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Assessing Future Market Opportunities for Information Technology in Operational Facility Management

A Master's Thesis submitted for the degree of
"Master of Business Administration"

supervised by
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Affidavit

I, **Raphael Riemer**, hereby declare

1. that I am the sole author of the present Master's Thesis, "Assessing Future Market Opportunities for Information Technology In Operational Facility Management", 57 pages, bound, and that I have not used any source or tool other than those referenced or any other illicit aid or tool, and
2. that I have not prior to this date submitted this Master's Thesis as an examination paper in any form in Austria or abroad.

Vienna, 27.06.2017

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Signature

Abstract

This work explores emerging technologies surrounding the facility management industry in regard to their possible impact on some of the current challenges for the Operations & Maintenance discipline. Despite the fact that facility management as a whole is rather slow in adopting to novel technologies, facility managers should be prepared to the possible impact that technology will likely induce upon the FM industry.

The result is a holistic insight into the landscape of emerging technologies that promise value either because of the explicit need of information technology in the facility management industry, or as possible, alternative solutions to selected challenges presented in this thesis.

By applying technology assessment methods to the literature research of up-to-date publications, facility management journals and papers on one hand, and to the identification of underlying, alternative solutions to the issues regarding the operations of facilities presented in this work on the other hand, a number of technologies have been identified with a focus to the operation of facilities.

In particular, Building Information Modelling (BIM), a methodology that has experienced rising prominence over the past few years, was analysed in more detail as a possible solution for the application of novel and state-of-the-art technology to the construction sector. BIM promises to increase the level of detail of electronic data that is gathered throughout the planning and construction stages, thus leading to an extensive knowledge database that can be later utilized by facility managers during or even in advance to the operations stage.

Furthermore, Augmented Reality (AR) emerged from the technology assessment analysis as an alternative solution to provide more sophisticated means for a mobile human-computer-interaction, in contrary to the common mobile device screens, with regard to a facility manager's daily tasks regarding the tracking of assets.

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1. Introduction

In any facility's lifecycle, a significant share that cover a facility managers' responsibilities are its operational management on the one hand, and its maintenance management on the other. Whereas just as recently as at the beginning of the 21st century, complex building equipment and technical appliances were almost exclusively installed in office buildings, today's modern buildings designed for residential purpose are nearly equally complex as their office counterparts. However, the job profile for property managers in charge of residential buildings has remained pretty much the same since before this trend, creating disparity between both the knowledge as well as the time effort needed to operate and maintain such complex buildings (and their assets) and the amount of knowledge and time that can actually be provided by the property management itself. (May & Williams, 2017, p. XXV)

Depending on the size of residential buildings, the scope of such technical appliances can range from centralized air-conditioning of apartments to access control systems for parking and certain common rooms to automatic fire detection systems. This in return leads to an increase in requirements for operations and maintenance, especially in the latter case of fire detection systems and similar appliances, where both Austrian and international law dictate regular intervals for inspection and maintenance of such equipment by qualified personnel to ensure proper functionality at all times. (OEBFV, 2005, pp. 5-6)

To cope with the increasing complexity of operational facility management and maintenance and their responsibility to detect and eliminate signs of possible danger to the safety of tenants, facility managers depend on the assistance of sophisticated information technology (IT) systems to assist them with and support their day-to-day business. Furthermore, technology is becoming ever more present as new developments enhance not only tenant's safety, but also their comfort and their possibilities at home and work (i.e. smart homes). Whether facility managers like it or not, they will have to embrace and learn to fully utilize the possibilities that are opened up through that technology.

Due to increasingly tightening laws, dire consequences may occur for the property managers in case of casualties, which are, but not limited to, a result of failure of their facilities' security systems and similar appliances whose sole purpose is to ensure proper safety for all tenants. This is only one of several reasons that, today, there is an almost soaring need for facility managers who are assigned with, and therefore responsible for the day-to-day operations and maintenance of a building's technical appliances as well as, in many cases, the regular assessment of overall safety, or danger, that is emanated from the building's structure and condition itself. These continuously increasing requirements for safety and comfort for tenants of both office and residential buildings in Austria have strong implications on the complexity and costs for constructing and operating facilities efficiently in regard to their economic viability, as well as sufficiently in regard to Austrian and international law and regulations.

1.1. Objective of the Master Thesis

The purpose of this thesis is to identify current and future developments in the information systems landscape that potentially change and/or interrupt the Facility Management industry and evaluate potential future applications that tackle some of the major issues for today's facility managers. The evaluation is to be conducted using a technology portfolio analysis and measurement indicators for technology attractiveness as well as adoption risk. Selected technologies are to be analysed in more detail with regard to their possible benefits for the issues presented in this work as well as the barriers for a possible adoption. However, this work does not aim to discuss about the advantages and disadvantages of specific software and/or hardware products or applications and certain manufacturers, but rather the whole landscape of information technology and building equipment.

As is happening in many other industries, information technology has already changed and will continue to significantly impact the facility management landscape as a whole. Regardless of whether a building is in its planning, construction or operations phase of its lifecycle, IT has changed the way facility managers fulfil their work. Even though this thesis focuses on the latter stage of the mentioned lifecycle, the preceding lifecycle stages have to be taken into account as well when evaluating future applications of IT in facility management, as these stages inevitably have a strong implication on how new and modern buildings will be operated. This is in parts due to the potential of synergy and cost-savings if the lifecycle is treated as a whole, rather than three separate areas. (May & Williams, 2017, pp. 28-29)

An example that strongly supports this claim is illustrated by the motivation of the United Kingdom government's construction department to enforce government construction projects to be realized with the help of so-called Building Information Modelling (BIM) systems since the beginning of 2016. The main goal of BIM is to ensure that all data, which is needed for construction as well as operations of a new building, is digitalized and gathered in one central place that is accessible to every stakeholder involved in the project. (U.K. Government Cabinet Office, 2011, pp. 13-14)

Therefore, the ultimate goal of this work is to present an overview of current developments in information technology that may increase facility managers' efficiency and also accuracy of their day-to-day business tasks on one hand, and that promise to resolve the current challenges for facility managers identified in this work, with regard to the following criteria:

- Increase in efficiency of current means to operate and maintain a building and its assets
- Reduction of overall lifecycle costs
- Establishment of novel and more sophisticated means that enhance or replace current work flows
- Leveraging on already available, but widely unused data (i.e. energy management)

1.2. Course of Investigation

This work will make use of two forms of research. To provide background information on the facility management industry, its evolution over the last two decades and its soaring necessity for information technology, literature will serve as the foundation for the primary research that is conducted. Furthermore, facility management journals, presentations, events and workshops will serve as the main literature for the identification of alternative, technological solutions.

In a second step, for the analytical part of this study, technology assessment methods will be applied to present the reader with an overview of the technologies identified, based on evaluations with regard to their benefits and efforts as well as risks for adoption on one hand, and with a detailed analysis of the issues that will be presented later in this thesis and how technology can solve them, on the other hand. The two main technology assessment methods used are the portfolio analysis as well as the relevance tree analysis.

1.3. Structure of the Work

In Chapter 2, Facility Management, the thesis provides a definition for the context of operational facilities management that fits the purpose of this work, to avoid confusion due to the widespread use and ambiguity of this term and its different meanings as well as the complexity of the facilities management industry itself. In a next step, the chapter deals with the development of operational facilities management to date to illustrate the vital role that information technology plays in this industry so far.

Chapter 3, Information Technology in Modern O&M, aims to cover the current state-of-the-art in regard to how information technology is being used in the respective field of operational facilities management. The chapter will continue to introduce the reader into the environment of so-called Computer-Aided Facility Management (CAFM) systems and its most important components that are relevant for understanding of the subsequent chapters. Chapter 3 will then conclude with an outline of the major challenges Facility Managers face to date in regard to their day-to-day operations and his main needs, but also dreams, in regard to the future of IT.

Chapter 4, Technology Assessment, and 5, Issue Analysis with Relevance Trees, will outline the role of technology assessment to identify and also assess emerging technologies and compare the different methods used for such an analysis. Succeeding, this work will present a portfolio analysis approach to give an overview of the novel technologies identified through the literature research process. Last, but not least, a relevance tree analysis will be performed on the issues identified in chapters 2 and 3 to derive possible alternative solutions by applying some of those identified technologies.

In chapter 6, Building Information Modelling, the thesis aims to make the reader familiar with one of the technologies that have been identified, namely BIM, as a proposed solution to solve some of the most pressing issues in today's facility management industry. This section will focus on how Building Information Modelling aims to solve those challenges, its impact on facility managers as well as other stakeholders, and the major concerns and issues that potentially block possible implementations of BIM.

Chapter 7, Augmented Reality, goes into more detail about the technology around AR and its potential impact on solving issues that BIM by itself cannot. This section aims to assess how Augmented Reality can be utilized to increase efficiency in accessing and communicating with mobile interfaces that are used for data management. Furthermore, this section will try to identify the major challenges and what facility managers have to get ready for adoption of AR into their existing system landscapes.

Concluding this work, chapter 8, Conclusion, aims to summarize the highlights of this thesis' research. The author will try to provide final remarks about the potential significance of his findings and discuss, how the findings could affect the course of his own business.

2. Facility Management

This chapter's main goal is to build a theoretical foundation for further research and empirical work in the course of the thesis. It is crucial to establish a consistent understanding for the term of facilities management, due to its widespread use, most likely correlating to the many disciplines that ultimately are a part of FM. Furthermore, this section hopes to generate appreciation for the various responsibilities of Facilities Management by illustrating the evolution of the facilities management industry since the term's first occurrence in history in regard to the design, construction and operations of facilities.

For the remainder of this thesis and for the purpose of reading fluency of this work, the term *O&M* will be used to refer to both operations as well as maintenance in facilities management.

2.1. Historical Background

As is the case with many other industries, the FM market has evolved and changed significantly for the past 30 years. According to Price, it was due to the growth in complexity of buildings and their operational costs that drove the ever-increasing need for facility management and its diverse functions. While today the industry is recognized as an emerging market with multiple, separate, yet also interconnected disciplines, use of the term facility management was not documented until the late 20th century. (Price, 2011, p. 56)

Defining an actual and precise point in time that marks the birth of the FM industry is difficult, if not impossible. However, according to (Nor, Mohammed, & Alias, 2014) there is no doubt to the assumption that the term originated in the U.S. More specifically, the author's findings suggest a possible theory where actually the American railroads that came into service in the middle of the 19th century were the first to experience the need for services that were simply coined Property Management and Services back then. American railroad companies employed train conductors, sales staff, engineers, construction workers and additional functions that were needed to successfully operate their railways. Due to that fact, the companies quickly realized the need for, and thus the emergence of "managers", who coordinated and administered all service related activities on behalf of the railroad firms. Whether or not this holds true, the railroad's job description for facility managers very much resembles those of modern-day managers in the FM market. What is important is the fact that the term facility management is not a hoax, because ultimately FM is about management, as the term suggests. (Nor, Mohammed, & Alias, 2014)

The most widely adopted and accepted definition of the facility management term and its first appearance in history is marked with the foundation of the U.S. National Facility Management Association in May 1980, today known as the International Facility Management Association (IFMA). (Price, 2011)

Today, properties and facilities can take up to fifty percent of a company's fixed assets, and as such may represent one of the largest positions on its balance sheet. Thus, (May & Williams, 2017, p. XXIII) argue that, based on this fact, the operations and maintenance of facilities significantly contributes to the profit or loss calculations, and therefore has moved into a signature position as a strategic, corporate resource.

2.2. Definition

A broad definition for the term *Facilities Management* (FM) is given by the International Facility Management Association (IFMA) as follows:

> *"Facility Management is a profession that encompasses multiple disciplines to ensure functionality of the built environment by people, place, process and technology."*
>
> (IFMA)

The IFMA, based in the U.S. and founded in 1980, is the largest international association for Facilities Management professionals and is active in 104 countries globally. On its web page, following the IFMA's definition for FM, the association further specifies the core competencies of the Facilities Management industry, as defined through a global survey and analysis including facility managers from 62 countries. These include, amongst others, O&M, technology, real estate and property management, environmental stewardship and sustainability, as well as technology. (IFMA)

Considering the vast diversity of responsibilities that the IFMA ascribes to the Facilities Management industry, it becomes evident that there is an immense potential for possible misunderstanding and conflict, when two or more parties discuss about FM. Therefore, it is vital to emphasize that the work of this thesis focuses solely on the operations and maintenance as well as the technology aspect of the Facilities Management industry. (Price, 2011, p. 73)

However, due to various interconnections between these separate disciplines, there will be a necessary overlap with and mention of other FM disciplines throughout this study, such as *Real Estate and Property Management*.

