There are several gaming engines available for these purposes, such as Unity 3D and Unreal Engine. However, Unity 3D is the ultimate market leader, which is chosen by 47% of game developers worldwide. (VisionMobile, 2014) Therefore the information further in this report will be based on Unity 3D.

6.2.1. Unity 3D

ñU[nity is a] development platform for creating games and interactive 3D and 2D experiences like training simulations and medical and architectural visualizations, across mobile, desktop, web, console and [Unity is] compatible with current industry standard CAD tools and it allows you to easily deploy to a vast number of platforms. With Unity, architects and engineers can inspire their clients wherever they are. It is easy to import models from design programs such as Autodesk Revit, ArchiCAD or Sketchup Pro to Unity and create an engaging interactive walkthrough (Unity Technologies, 2015a)*.*

Nevertheless, VR has traditionally been supported in Unity via external plugins, such as Middle VR. These plugins have been a necessary added tool to Unity in order to use Unity for virtual reality. Amongst other things, Middle VR added the following capabilities to Unity:

- Scale one visualization with user-centric perspective,
- Support for 3D interaction devices such as 3D trackers,
- S3D ï Stereoscopy (active, passive),
- Multi-screens / multi-computers synchronization for higher-resolutions and impressive VR systems,
- 3D interactions: navigation, manipulation,
- Immersive menus,
- Custom graphical user interfaces (in HTML5),
- Display any webpage inside the virtual world.
  (Middle VR, 2015)

However, starting from version 5.1 and onward, Unity contains a built-in support for certain VR systems, which was introduced in order to deal with the shortcomings the use of external plugins created. Unity now supports Stereoscopic 3D, Split-screen stereoscopic 3D, Oculus family of VR devices and Sony's Project Morpheus VR device for Playstation 4. (Unity Technologies, 2015b).

There are relatively many file formats supported by Unity 3D. It is possible to import numerous proprietary file types, such as .c4d, .max, .mba etc. into Unity, which brings the advantages of quick iteration, however, using proprietary files usually leads to files containing many unnecessary data and large files can slow down Unity processes. (Unity Technologies, 2015b)

Unity supports a number of exported file formats - .fbx, .dae, .3ds, .dxf and .obj. Unity Technologies (2015b) state the advantages of using exported files as follows:

¶ Exporting only the needed data,
¶ Verifiable data (re-imported into the 3D package before Unity),
¶ Smaller file size,
¶ Encourages modular approach ï e.g. different components for collision types or interactivity,
¶ Supports other 3D packages whose proprietary formats are not supported by Unity.

Disadvantages:

¶ Possibly a slower pipeline for prototyping and iterations,
¶ Easier to lose track of versions between source (original file) and data (e.g. exported .fbx file).
(Unity Technologies, 2015b)

Consequentially, use of exported files is suggested due to inability to export the files from AEC designed software directly to Unity 3D environment.

6.2.2. Workflow

A study done by Dalton & Parfitt (2013) compares eight workflows that are suitable for visualizing large models in a fully immersive CAVE from various 3D software products. This study analyses the workflows utilized in order to use pre-made 3D models in Unity 3D. The 3D modelling software used for the purpose are Navisworks Manage 2014, Revit 2013, Microstation V8i, Google Earth, Sketchup 2013 Pro, ArchiCAD 17 and Vectorworks 2013.

Dalton & Parfitt (2013) have also summarized the interoperability of the software in *Annex 7.* The table states which file formats are supported for importing and exporting in the software stated above, as well as 3ds Max 2014 and Unity 3D, which was discussed earlier.

Figure 6.6 visualizes the workflows analysed by Dalton & Parfitt (2013). It must be noted that the research was done for the model use in VR CAVE; however, the procedure remains unchanged when using other VR devices, e.g. Oculus Rift, since both Unity and Middle VR support the use of HMDs (Middle VR, 2015). However, in case of using an Oculus Rift VR device, Middle VR can be omitted.

