Faculty of Humanities

Performance Assessment of BIM in University Facilities Management Organisations :
Exploring industry perceptions in Australia and Sweden

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Declaration

To the best of my knowledge and belief this thesis contains no material previously published by any other person except where due acknowledgment has been made.

This thesis contains no material which has been accepted for the award of any other degree or diploma in any university.

The research presented and reported in this thesis was conducted in accordance with the National Health and Medical Research Council National Statement on Ethical Conduct in Human Research (2007) – updated March 2014. The proposed research study received human research ethics approval from the Curtin University Human Research Ethics Committee (EC00262), Approval Number # HRE2017-0707

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Abstract

This thesis investigates how assessment of Building Information Modelling (BIM) adoption can be made by Facilities Management (FM) organisations. This was done by investigating organisational dimensions mainly affected by BIM adoption and use.

Digitalisation of the built environment industry is increasing, however it still in its infancy relative to other industries. BIM has proven to contribute to work process optimisation through a wide range of digital information management approaches in design and construction projects. This leads to a need for assessing individual projects and organisational efficiency and performance in terms of BIM uptake, implementation, delivery and use. As adoption of BIM in the design and building phases is increasing, the projects and organisations active in this area are becoming more mature in their assessment of performance. The Facilities Management (FM) sector however, has at large, neither implemented practices for handling digital building information from BIM models nor established strategies for how to handle this in future development. Regardless of this situation, there are many advocates for establishing BIM practices that bridge the information gap between designing, building/constructing and facility/asset management.

BIM performance assessment frameworks have grown as a way of evaluating, measuring or assessing various aspects of BIM impact on performance applied to current state of practice. These are presented based on a scoping review methodology. These frameworks and methodologies are often applicable to larger organisations and projects; in some cases, they are even specifically developed to suit a particular project or organisation. This thesis also aims to develop a conceptual methodology in which organisations can self-assess BIM performance through crowd-sourcing.

The literature review presents five organisational dimensions in which preliminary BIM performance indicators can be identified. These dimensions are: (1) Technology, (2) Knowledge, (3) Communication, (4) Processes, and (5) Culture and Motivation. Based on these dimensions, a qualitative, interview-based case study approach including four organisations in Sweden and Australia was conducted. The study aimed at investigating the dimensions´ significance for BIM adoption, forming a basis for future development of a default set of BIM performance indicators (BPIs) for BIM performance assessment. All four organisations partaking in the study had university-based building portfolios.

The results show that while some of the respondents seemed more aware about how their organisation could benefit from BIM adoption, they were all still far from possessing a sophisticated BIM strategy. The empirical study showed that there is a perception that BIM adoption at large is a technological change, when the issues the respondents referred to rather relates to technological support in handling information, communication-flows and information management processes. Furthermore, interview respondents stressed the importance of having support from the organisation to pursue new innovative work practices. Moreover, the respondents stressed the potential implications a change in work practice would have on their current systems and processes that are not directly applicable with handling BIM data.

Preface

Disclaimer

Parts of this thesis are based on material published by the author as listed in this section. The original publications are attached as appendices.

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Publications

> Månsson, D., and Lindahl, G. (2016). BIM performance and capability. In. Sanchez, A. X., Hampson, K. D. and Vaux, S. (Ed.), *Delivering Value with BIM: A Whole-of-life Approach*, pp46-57. London: Routledge

This publication was written by the author, as the main author and Professor Göran Lindahl as co-author. It was published as a chapter in the book Delivering Value with BIM – A Whole-of-life Approach in March 2016. The publication addresses current perceptions of BIM performance and capability in academia and industry, existing frameworks and incentives in different regions.

> Månsson, D. W., Sanchez, A. X., Hampson, K. D., and Lindahl, G. (2016). Assessing BIM performance through self-assessed benchmarking. CIB World Building Congress: Creating built environments of new opportunities, Tampere Finland, 1, pp635-646. (Double blind peer reviewed).

This publication was written by the author, as the main author, Adriana Sanchez, Keith Hampson and Göran Lindahl as co-authors. It was published as a conference paper in the 20th CIB World Building Congress - *Intelligent Built Environment for Life* in June 2016. The conference proceedings were double blind peer reviewed. The publication builds upon the perception of BIM performance gathered in the first publication and proposes a methodology in which to assess BIM performance through self-assessment in the built environment industry. The paper concludes that a default set of BIM performance indicators is necessary for applying this methodology.

> Månsson, D. W., Hampson, K. D., and Lindahl, G. (2017). Industry assessment of BIM Performance in building management organisations: A study of university building management in Sweden and Australia. Paper presented at *9th Nordic Conference on Construction Economics and Organisation*, Gothenburg Sweden 13-14 June, pp375-386. (Double blind peer reviewed).

This publication was written by the author, as the main author, Keith Hampson and Göran Lindahl as co-authors. It was published as a conference proceeding paper in the 9th Nordic Conference on Construction Economics and Organisation held in Gothenburg, Sweden 13-14 June 2017. The conference proceedings were double blind peer reviewed. The paper addresses requirements and how to identify default BPIs for assessing BIM performance of Facilities Management organisations. It concludes with future research methodology recommendations that were applied in the empirical part of this research.