2.3. Operations and Maintenance (O&M)

Within the business segment of operations and maintenance, facility managers are responsible for all day-to-day tasks that are essential to operating real estates and ensuring the proper functionality of all their technical assets. More specifically, this includes the planning, designing and optimization of a building's daily resources as well as all necessary, regulatory and precautionary inspections of its technical equipment and the building's structure to reduce potential security risks for its inhabitants. (Hassanain, Froese, & Vaniert, 2011, pp. 199-200)

Thus, facility managers are confronted with a high number of different trades during their day-to-day work, as buildings, such as office and residential estates, are continually increasing in complexity as far as their technical appliances is concerned. (May & Williams, 2017, p. 41) This is, on one hand, due to the ongoing innovations and advancements in technology that aim to increase the level of comfort of both living as well as working environments, and on the other hand due to ongoing changes in national and international law, which target tenants' safety through regulations for minimum and recommended requirements of technical appliances for certain building dimensions. Following is a list of some of the trades that have to be operated and maintained and thus are of high interest to a facility manager:

- **Fire Alarm Systems –** These are comprised of a range of devices that are capable of detecting and informing tenants as well as responsible personnel, such as facility managers, about the imminent threat of fire, without the need for human intervention. These systems, if present, usually represent the highest hierarchy of automation equipment, and thus, depending on the technical complexity in a facility, may often control and operate other installation as well. Some fire alarm systems, mostly depending on regulatory circumstances and the nature and purpose of the facility, may directly involve a local firefighting department in case of fire, and as such these systems are very much regulated as far as their operational and maintenance requirements are concerned. (OEBFV, 2016)
- **Fire Doors** – Most conventional doorways in modern facilities already are so-called fire doors. Their main purpose is to keep fire smoke as well as fire itself contained in the immediate sector they originate from as long as possible, preventing fire to spread across separate areas

of a building too quickly and thus creating a time window for tenants and office workers to escape or hold out for firefighters to arrive. Due to their very frequent usage, facility managers have to keep a close eye on these doors on relatively short intervals. (OEBFV, 1991, p. 11)

- **Fire Extinguishers** – Acting as the primary means of fighting local and smaller sources of fire, fire extinguishers are almost a necessity in any modern facility. Despite their limited complexity in terms of their handling as well as in terms of the technology involved, regular inspection is crucial to precociously identify possible causes for malfunction. (OEBFV, 2017)
- **Emergency lighting** – Emergency lighting is a term used for equipment that provides the proper means for people to be able to reach a secure area (in most cases outdoor) from anywhere in a building, especially in the case of power outages and/or fire and smoke, and regardless of whether they are familiar with a facility or complete strangers. These appliances, mostly illuminates using either common light bulbs, or in the case of newer, energy-saving products, LED (light-emitting diode) bulbs, are some of the most crucial assets in the rather extensive list of technical appliances. Emergency lighting can be found in any office building as well as public facilities, especially where there's a high frequency of visitors, such as venues or airports, and gain increasing importance in residential buildings as well. (OEBFV, 2005)
- **Pressure Aeriation Systems** – A pressure aeriation system is a specific, highly technological form of a *Smoke and Heat Venting System*, whose main purpose is to keep particular areas free from fire smoke. They are mainly used in buildings and areas that go beyond a certain size, which would otherwise render more simplified venting systems useless. Pressure aeriation systems utilize the principle of high pressure to prevent fire, and especially the resulting smoke, from spreading to potential escape routes, such as staircases, extending the possible timeframe for people, who are in imminent danger, to escape. A system of this kind adds significant complexity to a facility, not least because of its interconnection with multiple appliances. (OEBFV, 2004)

2.4. Stakeholders in Operational FM

In the course of the regular activities of operations of facilities, a number of stakeholders is to be considered, especially when information technology is concerned. Different stakeholders usually take different views and stances regarding goals and expectations, and as such, the requirements for IT to fulfil all of these goals are versatile as well. (Smith, 2011)

(Smith, 2011, p. 43) argues that both clients or building owners, as well as tenants and occupants serve as the primary stakeholders with regard to facilities in general. Operation management must take into account both of these parties just as much, even though the primary line of communication runs between facility managers and their clients. These may either be the property owners themselves, or any third party that is assigned with the overall real estate and property management. With regard to customers and clients on one side, facility managers have increased reporting duties to regularly update and give feedback about the status of a facility, possible defects and regular maintenance tasks. Tenants, on the other side, interact with operational FM in a mainly indirect fashion, usually in case where there is an issue with equipment that directly affects and prevents tenants from using the facility in an intended way.

However, based on the life cycle of facilities, additional stakeholders should be taken into account as well. These include, during the construction phase, the general contractor in charge of construction, as well as other project partners involved and, during the operations lifecycle, the maintenance firms that are instructed by the operating facility manager to execute the necessary, proactive maintenance tasks.

2.5. Significance of IT

The above-mentioned trades' main commonality is their requirement to be monitored as well as maintained in regular intervals. These intervals are mainly derived through regulations of both national and international governance, and thus depend on the country, and sometimes even province, where such regulations apply. Considering the fact that the previous listing of trades is only a cut-out of some of the most common and important trades that are considered to be essential for modern real estates, depending on the country and the regulations applied, it becomes clear that there is enormous responsibility for the facility manager in charge of a building's operations and its maintenance alone.

Even though the majority of his working time is spent managing (as the term *Facility Manager* already suggests) rather than actually maintaining his building's appliances himself, his task becomes increasingly more impossible to fulfil without the proper systems in place. Especially due to the fact that, in many cases, facility managers will not be in charge of only one building, but rather multiple estates at the same time. Regardless of whether a certain trade is maintained by an authorized delegate of the facility manager, which is obligatory in some cases due to specific regulations, or the facility manager himself, it is his responsibility to assure the working state of all appliances in place as well as to coordinate their regular maintenance intervals.

To cope with the increasing complexity and responsibilities of a facility manager's work, suitable supporting systems were becoming necessary, and thus, as happened in almost all other industries, Information Technology (IT) gained increasing importance in the FM market over the years. (Smith, 2011, p. 126)

3. Information Technology in Modern O&M

The facility management market is no exception to the fact that the evolution of information technology and its influence on the world market and people's daily lives over the past decades has been tremendous. Therefore, this chapter focuses on current state of technology in the facility management market with an emphasis on the operations and maintenance discipline. This section of the thesis aims to connect the current state of the art with the subsequent research of novel and innovative technology and processes that have the potential to change the FM market's landscape.

3.1. State of the Art

Due to the rapid evolvement of building technology and a shift in real estate owner's mindsets regarding their facilities' maintenance and operation, the facility management market has developed to become an enormous and important part of today's world economy. According to a recent IFMA study, the global FM market currently sits at an annual worth of around $1.12 trillion. (IFMA, 2016) One of the key factors is the rise in outsourcing of FM services such as maintenance and operations, but also hot topics such as energy management. Real estate owners continue to realize not only their obligations towards their tenants, but also the tremendous potential that often hides within their buildings. By utilizing the knowledge of facility management professionals, property managers and owners can secure, and even further increase, their facilities' value. (May & Williams, 2017, p. 42)

Today, facility managers face the challenge to simultaneously operate many, diverse facilities that are completely different from each other. (Smith, 2011, p. 126)
Yet, property managers expect, and sometimes the law requires as well, that facility managers are up to date about their facilities on up to a daily basis. Whenever there is a sudden issue or a fault with one of the facility's appliances, a facility manager has to react as fast and accurately as possible. When tracking assets and reporting back to their clients on paper was becoming next to impossible to do, the FM market was in dire need of suitable support to enable facility managers with fulfilling their increasingly difficult and complex tasks. (May & Williams, 2017, p. 43)

As far as a facility's O&M is concerned, FM professionals have to deal with and keep track of a very diverse set of data, depending on the technical appliances that are present in a certain building. Moreover, regular maintenance intervals have to be coordinated and strategically planned by the facility manager on an almost daily basis. To manage a facility manager's efforts, several software development companies have created different sets of applications that have since been categorized as so-called “Computer-Aided Facility Management” (CAFM) systems. One of this software category’s main purpose is the support of all management activities that are related to the strategic operations and maintenance of facilities.

3.2. Computer-Aided Facility Management (CAFM)

CAFM systems provide a range of tools that enable facility managers to manage data for buildings and technical appliances related to their operational and maintenance responsibilities.

A suitable CAFM system enables its users, amongst other tasks, to do the following:

- **Storage and access of substantial amounts of data** – Depending on the level of detail regarding the information that is gathered through operating and maintaining a building, storing that data electronically can result in gigabytes and even terabytes (one-thousand gigabyte) of data. Such an amount of information is simply not manageable through paper records. A LexisNexis fact sheet (LexisNexis, 2007) claims that an average text file, with regards to formatting, in the common .doc format with an electronic size of only one gigabyte would result in over 60,000 printed pages. For example, the electronic size of the data gathered by the author’s firm in the O&M market with 10 employees over a four-year timespan has accumulated to around 2.7 gigabytes. Mid-and large-sized companies in the FM market are expected to handle databases with a size that is a multiple of this example size, with some of them gathering such amounts of data on even a daily basis. Due to the ongoing developments in the field of technology, databases will be required to handle even more in the years to come. (May & Williams, 2017, pp. 52-58)
- **Easily understandable presentation (graphical interfaces) of data** – Due to the fact that a majority of FM professionals are not experts in information technology, and are mere users of such applications, graphical presentation and means for working with the electronic information is obligatory. Such graphical user interfaces have to provide the functionalities discussed in this section. While, initially, such interfaces have almost exclusively existed for personal computers, modern CAFM systems have expanded to provide facility managers much needed mobile support, as will be discussed later in the chapter. (May & Williams, 2017, pp. 60-63)
- **Reporting to clients** – On one hand, clients can only appreciate the effort that facility management is putting in to sustain their facilities’ value if they are provided with the necessary feedback and reports. It is crucial for a suitable information system to provide the

means to generate meaningful reports that promote a clear message and thus are easily understood by the client. On the other hand, certain responsibilities not only appreciate, but even require to be reported back to the property owners, such as fire safety inspections, during which all of the above-mentioned trades are regularly inspected for visible faults. (Hassanain, Froese, & Vaniert, 2011, p. 203)

- **Application support for mobile devices** – Since most of the work FM professionals execute is done on-site, IT system providers have quickly caught up with the mobile market, when the technology was finally available, to provide the possibility to work with electronic data on the go. The main purpose for mobile applications is to provide a lean set of tasks and relevant data for the facility manager to work with. This step is a huge synergy gain for system users, as it allows for the O&M discipline to pretty much move away from paper and work with electronic information only. Thus, data can be gathered directly in the facility, automatically stored in the system environment, and if need be, further processed at a later stage. (May & Williams, 2017, pp. 79-80)

Below is an exemplary architecture of a common CAFM system:

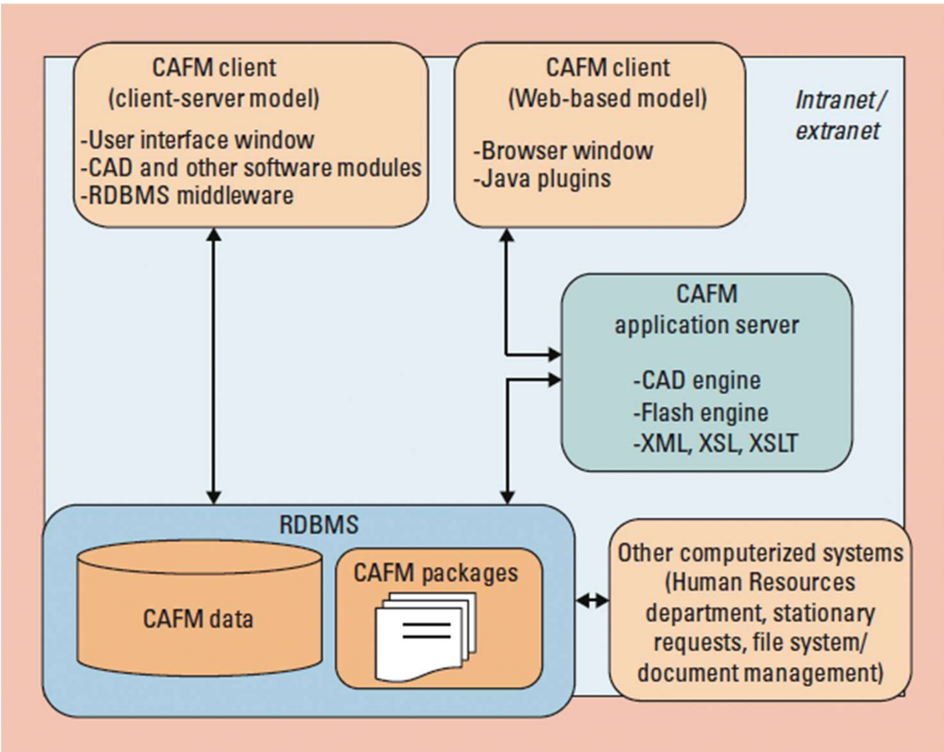

Figure 1: CAFM System Architecture as illustrated by (D'Urso, 2011, p. 49)

3.2.1. Database

At the core of any information system is a database, which is required and responsible to store substantial amounts of data electronically and in such a way that this data can be easily retrieved, changed and processed. Databases come in many different forms, and their technology as well has been significantly improved since their early days. A state-of-the-art database in many of today's use cases is a so-called *Relational Database Management System (RDBMS)*, which groups and stores information as specific, pre-defined datasets that may or may not be connected with each other through a unique-key-relationship. (May & Williams, 2017, pp. 58-60)

In most real-life applications, complex database structures usually lead to a certain distribution of data into different datasets, which is where relations come into play that lend a RDBMS-type database its name. Through unique keys that are provided to any dataset the database is able to establish a relationship between two separate, yet, from a contextual point of view, connected datasets. Whereat, at first glance, the methodology might sound somewhat unhelpful, this functionality ultimately allows the connection of seemingly unrelated data from multiple, separate datasets, to purposeful new information.