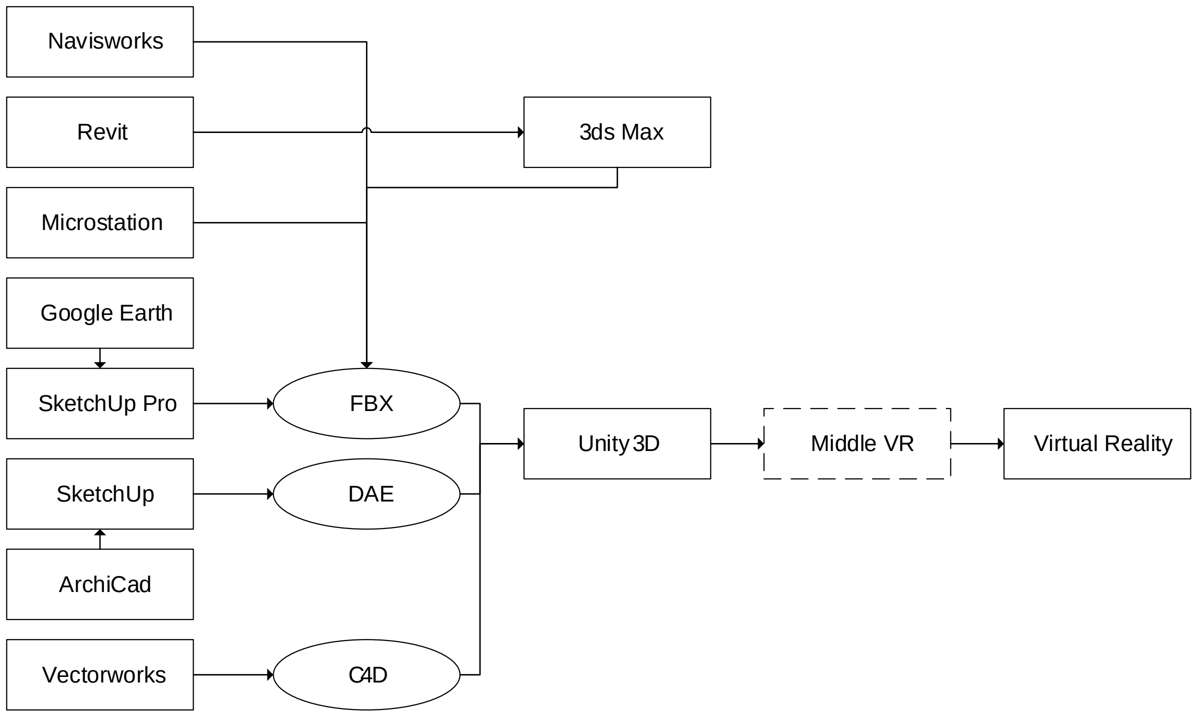

Figure 6.6, File conversion workflow, adapted from Dalton & Parfitt (2013)

As the figure suggests, the file formats that are mostly common for the 3D modelling software and Unity are .fbx, .dae and .c4d. These workflows have been generated while using a model from a real infrastructure project as the trial. (Dalton & Parfitt, 2013) The study concludes that each 3D modelling software has one conversion route that is best suited for it, respectively:

¶ Autodesk Navisworks Manage 2014 ï FBX file, with the only problem that Navisworks does not export double-sided materials,
¶ Autodesk Revit 2013 ï FBX file through 3ds Max (discussed later),
¶ Bentley Microstation V8i ï FBX file, since DAE file does not export textures from Microstation,
¶ Google Earth ï FBX through SketchUp for the terrain. DAE should be used in case of errors,
¶ Trimble SketchUp Pro 2013 ï FBX file to Unity,
¶ Trimble SketchUp 2013 ï DAE file to Unity (the non-professional version does not support FBX files), on rare occasions some textures might be lost,
¶ Graphisoft ArchiCAD 17 ï SKP file for importing in SketchUp, followed by DAE file from SketchUp to Unity or FBX file from Sketchup Pro.
(Dalton & Parfitt, 2013)

Autodesk Revit is currently the leading building design and BIM software, both in terms of user satisfaction and scale (based on market share, vendor size, and social impact) (G2 Crowd, 2015). Additionally, Revit is the software used by AAB, as discussed in *Chapter 5.3 Information Technologies within AAB*. Therefore, the workflow of transferring a 3D model from Revit to Unity and the underlying issues will be considered in greater detail.

Workflow ï a Practical Demonstration

The authors of this report have undertaken a small study regarding the processes that have to take place in order to experience an Autodesk Revit 3D model in Virtual Environment.