Acronyms

AECO – Architectural, Engineering, Construction and Operations

BEP – BIM Execution Plan

BIM – Building Information Modelling

BPI – BIM performance Indicators

FM – Facilities Management

ICT – Information and Communications Technology

IFC – Industry Foundation Classes

IoT – Internet of Things

LOD – Level of Development

LoD – Level of Detail

LOI – Level Of Information

RFID – Radio Frequency Identification

Table of Contents

List of Figures and Tables

1. Introduction

Building Information Modelling (BIM) can be viewed as a socio-technical system that is expected to contribute to a vast and rapid change in the built environment industry similar to that experienced by the automotive industry when Information and Communication Technologies (ICT) were introduced (Sanchez et al., 2016). BIM is considered to take the entire built environment industry containing Architectural, Engineering, Construction and Operations (AECO) sector to a new era in integrating data and communication and is in that regard perceived to be the future methodology of the industry (Tuohy and Murphy, 2015). The industry-wide and organisational changes, required to implement BIM more effectively and broadly, require significant capital and time investments from early adopters. It will also, most certainly, pose a challenge to the whole sector, equivalent to the move from drafting pens to Computer-Aided Design (CAD); from main frame computers to hand-held devices. These investments need to be justified by measuring organisational value-added Key Performance Indicators (KPIs) monitored in terms of the effectiveness of the chosen investment strategy.

As technologies continually evolve and procurement agencies release more detailed BIM directives, the AECO industry faces significant and quickly changing challenges. These challenges are exacerbated by the absence of an agreed BIM framework for assessing and comparing basic BIM capabilities across organisations and measuring their respective BIM maturity[1]. Developing such a framework is not a simple undertaking due to the wide range of AECO sector stakeholders, their multitude of disciplines and specialties, and their varied perceptions of expected BIM benefits. To date, very little effort has been exerted to develop formal guides and tools that can be used to establish and compare organisational BIM capability and maturity. Furthermore, guidelines and regulations provided by authorities tend to focus more on driving use of BIM rather than how it should be used.

The construction industry has traditionally been perceived as being conservative with low productivity but with maintained profitability. What a century ago was the cheapest expenditure during a construction project, labour, has during the past decades become one of the most critical parts of budgeting. As salaries increased so did the demand for higher standards of living. This has driven the construction industry to streamlining assembly through, for example, pre-fabrication and more efficient materials handling. As a consequence, to the industry's drive towards increased efficiency, digitalisation of the design and construction phases has become the primary focus of development in the built environment industry. The main contributing factor to this development is BIM, a concept that is constantly evolving and adapting to new ways of usage within the AECO industry. BIM is defined in varied ways across literature and the industry; from being solely perceived as a software tool for visual information-sharing by project participants; to an elaborate methodology for integrating data-rich, object-based models across the whole project lifecycle (Succar, 2009a).

Errors and omissions during design and construction phases are often the result of inefficient communication processes involving numerous stakeholders (Sebastian and Van Berlo, 2010). These projects are characterised by being information intensive, putting pressure on enabling participants to have easy access to accurate and up-to-date information (Matthews et al., 2015). Hence, successful project delivery within the built environment industry requires accurate, effective and timely communication methods including inter-organisational communication and information exchange (Becerik and Pollaris, 2006). This pushes organisations to move away from traditional inter-organisational communication and delivery methods towards implementing more effective contemporary digital methods, such as BIM.

[1] BIM Maturity - the extent, depth, quality, predictability and repeatability in which BIM services or products are delivered, applied or received (Succar et al., 2012).

BIM has proven to be an efficient methodology in enabling project participants to work together in design and build phases. When using BIM software tools, data and information associated with an object[2] upon its creation can later be referenced across several views or representations. When the source information is altered later, objects linked to the source are changed and are instantly visible. This is enabled using access databases. Through such interconnectedness, design problems and re-work are greatly reduced thus saving time and money (Lee and Sexton, 2007). By adding time and cost attributes to 3D elements – referred to as 4D and 5D respectively - organisations can reduce resources needed and streamline project execution. In addition to 4D and 5D, there are additional dimensions such as 6D (sustainability) and 7D (facilities management) which help extend the benefits of using BIM tools and methods. Also, multi-dimensional modelling or "nD" provide avenues for including additional data (Jung and Joo, 2011) and can integrate several additional benefits such as using models to assess energy use, materials re-cycling and operations' logistics. Using this multi-dimensional understanding, the BIM term can be expanded to cover additional analysis areas (Lee and Sexton, 2007).

From a different perspective, BIM represents the future of integrating processes through model-based information sharing. As BIM software tools evolve, the boundaries of BIM will continuously expand and allow the creation of new applications. However, in such a rapidly expanding technological environment, many questions arise including how best to measure the levels of BIM use and establish stakeholders' capability beyond the simple use of BIM software tools.