At this point it is suggested that, for further information regarding the principles of Relational Database Management Systems and their uses, the reader is referred to more fundamental literature. (Dr. Sumathi & Esakkirajan, 2007)

3.2.2. Graphical User Interface (GUI)

As a main tool for the strategic planning of daily operations for facility managers and to generate and work with the facilities' electronic data, CAFM systems provide FM professionals access to their task management mainly through graphical user interfaces (GUI). Whereat initially such interfaces were provided almost exclusively for the more powerful office work stations, user interfaces have extended to the web as well as to the mobile technology infrastructure to allow facility managers and clients remote access to their facilities' information. More on web and mobile interfaces is provided in the subsequent chapters. (May & Williams, The Facility Manager's Guide to Information Technology, 2017, pp. 60-79)

A GUI's main purpose, especially those interfaces that are suited for use on a desktop computer, is the graphical access to all of the information that is stored in the system environment's database, or possibly even multiple databases in the case of larger firms. (Smith, 2011, p. 139)

For each facility, the database holds information of all their technical appliances, as visualized by the model below:

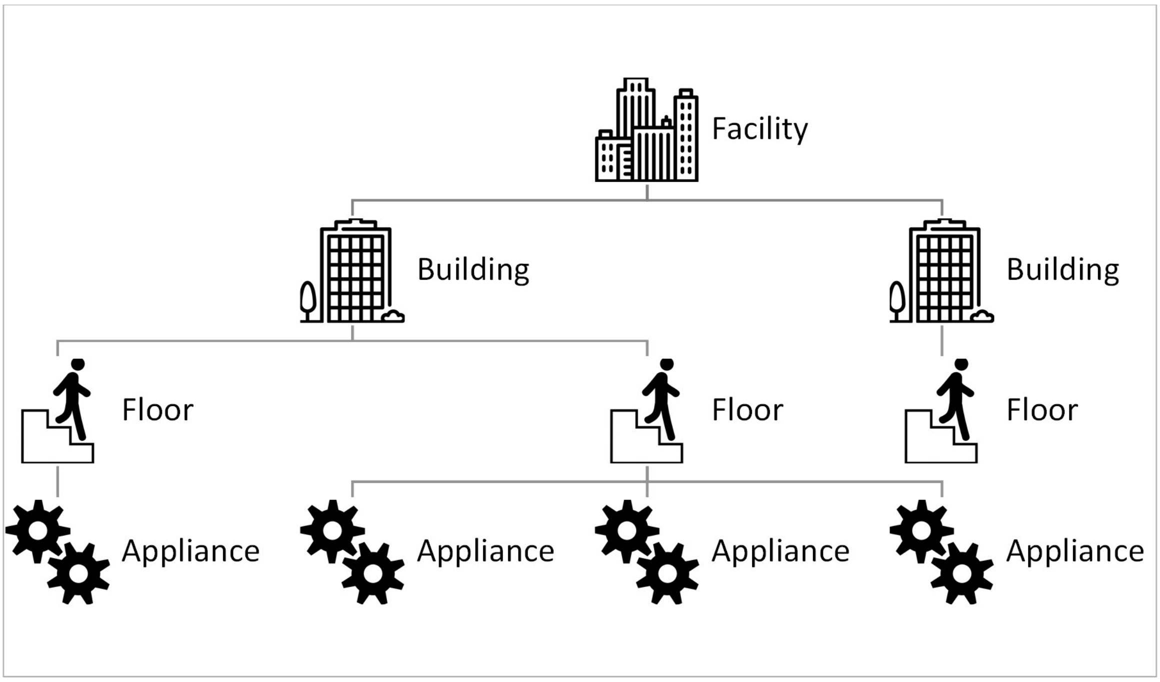

Figure 2: CAFM Data Hierarchy

However, such powerful graphical interfaces are not limited in their capabilities to simply manage rows of information in regard to a facility's structure. Depending on the GUI's purpose, facility managers can utilize reporting and task scheduling processes to visualize certain data and automate their strategic planning as far as their regular and recurring inspection and maintenance tasks are concerned. Instead of having to keep track of due dates for inspections and maintenance of technical equipment, a modern-day CAFM system is capable of generating the necessary tasks based on pre-defined time intervals, and reminding its users when they are due. Depending on the functionalities provided by a particular CAFM system, an abundance of processes can be implemented and tailored to a facility manager's needs. For example, the author's CAFM system in use in his firm was configured to utilize a mail service interface for sending automated reminders and similar messages to the responsible employees via mail. (May & Williams, 2017, pp. 117-118)

However, due to the fact that these tools have a restricted usage that is usually limited to the office workstations, there was a major downside for FM professionals as well. Since most of their working time is spent within the actual facilities they are responsible for, rather than at their office, there was only limited to no support by information technology on-site. Only due to the smartphone craze during the last decade it was possible that the CAFM system environment could be extended beyond the facility manager's local office.

3.2.3. Mobile Applications

As a result of the rapid advancements in mobile device technology in the beginning of the 21st century, IT support for the FM professional's daily activities has since spread from stationary office computers to the wide array of mobile devices, such as smartphones and tablet computers. (May & Williams, 2017, p. 78)

Challenges for Mobile Hardware

Even though mobile devices existed very well before the arrival of smartphones and tablet computers, mobile support for the FM market never really took off. These predecessors, called Personal Digital Assistants (PDA's), were developed by many of today's most well-known and powerful tech companies such as HP, IBM or Apple during the last two decades of the 20st century, and discontinued thereafter due to the rising popularity of their "smart" successors. (Nosrati, Karimi, & Hasanvand, 2012, p. 399)

Their functionalities, even though revolutionary and innovative at the time, and thus also important for the later developments of the mobile devices we know today, were not suitable for widespread use of FM applications due to several reasons: (Nosrati, Karimi, & Hasanvand, 2012, p. 406)

- **Lack of input methods** – Many of the different PDA's that did make it to the market were lacking sufficient input methods. Small keyboards and screens without the now standard touchscreen functionality, at least for earlier devices, were awkward to use at times and thus less comfortable than just writing on paper.
- **Limited storage capabilities and network bandwidth** – The rather tight storage restrictions on earlier mobile hardware prohibited facility managers from carrying around a majority of the information on their devices, which they needed to efficiently perform their work. On top of that, due to the low to non-existent network bandwidth that was available by mobile networks at the time, depending on the location of facilities, there was very limited possibility of accessing data on-demand.
- **Low battery durability** – Another restriction of past mobile devices were their limited energy resources. The available amount of battery was just insufficient to power high-capacity applications for a suitable amount of time. Even with the current advancements in battery

technology to-date, facility managers might run dry prematurely when using their smartphones and tablets constantly throughout the course of a work day.

Smartphones and Tablets

With the arrival of smartphones, and tablets shortly thereafter, and especially since the emergence of and dominance of the mobile operating systems market by Apple's iOS, Google's Android and, to a smaller extent, Microsoft's Windows Mobile, application developers of Computer-Aided Facility Management systems have gained a completely new market for developing their mobile solutions. Larger screens with novel technology such as touch functionality, enhanced storage capabilities, the arrival of super-fast mobile networks that can even surpass the bandwidth of some physical networks, and processing power similar to state-of-the-art work stations are only some of the reasons for almost unlimited, new possibilities. (Stack, 2012, p. 482)

As was already mentioned in a previous section, mobile applications are extending the reach of a CAFM system environment beyond the FM professional's own office. In fact, the majority of time a facility manager spends working with his CAFM system arguably could be spent with such mobile solutions, depending on how much of his administrative work is actually done by the system itself.
Below is a summary of some of the most important O&M processes that today's mobile solutions for the FM market have already covered:

- **Access relevant information on-demand** – Despite the growing storage capabilities of mobile devices that already allow the storage and synchronization of a majority of relevant information on the mobile device, some applications go beyond that and query some of that information from the remote database only when needed. On the one hand, this process keeps the application storage clear from an unnecessary bulk of seldom accessed data, and on the other hand, due to the synchronization requirements to keep information on both the mobile device as well as the central CAFM database consistent, this also reduces the overhead on the network bandwidth. (May & Williams, 2017, p. 79)
- **Defect management** – From an operations point of view, facilities are in fact living entities. Due to the frequency of daily activities that occur inside a facility, all its appliances and even the structure itself are prone to defects and damage. Regardless of whether they happen due to external factors or, seldom, due to premature failure, defects have a facility manager's top priority. Although the task to record and track defects on mobile devices is not a complex one, it

is one of the most fundamental processes that facility managers go through several times a day. (May & Williams, 2017, p. 86)

- **Regular inspection and maintenance tasks** – Another key process that mobile applications support FM professionals with is working off their responsible, recurring inspections and maintenance tasks. Due to the potentially high number of facilities, even greater number of appliances within their buildings, and these appliances' wide variety of trades, keeping track of all these items, their due dates and the single tasks that need to be performed is becoming increasingly more difficult. Providing a list of assignments that are due within a certain time frame and guiding facility managers in working off these tasks based on check-lists that provide detailed steps allows them to document everything they do electronically. (May & Williams, 2017, p. 86)

3.3. O&M Challenges Deriving from a Lack of IT

Despite all the existing technology and systems to-date, information technology and FM are far from their peak values. The past years have led to exiting and innovative ways for IT to support FM companies and provide major value to the market. However, technology is one of the fastest growing industries and as such the facility management market will inevitably be affected. Whether it be through new appliances that further enhance the safety for tenants, or novel ways of lighting as well as heating and air-conditioning that reduce the overall energy and thus life cycle costs of facilities, facilities will keep changing as they have in the past. And with an increasing interest in property owners to outsource their FM tasks, companies will want to aim for the best possible support they can gain through technology. (May & Williams, 2017, pp. 31-33)

Even though CAFM systems have added immense support for operating facilities throughout their lifecycles, there still is much room for improvement. (BIFM, 2013, p. 2)
Due to the fact that an extensive list of issues is out of the scope of this thesis, the following chapters will evaluate in more detail two of the most pressing issues in today's facility management.

3.3.1. Knowledge Transfer during A Facility's Lifecycle from Planning to Operating

Currently, there is next to no synergy gained from transitioning throughout a facility's lifecycle from planning to operations. This is in parts due to the fact that the amount of electronic data that is gathered throughout the planning and construction lifecycles is limited. This mainly leads to the fact that the facility managers in charge of a new facility have to rely on the bits and pieces that have been gathered throughout construction and dubbed as *Technical Documentation*. At best, this documentation contains printed plans and itemizations that can be used to derive the proportions of how simple or complex the O&M lifecycle for a specific facility is going to be. At worst, there is almost no information to extract that has any relevance for operations. Thus, a significant amount of effort is required for facility managers to gather all the necessary information and establish a complete electronic record in the CAFM system. (May & Williams, 2017, pp. 115-116)

However, due to the fact that the nature of this issue is not only present in Austria, but rather has significance in many countries, the concept of Building Information Modelling (BIM) has been around for 15 years, and recently been adopted by the British Government to include this methodology in all its government construction projects. The term Building Information Modelling has already been established in the late 20st century, but has only been brought into the context it is known for today by the software development company Autodesk Inc. (Autodesk, Inc., 2002) to describe its approach of applying information technology to the construction industry. BIM in particular is an approach to capture all elements of the planning and construction processes, including drawings and all specifications that define the buildings, meaning their structures, and their appliances, and stores that data in a central database. Information about single trades is no longer kept in separate files, but is centralized within this environment, thus creating a complete electronic record of new facilities prior to the operations lifecycle.