The 3D Model creation and further editing was performed on consumer laptops. The system for visualisation process was based on a game-oriented desktop computer. Furthermore, for navigation within the virtual Environment, an Xbox controller, Leap motion and a Joystick were set up to the system. A head mounted display, namely Oculus Rift, was utilised to provide a fully immersive virtual reality. Information regarding the hardware is given in *Chapter 2.4 Virtual Reality System.*

Several software products were utilised during the process. The particular software and the main steps are illustrated in *Figure 6.7*. A detailed step-by-step guide of transferring the file, created by Evokon Aps is shown in *Annex 8.*

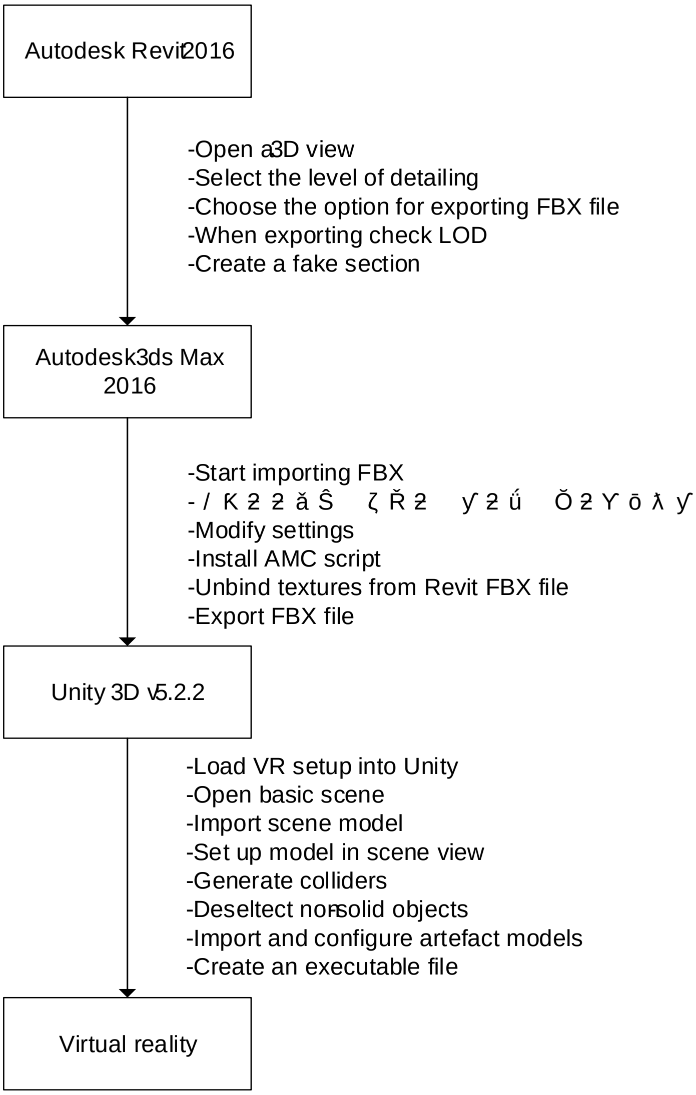

Figure 6.7 Conversion process, adapted from *Annex 8*

AAB have provided a 3D model of multifamily residential building, which includes the textures of e.g. brickwork and tiles. As shown in *Figure 6.8*, the software has the possibility to export files into .FBX format, which helps to make a smooth flow in creating a virtual environment model. Before exporting the model into .FBX format, the level of object detailing has to be chosen. There is a trade-off between the amount of information that needs to be present for visual evaluation and the power of the computer that has to compute that amount of data.

Figure 6.8 Converting Revit model in .FBX.

Further, when exporting the FBX file, it is important to make sure that the exporter only uses the level of detailing that is currently applied in the model. After saving the model into .FBX format, it can be imported into Autodesk 3Ds Max. There are several reasons for including 3Ds max into the process. Firstly, there is the need for converting the textures and colours into the imported 3D object and secondly, for optimization of the 3D model in case it is a large-scale model with many polygons, which would slow down the walking experience in the virtual environment.

According to Dalton & Partiff (2013), prior to 2011 it was possible to import the .FBX file from Revit straight into Unity, since the procedure of exporting the .FBX would also create an FBM folder, which contains all the properties of textures used within the model. However, since 2011 Autodesk changed their materials to Protein 2.0 type, in which textures are now encrypted within an Autodesk library file in the FBM folder and cannot be interpreted by Unity 3D. For this reason, an additional step is needed to transfer the file. Since 3Ds Max is an Autodesk software, it has the capability of reading the encrypted Autodesk Library materials and consecutively exporting FBX files with the textures embedded within them that Unity is able to detect. (Dalton & Parfitt, 2013) The colour and texture conversion is a generally simple procedure; however, it requires the pre-made AMC script in order to access the original textures that were assigned to the model in Revit. Another option is to apply textures in 3Ds Max, which would make the textures appear more realistic, but the learning curve and time consumption would influence the consideration of using VR on a daily basis. In the current workflow, the main aim is to investigate the level of complications for a regular user that operates with AEC software. Therefore, using the existing AMC script is the best option, which enables the use of the same textures that were applied to the 3D model in Revit to the FBX file in 3Ds Max.