BIM currently is one of, if not the most talked about methodology in the world of facility management around the globe, and it promises significant value to the overall building lifecycle. Hence, BIM, its advantages, pitfalls and how it can be implemented in FM companies with focus on the Austrian area will be explored in more detail in the next chapters. (BIFM, 2013, p. 4)

3.3.2. Operational Asset Tracking

Due to the diversity and enormous number of appliances that facility managers have to operate and maintain, tracking these appliances is becoming more difficult by the day, as their complexity and numbers increase only further. Even though best-practices and applications, such as GPS navigation and near-field communication, have enabled more sophisticated processes already, these are not always suitable for the task. GPS, for instance, might not be available throughout an entire building, especially in such areas that are either below the surface or surrounded by solid walls. (Ozdenizci, Ok, Coskun, & Aydin, 2011, p. 11)

Furthermore, near-field communication methods such as RFID (Radio-Frequency identification) and Bluetooth beacons that carry a unique identifier, which is received by a mobile device and mapped to a certain appliance in the database, as well as simpler methods of identifying objects such as using QR Code or barcode scanners are increasingly difficult to apply in public areas that are accessible to all occupants of a building. For instance, experience from the author in the field of operating residential buildings has shown that using QR codes for asset tracking, which are not only visible to the facility manager, but to all tenants, often result in these codes violently being removed. In most cases, tenants are not aware of the functional purpose these codes fulfil, but these codes also negatively influence a building's overall appearance, if used excessively. On top of that, using more complex technology, such as RFID chips or Bluetooth beacons for thousands of assets quickly is becoming a major cost factor. A factor that, once construction is completed, is expected to be as insignificant as possible. (Ozdenizci, Ok, Coskun, & Aydin, 2011, p. 11)

3.4. Emerging Technology Literature

During the literature research, a number of sources have been included to gather a number of new and emerging technologies that have either yet to prove their use within the facility management industry, or are still only in a development stage.

The list of research material includes, but is not limited to, a number of IFMA publications of its *Facility Management Journal (FMJ)*, *The Facility Manager's Guide to Information Technology (2nd Edition)*, trend reports from the British Institute of Facility Management's *FM Leaders Forum*, as well as a number of online resources from separate, independent expert websites.

4. Technology Assessment

This chapter introduces the reader to the main course of investigation in regard to current trends in Information Technology, which promise to provide significant value for the issues presented in this paper, and explains in detail the different IT trends that have been picked by the author. For each trend, this chapter will provide a definition and its possible fields of application.

4.1. Definition

To assess existing as well as emerging technologies and methodologies, the discipline of Technology Assessment (TA) has been around for many decades. It serves not only as a scientific approach, but also as an interactive and communicative approach to forecast the potential impact of new and emerging technologies. The TA process is versatile and incorporates a variety of different methods, with each fulfilling a different purpose. Initially, early technology assessment methods mainly focused on the public sector, and as such, TA was mostly a government discipline, as, for instance, was the case with the now defunct Office of Technology Assessment (OTA), a former office of the U.S. congress from 1972 to 1995. Its main purpose included the objective analysis of the evolving issues, both from a scientific as well as technical nature, during its term. Since then, the process around assessing various kinds of technologies has spread and is now found not only in the public sector, but increasingly in areas for business purposes and business concerns.

Prior to the emergence of TA as a process for business professionals, technology assessment was considered and has spread as a means to evaluate the potential impacts and consequences of the introduction of new technologies and the extension of existing technology on society from the most extensive scope possible, in the context of public decision making. (Tran & Daim, 2008, p. 1397)

4.2. Forms of TA

The development of Technology Assessment over the past decades has brought forth a versatile portfolio of methods and approaches to the TA terminology. This section gives to the reader an overview of current methods and tools that have been established throughout the history of TA.

- **Participatory TA (pTA)** – Participatory Technology Assessment comprises a set of interactive tools and methods. These methods usually involve a range of stakeholders, experts and citizens in a set of discussions, to evaluate a given problem based on three dimensions: cognitive, normative, and voluntary, and through the questions of what can be done, what should be done, and what is to be done, respectively. Such methods include consensus conferences, scenario workshops, focus groups and other interactive forms for discussion, and sometimes are further split into expert-stakeholder *pTA*, which focus on the scientific expertise on given issues, and public *pTA*, including citizens. (Abels & Bora, 2013, pp. 109-111)

- **Parliamentary TA (PTA)** – Parliamentary Technology Assessment activities, as briefly described above, are a result of an increasing importance of technology and science for the development of society in all aspects, such as health, business, research and wealth. Public institutions are confronted not only with possible scenarios involving future technology, but also with the question in regard to their use and limitations. (Grunwald, 2013, pp. 91-94)
- **Constructive TA (CTA)** – The purpose of Constructive Technology Assessment is the aim to proactively get involved in the innovation and development process. Specific, societal problems usually form the starting point for inter-disciplinary analysis and design processes, which should involve all relevant stakeholders. As such, the portfolio of methods in the CTA process is versatile and involves, amongst others, collective discussion and scenario approaches. (Kuhlmann, 2013, pp. 129-130)

4.3. Technology Portfolio Analysis

A portfolio analysis typically presents a number of options (products, technologies, methods, etc.) on a two-dimensional matrix, where each option is plotted relative to its underlying, mathematical assumptions that are calculated based on the before-mentioned KPI's for both the horizontal as well as vertical axis. Usually, there are several measurement variables that compute the ultimate value for any one option on the 2 axes.

The technology portfolio analysis as proposed by Pfeiffer et al. focuses in particular on a company's products and processes, both existing as well as emerging ones, along the two axes of Technology Attractiveness and Resource Capability. Pfeiffer et al. further suggest that the two dimensions are composed through several, separate indicators that can differ based on the area of analysis as well as the company's business area. On top of that, additional indicators may be defined and included in the matrix calculation to appropriately cover the key factors for any specific portfolio analysis. (Pfeiffer & Dögl, 1990, pp. 259-260)

The following figure shows the typical structure of such a technology portfolio:

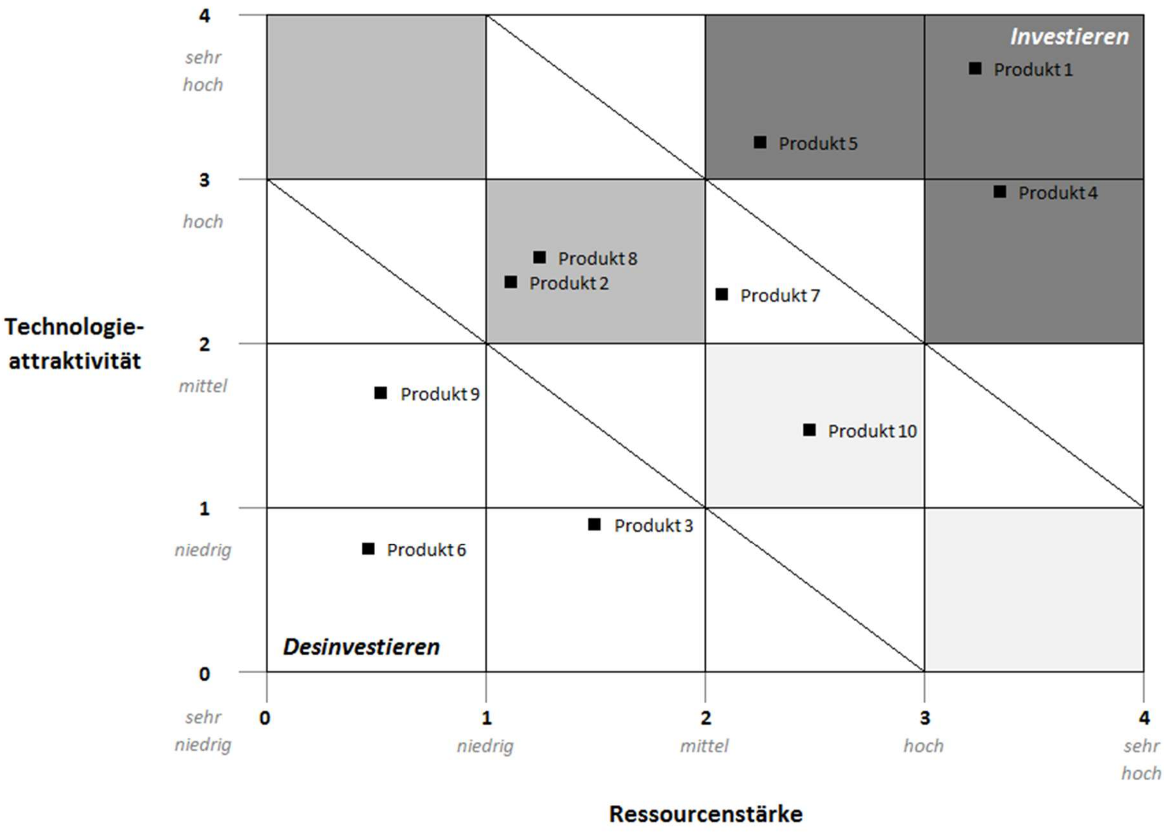

Figure 3: Technology Portfolio according to Pfeiffer (property of controlling-portal.de)

While the technology attractiveness, on the y-axis, represents the sum of all possible benefits that the evaluated technologies may deliver during their development stages, the resource capability dimension, on the x-axis, represents the sum of resources, both economic and financial, that the company owns with regard to each technology and process.

As a result of the positioning of a company's set of products and processes on the matrix shown above, the portfolio approach suggests the interpretation of results based on three separate areas within the matrix. Products that are positioned in the bottom-left area of the matrix, suggesting that the technology or product does not promise a high level of benefits from future developments and a low resource-level from a company's point of view, should slowly be retired from the company's portfolio and its resources allocated to more promising technologies and products.
In contrary, those products that appear on the top-right area of the matrix are expected to deliver high value from future development efforts and as such should be promoted and supported as much as possible, for example by allocating additional resources.
Last, but not least, products that appear in the middle area, also called "selection", have to be analysed in more detail prior to further decision making. Those products that feature a high level of attractiveness but a low level of company-related resources should only be invested into, if, as a result, the product can catch up to its competitors. Otherwise, a company only risks of further falling short to the competition in high volatility areas, despite their investment. On the other end of the field, products with a low level of attractiveness, but a significant advantage in company-related resources compared to competitors, may present further investment opportunities, if the lead can be sustained and the technology/product is not in danger of substitution, meaning that novel technology may replace them in the near future. (Pfeiffer & Dögl, 1990, p. 269)

To reach consensus about some of the potentially most impactful innovations present in the FM industry, this chapter will attempt a technology portfolio approach to give an overview of possible innovations in IT, based on predefined key performance indicators (KPI).

The main input method used in the course of this work for gaining insight about potential innovations was the screening of state-of-the-art literature, journals as well as articles on the field of IT in facility management.

The portfolio matrix concept was applied to the screening process of this thesis to deliver an outline for the state-of-the-art in emerging technologies for the FM market. More precisely, the short- to medium-term technologies that have been identified throughout the screening process were plotted along the two axes of both effort and benefit, depending on a set of measurement variables that are described in more detail below.

4.3.1. Dimensions and Metrics

Due to the fact that the technology portfolio presented above is only suitable on a company level, but not so much on an independent industry level, this section proposes an alteration to the original technology portfolio by introducing the Effort/Risk dimension as a replacement for the company's resource capabilities as the main driver for potential investments into new technologies.

The following metrics, in regard to emerging technologies for the Operations & Maintenance market, and ranging from values 1 to 5 (low to high) have been proposed by the author as a result of personal education and experience in the fields of IT and FM:

Speed to market (Benefit) – Due to the rapid advancements in technology in general, facility management companies are expecting short- to medium-term improvements of their processes through technology. Furthermore, the longer the waiting time for expected technologies to be market-ready, the greater the potential for unexpected disruptions through novel, other technologies. Technologies will be rated low if they are only in a research phase where possibilities and limitations have not yet been well-defined. A higher rating indicates that the purpose for facility management is well defined and the technology has at least been subject to pilot testing in real-world environments.

Cost reduction potential (Benefit) – Technologies that compel with significant cost saving potentials add to the attractiveness and the benefit for adoption by facility management professionals. If, by adopting novel technologies and ways to increase efficiency and accuracy of executed tasks, facility managers can free up various resources to allocate for other tasks, the adoption of such technology should ultimately lead to better cost performances in comparison to competition. A low rated potential indicates a limited impact on cost savings due to a narrow field of applications or a high uncertainty in the technology's future potential, whereas technologies, that may be adopted for multiple, possibly high-impact applications, are rated higher.

Expected value for facility managers (Benefit) – In accordance with the key issues for facility managers outlined in the previous chapters, benefit for the facility managers themselves can only be expected if technology improves their daily business processes. In essence, value for facility managers is generated in a multitude of ways and should consist of an efficiency gain expected by facility managers through using novel technology, the satisfaction of stakeholders, especially clients, with regard to the work that is delivered, as well as a healthy work-life-balance. Because if users are satisfied and feel empowered through technology, their possible output will most likely be significantly higher than those that feel restricted and powerless at work. Therefore, a high value suggests that not only will a certain technology boost a facility manager's output, but also that this technology is positively affecting the collaboration between FM and its clients, whereas

Perceived value for clients/property owners (Benefit) – Furthermore, FM service providers should expect novel technology to increase value not only for their businesses directly, but also for their clients, as they increasingly become aware of their properties' value. For example, technologies that help to increase a facility manager's efficiency with day-to-day tasks as well as help to reduce costs on the client's side can be expected to deliver additional benefit. As such, clients should be considered as a major stakeholder when aligning future technology adoption plans. Therefore, technologies that are not or only limitedly visible to the client stakeholders are rated lower, given the assumption that the actual value that is generated is often not tangible to the client, unless the technology is being understood. High values indicate that the client very well understands his benefit for a technology's adoption by FM, either due to tangible results or a direct involvement of the client in the course of this technology's usage.

Implementation and adoption costs (Effort) – One of the major barriers for adopting any kind of novel technology that has yet to prove itself is the costs for adopting and implementing this technology within the current business settings. Regardless of the possible benefit, these costs should always be considered as a separate risk factor for the ultimate success or failure of adopting new technology. As such, lower values indicate both a low initial cost factor for acquiring certain technologies as well as a limited complexity with regard to the actual implementation into the existing environment. On the contrary, necessary and expensive up-front investments paired with a significant amount of effort and expense to adapt a technology to specific needs speak for higher ratings.

Impact on adjacent FM disciplines (Effort) – Due to the existing connections between operating properties and planning as well as building them, some technologies that promise to relief a facility manager's work load are dependent on other disciplines, and as such can only deliver their full potential if there is a shared willingness to adopt these technologies across all disciplines involved. A low rating for this indicator assumes that a technology affects only its immediate environment, and thus limits the amount of stakeholders involved, whereas a higher rating indicates not only a higher amount and diversity of stakeholders, but also a possible involvement of other disciplines, such as in collaborations between construction and operations.

Development uncertainty (Effort) – While some trends are already in adoption phases and have in parts proven to deliver value to the FM market, other technologies remain, at least in part, in the theoretical world for now, further adding to the costs of adoption a potential risk that the promised value ultimately cannot be delivered at the end of a technology's development stage. This indicator may be considered in a reciprocal effect with the *Speed to market* indicator, meaning that a faster time-to-market correlates to a rather low amount of development uncertainty, due to the fact that the possible changes in a certain technology are limited. A high rating, however, suggests that a technology is still in its infancy, and thus the possible time-to-market is significantly slower, while at the same time the possible changes to the underlying technology can affect future adoption both positively, but very well also negatively.

Technological interdependencies (Effort) – Certain trends, for example more well-known ones such as the Internet of Things (IoT), additionally depend on the existence or incorporation of certain conditions and technologies. This factor becomes increasingly important as technology trends that have been identified could develop interdependencies with each other, in order to truly deliver the value that could be expected. Thus, a higher rating suggests that a technology should not be considered as a stand-alone solution, but rather a fraction of a complex environment that incorporates other technologies in interplay. Technologies that are rated low in this regard will deliver the suggested benefit regardless of the existing environment.

4.3.2. Emerging Technologies Portfolio

The succeeding figure is an attempt to visualize possible innovations in IT for FM, based on their benefits and efforts:

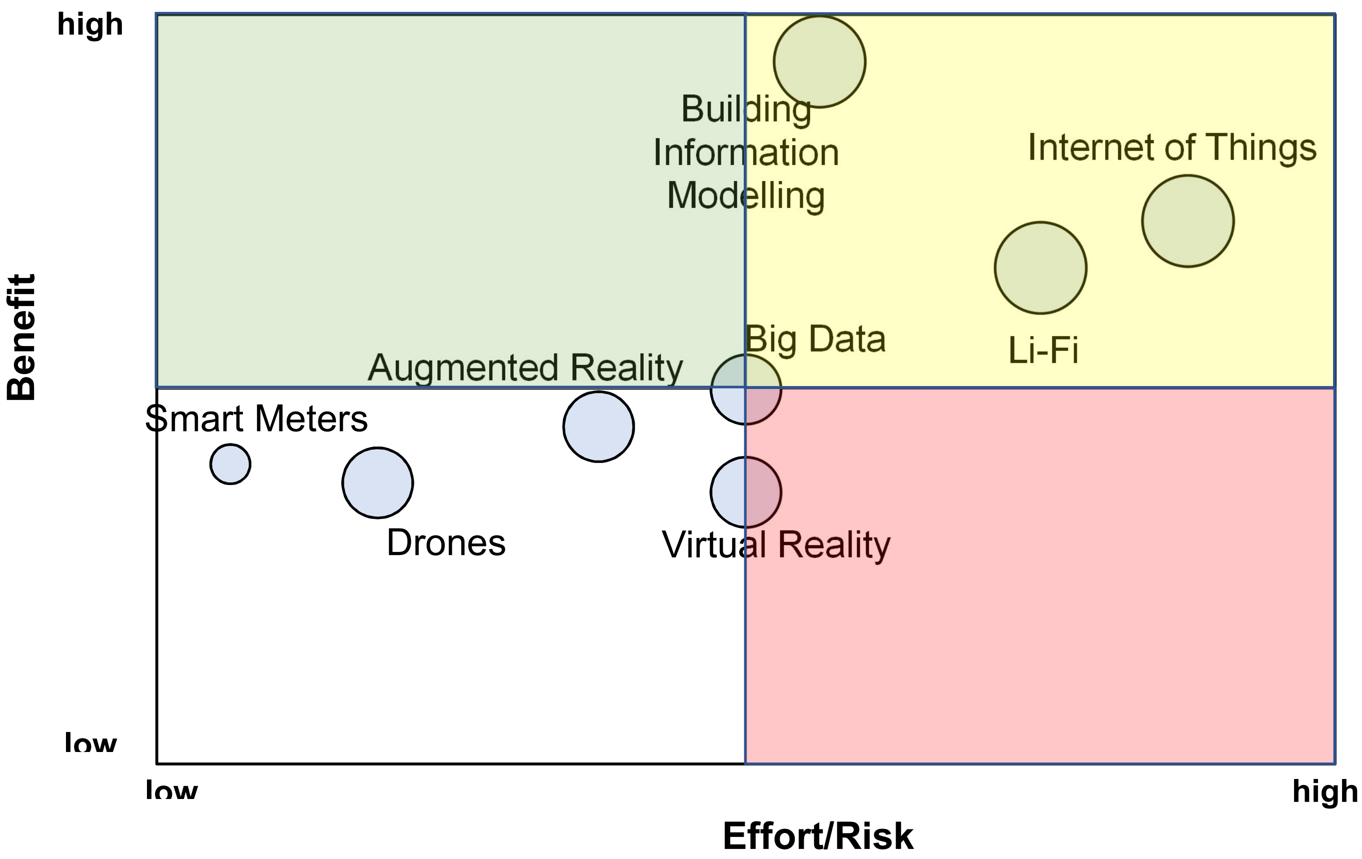

Figure 4: Emerging Technologies Portfolio

The emerging technologies identified have been valued according to the metric system introduced above, valued based on experience and assumptions of the author, and aligned on the technology portfolio accordingly. Technologies in the top-left quadrant would have been valued as high-impact and low-risk, suggest them ideal for near-term implementation, whereas those technologies, which appear in the bottom-right quadrant, would be considered as high-risk and high-effort compared to only a low overall benefit for the O&M discipline, thus suggesting that, at least in the short-term, these technologies may not suit current expectations. It is suggested that particular attention is also turned to the top-right area of the portfolio, considering the possible high-benefit and high-risk technologies. Further development might result in some of these technologies to become more or less attractive, and as such could be considered for a medium-term implementation strategy. However, the distinction between technologies into separate areas in this case is to be taken with a pinch of salt, considering the lack of leeway, suggesting that single technologies should be analysed separate and in more detail.

Building Information Modelling (BIM) – Building Information Modelling is an attempt to deliver a unified technology platform that covers all of a property's life cycles in order to decrease construction costs, as the potential for design errors is expected to decrease, as well as to increase the level of information that is available for facility managers at the beginning of the operating life cycle by providing an extensive property knowledge database that was built up during the planning and construction stages. The methodology has already been around for more than a decade and countries such as the United States and United Kingdom have started to incorporate parts of the BIM methodology in public construction projects. Isolated pilot projects and research groups in Austria have been established meanwhile to close the local knowledge gap regarding BIM. Its positioning in the portfolio suggests a significant benefit to the FM industry, while being subject to a high amount of effort. This is due to the enormous environment that BIM affects, including a multitude of stakeholders and the related effort to implement this system at all parties involved, including the construction and operations disciplines. (U.S. National Institute of Building Sciences, 2014)

Light Fidelity (Li-Fi) – As the name suggests, Light Fidelity (Li-Fi) is a rather recent proposal by science to transmit data through light, more specifically through Light-Emitting-Diodes (LED's). By switching them on and off on a rate that is faster than human eye can detect, researchers have succeeded in transmitting data through light on a faster speed than current developments in Wireless technology allow. Due to the fact that light is a crucial component in any property and that LED's are becoming increasingly more popular because of their significant cost reduction potential during operations, this technology could potentially solve a number of issues that are related to indoor navigation, asset tracking or even more intelligent buildings, simply by establishing a vast data network across properties. The positioning within the portfolio suggests that Li-Fi, at least at this point in time, may be considered a high-impact and high-risk technology. Even if possible applications and benefits seem evident and attractive, the number of buildings with LED-only lighting is still limited, while at the same time a part of the value that Li-Fi could deliver is subject to other technologies, such as IoT, since a data network by itself might appeal to a building's tenants, but not so much to facility managers for doing their work. (Lind, 2017)

Internet of Things (IoT) – The term Internet of Things (IoT) has been around for a few years and has so far gathered a lot of attention from both the public as well as the business market. To summarize, the IoT encompasses all physical assets that form a global information infrastructure through interconnections that allow any IoT based device to gather and exchange data. (Harvard Business Review, 2014, p. 1) Prominent usage of so-called "IoT devices" in the private sector started with the home-automation or "smart home" trend, where intelligent devices are used for automatic control of certain building aspects, such as lighting, heating and ventilation as well as remote control of those systems without the need for physical access. According to (Gartner, Inc., 2017), a renowned consulting firm, an approximate 8.4bn IoT devices will be deployed by 2017, up 30% from 2016, suggesting that the push into new IoT-based services will continue. Given the possibility that manufacturers of certain trades, which have been mentioned throughout this thesis, invest in developing smarter systems that could end up diagnosing themselves for potential, upcoming failures and possibly even repair themselves, the role for facility managers in the Operations & Maintenance discipline will change drastically. However, given the fact that there are a multitude of different stakeholders involved and given the necessity for access to a data network for all future IoT devices throughout a property, constructing and operating such smart properties may be a mid-term possibility, rather than a short-term guarantee. As a result, its position in the portfolio reflects the highest risk/effort value due to a yet unknown, clear definition of how IoT will impact the future FM market.

Augmented Reality (AR) – Since the emergence of mobile interfaces, as mentioned earlier in this work, for the previous restrictively accessible information systems that have been employed to assist facility managers with their duties, the possibilities for support of IT on-site have increased manifold, and with that also have expectations for further developments. Augmented Reality (AR) might be a possible answer to the next level of technology integration for facility managers on the go. In essence, AR enhances, or augments, a person's field of view, in other words the real-world environment, by a computer. In contrast to the 2-dimensional user interfaces that are available through smartphones, tablets and other mobile devices to date, Augmented Reality enables users to access and interact with relevant, location- and asset-based information within their real-world field of view, through speech recognition, hand gestures and other means. As of now, specially designed and developed glasses, such as the Microsoft HoloLens, that are worn like any other kind of conventional glasses, act as the mobile computer that creates the enhanced layer of information that users can see while navigating through the real world. While the potential use-cases within the O&M discipline have barely been explored and developed, international as well as Austrian-based pilot projects using AR-based solutions for facility management purposes underline the FM industry's general interest in this topic. Valuing AR in accordance to the technology portfolio is mainly affected by the promising, yet currently limited benefits for facility managers in operations on one hand, and by an average rating with regard to the related efforts and risks on the other hand. As is explained in more detail in a later chapter, Augmented Reality depends on other technology despite its narrow field of application, thus greatly influencing the overall ratio. (ViewAR, 2017)

Virtual Reality (VR) – In contrary to the AR's intent of augmenting a user's view of the real world, the concept of Virtual Reality (VR) is entirely based on replacing the real-world environment with a virtual one. Albeit its first modern-day applications are mainly centred around the gaming industry, VR arguably has grown to be of interest to many industries. However, probably in parts due to its technology still being rather infant, current (pilot) applications of VR in the facility management market are mainly positioned in the planning and construction stage, where stakeholders and clients involved in the process can immerse into a three-dimensional view of buildings and their assets before they are even built. On top of that, some applications even allow users to alter the design of this simulated world, for example to let customers decide for themselves about the look of certain elements of new construction projects. Similar to the underlying technology in AR, special glasses and head-mounts currently serve as the main devices to create and simulate such virtual worlds and objects. While Virtual Reality may deliver significant benefit, especially to client stakeholders, for narrow applications within the planning and construction market, its application to the operation and maintenance of facilities appears limited at this point in time. While this might change at a later stage, when facility managers start controlling and monitoring building equipment from their office cockpits, the cost factor for implementation and the dependencies on other technology, especially those delivering graphical representations and data of buildings and equipment, may not justify the outcome.

Big Data Analysis – Another buzzword that gained quite some popularity over the past couple years is “Big Data”. In fact, the amount of electronic data that is being generated by people and smart devices all around the world already exceeds human capability to manually process all this information by far. (Marr, 2015) The underlying theory of Big Data is the assumption that with all that gathered data there is a lot of new information in different contexts to be revealed, and the facility management industry is no exception to that. Especially when it comes to operating and maintaining facilities, where, depending on the complexity and features of properties, a lot of different data regarding usage, environmental factors and other aspects could be gathered. Together with the possible rise in popularity of IoT-based smart systems and devices in facilities, analysing and processing the data generated by those assets may lead to sophisticated algorithms that help buildings regulate themselves and reduce the need for preventive maintenance, amongst other things. Big Data’s current positioning in the technology portfolio is mainly a result of missing evidence as to what benefit facility managers gain out of the building data that is monitored right now, not least due to the fact that this aspect often changes from building to building. On top of that, Big Data is not so much a technology by itself as it is a method to harvest useful information out of data from other technologies, thus adding to the risk parameter.

Smart Meters – Energy consumption is amongst the most significant cost factors during any property’s operations life cycle. As such, regular readings of electrical and volumetric meters that record a building’s electric, gas and water consumption, to detect possible faults with the supply lines or abuse of consumption, in the case of outliers, not only make sense for environmental and financial purposes, but are even required by Austrian law in certain instances. REFERENCE Smart meters, mostly deployed by the respective energy supplier, remove the need for physical inspection by facility managers or external personnel, since they are remotely accessible. Paired with proper analysis systems, consumption could be automatically traced in any chosen intervals and monitored for irregularities, thus reducing operating expenses through energy consumption while also minimizing the effort required by the facility managers. Considering that smart meters have been established on the market and are comparably simple in their technology, the effort required to gain the possible benefit is suggested to be rather low. However, so may be the potential benefit for facility managers as well, seeing that the fields of application for smart meters are narrow to begin with, and may not extend as much in the future.

Commercial Drones – The term "drone" is referring to the initial military application of so-called UAV's (unmanned aerial vehicles), allowing for such vehicles to be flown without a pilot at its controls, either manually through a remote-control system, or autonomous through on-board computers. Recently, usage of such UAV's has expanded to commercial applications, including surveillance, product deliveries and photography. Commercial drones that are equipped with video cameras, allowing for their controllers to follow the drones' field of view in real-time, could become a potential asset for facility managers for inspecting areas where there's only limited access or a potential risk of falling. Furthermore, autonomous systems that are able to scan areas with the accuracy and level of detail required by current business processes, could potentially lead to significant increases in efficiency for facility management companies. The results with regard to the portfolio are mainly affected by a high uncertainty in both the future applications of drones as well as the costs for adoption. On one hand, current applications may be limited to the inspection of hard-to-reach and unsafe environments on a surface-level, whereas future applications might be high in number given the necessary technological advancements in self-driving vehicles.

5. Relevance Trees

This chapter aims to explore in more detail viable solutions with regard to the emerging technologies identified for current FM issues that facility managers are confronted with on a day-to-day basis in an analytical process, using so-called relevance trees.

The main purpose of such an analysis is to divide a problem formulation into smaller, separate categories until one or more tangible solution proposals can be derived from the process. Therefore, the tree starts out with a high level of abstraction and gets into more detail with every new level in the analysis step. Relevance trees are very much similar to common organizational diagrams in a way that, once they reach their last levels, any form of structure, simple or complex, is divided into its categories and subcategories, or in the case of an organization, departments and teams. Furthermore, they are applicable for both continuous as well as discontinuous technologies and particularly useful for areas of fundamental research. The aspired goal is to identify a certain technology that assists in solving the overall problem. (Cho & Daim, 2013, pp. 94-95)

The following steps are suggested when conducting relevance tree analysis:

1. Definition of the problem for which a solution is sought after
2. Definition of all relevant parameters that split the initial issue into more tangible packages and help to formulate viable solutions
3. Construction of the relevance tree, containing the holistic problem formulation and all steps that lead to a solution
4. Interpretation of results with regard to feasibility and the achievement of initial goals
5. Detailed analysis of final options and solutions that are considered as the best alternatives

As a result, following the outcome of the relevance trees that are created in the following sections of this chapter, the thesis will further analyse in more detail the solutions that have been outlined and considered as the most impactful and beneficial alternatives for future technology in the facility management market.

5.1. Knowledge Transfer Analysis

The first relevance tree attempts to propose at least one solution to the current obstacle with transferring knowledge, and most importantly data, from the planning and construction life cycles of properties to their operating life cycles. As the thesis earlier suggested, the facility management industry, specifically the O&M discipline, currently struggles to efficiently make use of the data and documentation, granted that there is any, which is generated and gathered during planning and construction life cycle of facilities.

The figure below presents the initial problem formulation and its detailed steps to viable solutions in form of a relevance tree:

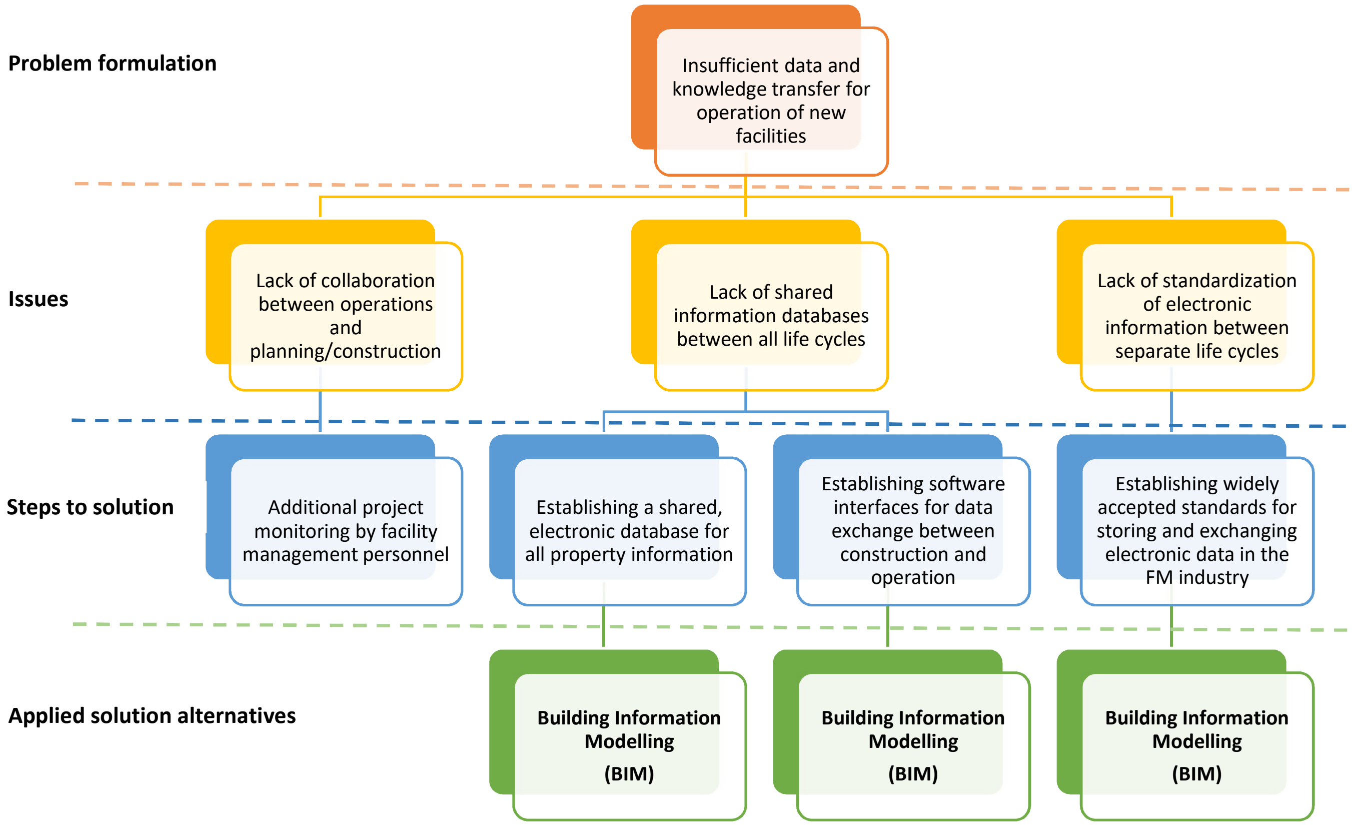

Figure 5: Knowledge Transfer Relevance Tree

The first major obstacle identified is a lack of collaboration between separate disciplines during construction projects. This is particularly the case at the connection between construction and operations, but less so for the correlation between planning and construction, due to their interdependencies. With the exception of initial specifications by clients and authorities, the construction industry is not dependent on further input from those in charge of future operations, thus leading to a natural separation between these two markets. Due to the fact that this issue is a matter of societal and corporate circumstances, the simple implementation of technology cannot be a soluble workaround. It mainly depends on creating a need for facility managers to closely working together with property owners and those responsible during the construction of facilities, at an earlier stage than at the end of the construction phase.

Secondly and thirdly, due to the fact that the facility management industry as a whole is rather slow in adopting technology, digitalization has yet to encompass every detail of the planning and construction process. On one hand, there is only limited standardization in regard to what kind of documentation and information is to be created and stored in an electronic form, and on the other hand, granted that there is some electronically available data, it is scattered all around different environments. The latter is essentially due to the nature of the construction industry, where a multitude of different partners work together in any construction project, with each partner delivering his own set of data, usually in a different format than the rest. To fight these inefficiencies, viable solutions include the standardization of electronic data in a shared format and the storage of all, project-wide data in a centralized database. This database in return can be used, given the fact that there is an existing interface, to transfer such an extensive set of information into the facility manager's environment that is later used for detailed planning of the operational and maintenance duties. (May & Williams, The Facility Manager's Guide to Information Technology, 2017, pp. 115-116)

To tackle these issues, amongst others that are out of the scope of this work, the previously mentioned methodology of BIM has been around for discussion for years now. Considering the quite enormous amount of work and development effort that was put into forming and distributing this "ideology" throughout industry and governments, this work suggests BIM not only as the most holistic approach for the various needs in regard to gathering and using electronic property data for the operations life cycle, but also as the most advanced and ready-to-apply set of techniques. Therefore, chapter 6 will focus entirely on Building Information Modelling.

5.2. Asset Tracking Analysis

The second key issue, as outlined by this thesis, that facility managers currently face in the O&M industry is working with all the different assets throughout their managed buildings. Keeping track of the various maintenance intervals and possible defects for an ever-increasing number as well as complexity of equipment is time-consuming at best, and afflicted with inaccuracy and fault at worst. Facility managers spend a majority of their time with tasks that are somehow connected to these assets, and as such the adoption of suitable technology that assists with these tasks could prove to provide a much-needed improvement, not only to efficiency, but also to quality, for the work of FM professionals in the O&M discipline.

Thus, the second relevance tree analyses in more detail the issue around working with property assets on-site:

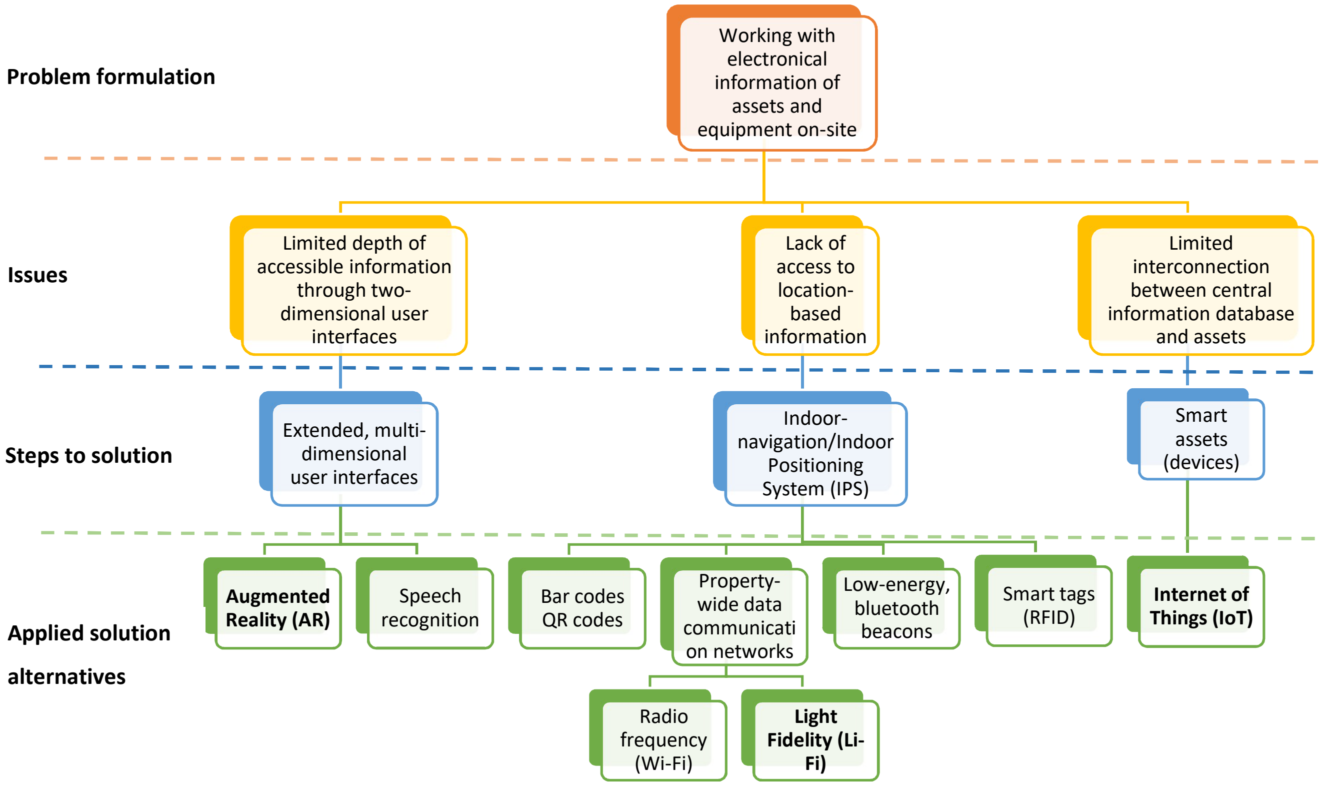

Figure 6: Operation Asset Tracking Relevance Tree

The first issue as a part of the inefficient tracking of a significant number of assets is related to the current limitations of state-of-the-art mobile interfaces, such as smartphone and tablet displays. This mainly means that working with the desired information is limited to the size of the given display as well the input methods allowed through these interfaces. These, in most current applications, are more or less limited to interacting with the display by touch. (Nosrati, Karimi, & Hasanvand, 2012, p. 406)

Without any enhanced forms of intelligence, and given the fact that the amount of information needed in a rather short period of time is mostly scattered and not always accessible in a quick and easy manner, working with mobile interfaces is sometimes a taxing task. (May, Clauss, & Salzmann, 2017)
By adding additional layers of intelligence, such as those represented by the succeeding issues in this analysis, or even additional dimensions, accessing and working with data could become a much more streamlined and even "natural" process. One of the possible approaches to add a third dimension to the user interface is by replacing the mobile display with an enhanced real-world view through Augmented Reality. The possibility to embed electronic data into our field of view through special glasses or other means of simulation completely changes how users could interact with and also change desired information. This is as much true for the FM industry as it is for similar use cases in distant markets. Alternatively, or even in combination with AR, advancements in speech recognition allow users of state-of-the-art mobile devices to reduce the barrier for interaction by naturally talking to a computer about what to do, instead of having to tediously navigate through a display or even type on it. (May & Williams, 2017, p. 403)

Even in small-sized FM firms, depending on their core business areas, the number of total assets that are processed on a regular basis can far exceed anything that is considered manageable without proper segmentation and filtering. However, doing so manually by the system users every time they try to locate specific information is a very time-consuming process. And at the current state, and this is especially true for non-office buildings with usually less technology, there is a lack of possibility to intelligently locate assets based on their location. One of the possible layers of intelligence that could very well ease the process of locating desired information more quickly is to link the user's position, as known by a mobile software interface, to the known location of nearby assets, thus greatly increasing the focus that could be of possible interest to the user. Possible solutions have been grouped together to what is currently well-known in general as indoor navigation or an Indoor Positioning System (IPS). Due to the fact that, as is the case in most facilities, at least some areas of a property are out of reach for the current technology in cellular networks, GPS (Global Positioning System) is not a reliable technology that solves the issue. (May & Williams, 2017, p. 401)

Thus, viable solutions in the indoor navigation group have to be considered separate for each and every facility at hand. Especially for aged facilities that were constructed decades ago, which usually facilitate only a very limited and simplistic form of equipment that was considered state-of-the-art back then, using simple, unique identification of assets in the form of bar or QR codes can already significantly decrease the time spent searching through a two-dimensional, mobile interface. In summary, each asset in any well-defined database should carry with it a unique identifier that is, at least in this information ecosystem, the only one of its kind. Printing these identifiers as bar or QR codes and attaching them to their assets thus allows mobile systems that have the ability to scan such codes to quickly link between an identifier and the connected asset, and present the user with the information he desires. (May & Williams, 2017, pp. 80-82)

However, as facilities become more complex and are equipped with an increasing level of technology, such simplistic methods look much less desirable in the light of possible alternatives. Because, on one hand, literally "pasting up" buildings with visible codes is not positively adding to the overall picture, and thus not preferred by owners and tenants, and on the other hand, considering the possibilities of today's and tomorrow's technologies, this method loses out also in terms of performance.

With the rising prominence of everything "being connected", property owners and facility managers could look to providing network access throughout properties as a possible solution. The idea of always being connected to some sort of network can then be used to pinpoint a user's exact location, and as such also the assets that are closest to that location. First of all, there is the possibility of using common Wi-Fi environments to provide such extensive data networks. However, given the challenges of the limited bandwidth of available radio frequency, security concerns in regard to unauthorized access, and radio waves' capability of passing through walls, thus reducing the possible location accuracy for such systems, apart from considerable costs to establish and maintain Wi-Fi networks, it is not surprising that such facilities are not common in the office as well as residential building segment.

Latest research, however, has led to promising new ways for exchanging electronic data over air. More specifically, Harald Haas, a Professor on Mobile Communications at the university of Edinburgh, who coined the term "Li-Fi" (Light Fidelity), made prominent the science of visible light communication as a possible form of data transmission by successfully transferring electronic data through Light Emitting

Diodes (LED’s) at very high speeds. Combining the rising prominence of deploying LED’s as the main form of providing light due to their significantly reduced energy consumption with the research in utilize them to transmit data wirelessly makes for a promising technology for the future. Granted that all areas of new properties are lighted through LED’s that are capable of transmitting data, indoor positioning can easily be achieved on a room-by-room basis. (Lind, 2017)

Last, but not least, likely in parts due to the FM industry adapting to new technology at a rather slow pace, the state-of-the-art in safety equipment and systems for buildings has yet to incorporate a particular “smartness” of these assets. As such, there is almost no bi-directional communication between the deployed assets and the information systems in use by facility managers. Even if some of those assets have the potential to regulate themselves with consideration to their surrounding environment (air ventilation, heating, etc.), they are missing the capability to communicate such changes, or any information for that matter, to the responsible manager’s information system environment.

To propose a solution to this issue means to suggest that systems and other assets used within buildings have to elevate to the next level of information technology by opening up to the global information ecosystem. If devices were able to communicate and send up-to-date information about their condition and usage to the common CAFM systems in place, asset tracking could essentially turn into a rather reactive than a proactive process. Such smart devices are in general covered under the term Internet of Things, as mentioned earlier in the technology portfolio analysis.

Due to the nature of the industry, involving a multitude of different disciplines and trades, pushing towards an information society might be subject to a tedious and long process where FM professionals in the end will not be the only stakeholders. Still, with the rapid advancements in information technology to-date, where costs sink, and new possibilities open up day by day, having a building talk to you instead of the other way round may well be part of how operations of buildings could change in the near future.

5.3. Summary

Using an analytical TA process to understand the bandwidth of possible technological trends and to get a better understanding about the underlying issues that can be tackled with certain technologies at least allows to reduce some of the high amount of uncertainty when it comes to emerging technologies. Portfolio analysis methods help to get a good overview over certain aspects (product lines, services, processes, emerging technologies) and put those in perspective. By valuing possible technologies by their possible benefits versus their costs and risks of adaption, this chapter compares eight different technologies and methods for different purposes with the aim of narrowing down the possible, future paths for novel technology in the field of Operations & Maintenance. While there are some that have already proven themselves in practice, others still need to be developed and adapted for the FM industry to increase the industry's value. However, those that promise significant benefit for FM professionals as well as their clients and customers also tend be connected to both a significant effort for their remaining stages of development and the possible risks for adoption.

Furthermore, this chapter also looked at the issues presented earlier in this thesis and separated those to more tangible and measurable packages by using a relevance tree analysis. Despite their simplicity, these organizational, hierarchical views helped in getting from an abstract issue to specific solution proposals. In the first case regarding the "invisible wall" that stops the construction and operations disciplines from efficiently collaborating and to transfer this crucial, already available data, many of the issues presented led to the same methodology, namely Building Information Modelling. Emphasizing on the term "methodology", BIM is not essentially a novel technology, but rather a set of tools, existing technologies and standards to solve a wide variety of issues, as is suggested by the first relevance tree analysis. Despite its increasing acceptance and large support for practical use, BIM as the digitalization of the construction industry is still in its infancy, and thus will be analysed in more detail in the next chapter.

The second relevance tree focused on the versatile set of tasks and responsibilities in regard to tracking a large number of assets for multiple properties. Even though the emergence of mobile applications greatly increased the possibilities and the ability for facility managers to work with electronic information on-site, the technological progress already allows for way more than what is currently the state-of-the-art. Depending on the underlying issues regarding this major challenge, a number of potential technologies have been identified as a remedy to the sometimes tedious processes that are involved. In particular, Augmented Reality, identified as a way to essentially add a new dimension to how data is currently being presented and interacted with. Therefore, AR will be explored in more detail in a later chapter to explore the possible use-cases for the O&M discipline.

6. Building Information Modelling (BIM)

6.1. Emergence of BIM

During the planning and construction stages of any facility, architects, and subsequently all other project partners responsible for the various aspects of that facility, including its technical appliances, create detailed graphical representations of building structures and the location for their doors, windows as well as interior. On the one hand, such graphical visualizations not only enable project partners to communicate clearly with each other, but also allow for clients to get a clear picture of what is being planned, and how exactly their property eventually is going to look like. On the other hand, depending on the national laws applying, certain plans might even be obligatory to be created and maintained up-to-date throughout the planning and construction stages.

However, prior to the methodology that evolved around the term of Building Information Modelling, the planning and drawing processes from the various project partners, like architects, electricians, plumbers and the like, were kept isolated from each other. Separate plans have existed for pretty much all professions, and thus the possibility for deviation and loss of accuracy across these plans increased with the duration of the planning and construction phase. The likelihood for errors caused by a lack of communication about changes to specific design aspects between all project partners also increased with the size and complexity of a property. This, in return, leads to necessary and costly adjustments to the structure and/or the type and volume of equipment, often during or even after the construction stage, that have not been considered in the initial plans. As a result, the construction of properties is often associated with higher costs than the actual predictions and budgets. For example, the U.K. Department for Business, Energy & Industrial Strategy, in its 2015 strategic plan to adopt advanced Building Information Modelling in the U.K. construction sector, cited an analysis executed in 2013 by EC Harris consulting company, claiming that up to 20% of spending, or around €11.3 billion for the year 2013 in the U.K. construction industry alone, could be attributed to overhead costs. (U.K. Department for Business, Energy & Industrial Strategy, 2015)

Furthermore, the major effort invested in creating and maintaining these building plans for the construction process is almost nullified after construction is completed. This is, in one part, due to the lack for a seamless integration between the construction and operations stages, where facility managers often find themselves having a tough time in gathering the data and information that was generated in the various plans and other, project-relevant documents. On top of that, there is only limited to no compatibility between the data gathered in these project-relevant documents and CAD plans, and the IT system environments that are commonly used by facility managers, such as CAFM systems. This left facility managers with next to no useful data to start with, requiring them to establish a costly, time-consuming electronic profile of a new property and its equipment, even though the data was there.

BIM tries to tackle these major cost factors by establishing a joint knowledge base for all partners involved in a construction project, that, in a next step, is structured in such a way that it is compatible with later usage during the operations life-cycle.

6.2. Advantages and Possible Benefits for O&M

An established Building Information Model during the planning and construction stages can offer numerous benefits for the facility manager:

- **Extensive knowledge database with project-relevant data in advance of operations** – A BIM database that is populated with extensive information about all of a building's components promises a level of knowledge that a facility manager would otherwise have to invest a considerable amount of time into to gather himself. Besides, due to the lack of interconnection between construction and operation, some of this data might even be unobtainable to him, as certain, asset-specific, information can be provided only by the responsible project partner. By the time facility managers get to ask for information, which usually happens post-construction, the relevant firms are already working on the next project, providing only limited help to the operating FM professional. (Blanco & Chen, 2014, p. 518)
- **Graphical representation of buildings and their appliances** – A visualization of buildings and all the installed equipment can help facility managers locating certain assets more quickly, especially where facilities reach a certain complexity.
- **Enormous cost-saving potential** – Removing the facility manager's requirement to gather all relevant data in his properties himself allows him to start with the strategic planning at a much earlier stage and extends the productivity phase for the actual operations and maintenance life-cycle by weeks, if not months, depending on the complexity and size of a facility.

6.3. Current Fields of Application

Whereas BIM is still more of a dream of the future in the majority of developed countries, with the exception of some individual pilot projects in some of these countries, both the U.S. and the U.K., as well as parts of the Northern European countries, such as Norway, have already adopted Building Information Modelling for use in some of their construction projects. For example, as part of its Government Construction Strategy, the U.K. government requires all government projects, starting from 2016, to be conducted using 3-D Building Information Modelling, thus expecting that all project and asset information and data be electronic. (U.K. Government Cabinet Office, 2011)

6.4. Challenges for Adoption

The construction industry, and with that, facility management as a whole, usually is slow with adopting the possibilities of digital technology. “We have always done it that way” is a common conception, not only for FM, but for professionals in various industries and disciplines. Even though facility management has gained significant attention since the first definition of its market and responsibilities, and further continues do so, some disciplines still remain more important than others. Property owners have yet to realize that facility managers can add significant value and reduce overall life-cycle costs in all three stages of their properties (design, construction, operation) by applying novel IT support systems to their processes. Additionally, operations and maintenance by itself is mostly a user of BIM, but not a main contributor, and as such it has only very limited power to push for the adoption of a methodology that affects several FM disciplines simultaneously. To successfully help BIM become a standard, management authorities in the construction industry as well as property owners are required to support and pave the way for BIM to set foot in markets where the willingness to adopt is limited. Not less important, however, is the fact that facility management professionals of all disciplines, especially operations and maintenance, will need to actively get involved, if they hope to reap the benefits that BIM can bring to the various stages of a property’s life-cycle.

Furthermore, compatible data formats pose another challenge to a successful adoption of BIM. Considering the fact that BIM by itself is a methodology, but not a specific software application, multiple software development companies create and advertise their own implementations of BIM, which all use proprietary data formats that cannot be used freely with other applications and systems. In Germany, for instance, the Association for German Engineers (“*Verein Deutscher Ingenieure*”) proposes its own set of standards used for exchanging data of building services through its *VDI 3805* specification, whereas both the U.S. and U.K. each have developed their own standards as well. Regardless of industry or purpose, developing a standard that is expected to be used throughout all kinds of BIM implementations, takes time, effort and fruitful collaborations of and between those that are at the forefront of adopting BIM.

Last but not least, considering that BIM applications are not just simple tools, but often very complex system environments, access to using such applications, and thus being able to contribute to construction projects that utilize BIM, is still a major issue for small firms, since they often lack both financial as well as human resources. If BIM expects to become a broadly accepted standard of how IT can change, and most importantly improve, the construction and operations life-cycles of new properties, access to and use of BIM applications is required to be suitable for firms of all sizes.

7. Augmented Reality

7.1. State-of-the-Art

Augmented Reality, as the name suggest, is based on technology that presents users with an enhanced version of the real-world environment, thus, an augmented reality. The data that is presented to the user at any given time can range from any kind of shapes and objects to the simple display of text, on top of their current field-of-view. Current means to enhance an AR user's perception of the real-world to wherever he turns are mostly limited to specially developed glasses that utilize highly advanced, built-in computer hardware to display electronic information to the user and also enable the user to interact with this new, three-dimensional user interface through hand gestures. (May & Williams, 2017, p. 403)
However, the development of AR, especially into the field of wearables, such as glasses, has only recently gained a lot of traction and attention. For instance, for the year 2016 alone, the combined AR/VR market experienced a total investment of $2.3 billion, which is an increase year-on-year of over 300%. (Digi-Capital™, 2017)

Thus, even though development efforts apparently increased manifold recently, the adoption of this technology into the facility management market is still in its infancy. However, several pilot projects already developed for specific purposes in the FM industry promise that AR may deliver significant value to the future IT market.

7.2. Benefit for Asset Tracking

Through the application of a relevance tree for the identification of root causes for inefficient tracking of assets and equipment, Augmented Reality has been identified as a possible solution, and at the same time a replacement for today's common mobile interfaces, which exist mainly in the form of touchscreen displays. The unique difference that distinguishes an enhanced real-world view from these conventional displays is the ability to utilize a much wider area for display of information and interaction with that data, without limiting users in their mobility, because the technology, and hardware, more or less comfortably rests on their heads. Thus, the liberty of action that is gained in return can be used to full capacity for the actual interaction between user and system, such as moving a user's hand over certain, displayed information and invoke pre-defined actions through certain hand gestures. Not only may this way of working with electronic data feel more natural to the user, but, given the assumption that there is a context present for the Augmented Reality system to know which asset to present information about at any given point in the facility, the significant amount of time usually spent looking for the right information can actually be spent working with that information.

In essence, AR could be utilized by facility managers to decrease their time spent searching for the right information and working with that information through the following benefits:

- **Extended interface through augmented field-of-view** – While conventional mobile computers such as tablets, and smartphones especially, feature a rather limited screen size for the human-computer interaction, due to their requirement of being mobile and handy, glasses with AR technology essentially turn the real-world environment around their users into that same possibility for human-computer interaction. Thus, facility managers could be presented with information for multiple assets at the same time, rather than being limited to the scope of a display screen.
- **Context-based display of information** – Granted that a proper context is provided for the AR device to know, which assets in particular the facility manager is nearest to or even looking at, at any given position within his buildings, the computer can change the display of information without further effort by the user. The challenge regarding contexts will be explained shortly in the following chapter.
- **Additional depth when working with data** – Furthermore, the possible human-computer-interaction on a common mobile device's screen is usually limited to confined area of two dimension. With the exception of gestures, like "zooming" or "swiping", or the so-called "force-touch" feature of modern mobile devices, where the touchscreen is actually able to distinguish different pressures of contact between user and screen for additional functionality, the possible interaction is restricted to a simple tap, thus limiting the depth of information that can be displayed at the same time. In contrast, through the display of information in a three-dimensional environment, facility managers can navigate through sets of information without immediately losing the connected information. For example, by simply putting the more recent information in front of the previous, but still connected data, FM professionals can be presented with a whole dataset at the same time, without losing probably important information through navigating.

7.3. Drawbacks, Challenges and Barriers

First of all, the availability of wearable consumer devices to-date is limited to only a handful of manufacturers. As such, those glasses that feature the most state-of-the-art level of technology are only available at a high cost of acquisition. For instance, Microsoft's version of an AR-wearable device,

the HoloLens, which claims to be the market-leader for mixed-reality technology, is available for companies at a price per piece of $5,000. (Microsoft Corporation)
Considering that for smaller FM companies on one hand, where IT budgets probably are limited, and larger firms on the other hand, where there are high numbers of potential users, the acquisition of such devices could be considered a major investment factor.

To add to the issue of high initial costs for a suitable AR device, these costs do not include a specific software solution for FM professionals. Thus, whether an FM company develops its own, tailored solution or buys off-the-shelf software from third-party suppliers that is suitable for working together with the given hardware as well as the existing CAFM environment in a firm, additional implementation costs will arise that add to the potential barrier for the adoption. Because, at last, technology appeals most when the expected benefit can be promised, rather than only hoped for.

Last, but not least, for the proper presentation of the correct data for an asset that facility managers might look at with such AR wearable devices, any given AR system is in need of a specific context to know what data to display at any given point. Without such a context, the benefit for facility managers from an AR device is slim to none, because then there is no indicator for the system as to what information the user requires. The most significant context that an AR system could be provided with is a unique identifier of the asset(s) that a user is closest to, or a point of location, for instance through an indoor-navigation system, which allows the system to determine the relative position between the user and the surrounding equipment. (Gotze, Schumann, & Muller, 2014)

Given the fact that indoor-navigation and other means of locating users and assets within a building has been identified as a separate issue in this work, there arguably is a dependability between a well-functioning AR interface for facility managers and the existence of some sort of indoor-navigation.

7.4. Prerequisites for a Successful Implementation

Based on the benefits and challenges identified in this chapter and the author’s experience with technology, this section tries to summarize some of the major potential conditions that should be considered in order for AR technology to be implemented and used successfully in a business environment:

- **Evaluation of suitable hardware** – Due to the mobility requirement for facility managers, a suitable Augmented Reality device should adhere to multiple factors. These include comfortable and easy wearability and durable battery life. Furthermore, sensors and additional input methods such as microphones could very well be considered for future development that further increases the possibilities for a human-computer interaction, such as speech recognition.

- **Qualitative data management through CAFM** – Augmented Reality is essentially just an alternative interface that presents electronically stored data to a user. If facility managers expect to reap the possible benefits of AR, as described above, an extensive database is required that stores as much data as possible about all managed assets, such as a CAFM system. The AR interface then acts as the presenting medium, which facility managers may use to quickly retrieve information and also gather additional information.
- **Commitment from IT and facility managers** – Especially in the case, where there is no existing interface between the information database of a CAFM system, and the augmented environment from the AR system, it is crucial that both IT as well as FM professionals clearly communicate requirements as well as current limitations of a possible solution with AR devices.
- **Provision of asset- or location-based context throughout properties** – Whether through the use of QR-codes, specific indoor-navigation solutions or smart assets that can broadcast information about themselves on their own (Internet of Things), facility managers, who want to utilize the benefits of AR have to consider a way to provide a suitable context throughout their facilities. Due to the unique nature of circumstances in each facility (GPS partially accessible, office / residential building, complexity of equipment) a specific solution for the context provision for each facility will be required.

8. Conclusion and Future Work

The screening process for emerging technologies in the O&M discipline revealed surprising, yet promising technologies that, if utilized to their full extent, would promptly change not only the way facility managers perceive and execute their work, but also how buildings and their equipment themselves are perceived. Taking for example the research in visible light communications through Li-Fi, where LED-only lighted buildings with the capability to transmit data can both be perceived as highly cost-effective in contrary to buildings still using common lightbulbs, which is very favourable for tenants and property owners, as well as an intelligent building that submits data from and to IoT-enabled equipment.

While the issues around transferring knowledge from the construction site to the operational facility management and working with asset information on-site in an efficient way are by no means the only challenges that would highly appreciate more sophisticated solutions, they increasingly stand out in a time where IT is ever more present in everyday lives, and when it seems almost silly that electronic information is either not available, or getting more difficult to work with.

To my personal surprise, the willingness of the FM industry to delve into new, yet unpolished technologies is far bigger than initially expected. Both local, Austrian companies (private and public sector) as well as international firms are already experimenting with technologies such as Augmented Reality and Building Information Modelling on a larger scale. Whether or not these pilot projects are pure show-cases for these firms' image, or actual implementations into the day-to-day business processes remains an open question, but it still generates excitement about what is already possible as well as about the apparent collaboration between FM and IT to bring forth Industry 4.0 in the FM market.

However, due to the chosen scope of this work, analysis remains mostly on a holistic level. Optimally, readers will be introduced to certain technologies they have not been introduced to yet and gather more ideas about the possible applications for the FM market. With that said, in my opinion almost every one of the technologies identified in this work deserves a separate thesis, and thus a detailed analysis about the possibilities they offer for the O&M discipline, and the FM industry as a whole.

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Appendix A – Technology Portfolio Analysis Datasheet

Evaluation of Options

		Weighting (%)	Options: Building Information Modelling	Big Data	Li-Fi	Augmented Reality	Virtual Reality	Smart Meters	Internet of Things	Drones
Benefit of Option	Speed to market	20	5	3	2	3	3	5	2	3
	Cost-reduction potential	25	4	3	3	3	2	2	4	3
	Expected value for facility managers	30	5	3	5	4	2	2	5	3
	Perceived value for clients/property owners	25	5	3	4	1	3	2	4	1
Effort/Risk of Option	Implementation and adoption costs	25	5	3	4	3	3	2	5	2
	Impact on adjacent FM disciplines	25	5	2	5	1	4	1	5	2
	Development uncertainty	25	2	2	4	3	3	1	4	2
	Technological interdependencies	25	1	5	3	3	2	1	4	1
Investment necessary			5	3	5	3	3	1	5	3