At the same time, the degree of competitiveness on the market amongst building owners and managers has increased the need for optimisation of processes delivering a streamlined building operation (Zhang et al., 2009). Consequently, implementation of BIM in FM organisations may constitute an effective platform for long-term strategic business outcomes (Love et al., 2014). BIM performance can be described as how capable and mature the project team or organisation is in terms of their BIM use and can mirror efficiency (Succar et al., 2012). Assessment of BIM performance can contribute to both preparation for efficient implementation and streamlining future use of BIM in FM. This thesis will investigate what prerequisites are necessary for a common methodology for assessing BIM performance of FM organisations.

1.1 Problem Statement

Sectors that have undergone a digital revolution in previous years, such as finance and banking, have been successful in documenting efficiency improvement through benchmarking indicators (Tuohy and Murphy, 2014), an example being cost per financial transaction. However, the built environment industry has a high level of inter-organisational relationships, which are different to many other industries and provide industry-specific challenges and opportunities. Even though a collective goal may be defined within the context of a single project, actors contributing to it may have particular interests that are not shared with other stakeholders as well as diverting perspectives and internal organisational goals. It follows that within a single project, different stakeholders may have different approaches to implementing BIM and different ways of thinking about and measuring performance. However, implementing BIM effectively, requires a collaborative and integrated approach to maximise efficiencies across stakeholders and lifecycle phases (Sanchez et al., 2016). As noted by Sebastian and Van Berlo (2010), "BIM comprises collaboration frameworks and technologies for integrating process- and object-oriented information throughout the lifecycle of the building in a multi-dimensional model". Benefits expected from implementing BIM include more effective, efficient, fast and error-free

[2] A BIM object is a model element that contains; information that defines the product or element, geometric characteristics of the physical product or element, visualisation data giving the object a recognisable appearance and functional data that allows the object to be positioned or to behave in a certain manner. (Sanchez et al., 2016)

collaborative processes (Sebastian and Van Berlo, 2010). Nevertheless, implementation and value monitoring strategies that have not been well defined and optimised through evidence-based processes can quickly lead to efficiency losses and cost overruns.

One of the main reasons for ineffective implementation and monitoring strategies to occur is the lack of standard frameworks to assess and benchmark performance within and across organisations (Sebastian and Van Berlo, 2010). Although this area is progressing quickly, there is often a lack of appropriate guidelines that help organisations and project teams identify and prioritise performance requirements (Succar, 2009b). At the same time, while there is a market-driven pressure for organisations to invest in implementing these kinds of technologies and processes, they may not be able to access sufficient information to justify such investment and evaluate the effects of its implementation (Van Grembergen, 2002). Although organisational performance deriving from using BIM is important to justify investment, assessing the actual BIM performance at the project level is as important to understanding the effectiveness of the investment strategy. BIM performance is identified by Succar et al. (2012) as being divided into BIM capability, the ability to generate deliverables and services, and BIM maturity, the extent, depth, quality, predictability and repeatability of the capabilities.

The design and build phase only constitutes a fraction of a building's life time. Furthermore, Pärn et al. (2017) state that 80 percent of a buildings lifecycle costs are occurring during the operations and maintenance phase. Hence, information created through the BIM process should ideally be utilised in the building's entire lifecycle rather than current practice.

Self-assessment by AECO actors can prove to be a versatile and easy accessible way for all stakeholders to assess their performance of delivering and receiving BIM services and products and hence, improve their own and the overall project performance. To enable a methodology in which assessment of BIM performance of all stakeholders involved in and affected by BIM projects can be possible, potential ways of assessing the weakest link, FM, will need to be investigated.

According to Matejka et al. (2016) the operational phase of a building should be considered as the most important from a lifecycle cost (LCC) perspective. Utilising BIM data in the operational phase, FM organisations can improve the operational quality and efficiency and reduce costs.

The FM sector has started looking towards solutions that can enable an increased digitalisation level as well as interoperability between design and build projects and operations. Digital advancements in the projects has been increasing for some years though BIM, but has so far failed to include and thus engage FM actors in this development. At present, in most cases, the interoperable digital building information created in the design and build phases does not reach the operations phase. For FM organisations, there is a significant value potential in the ability for BIM to embed key product and building data within an object-based 3D model to improve the management of buildings (Pärn et al., 2017).

1.3. Research aim

The aim of this thesis is to investigate how assessment of FM organisations BIM adoption can be made through mapping organisational dimensions mainly affected by BIM adoption and use.

1.4. Research Questions

This thesis presents the research carried out within the framework of this Masters of Philosophy (MPhil) project at Curtin University, the background being BIM performance and digitalisation in the construction sector. This research focuses on answering the following questions:

1. What capabilities and level of BIM performance understanding do FM organisations focused on university management have?
2. What do they perceive as future potential?

1.5. Objectives

The research presented in this thesis, will compile information related to BIM performance in FM organisations to build a foundation on which BIM performance Indicators, BPIs, can be further developed. The objective is to identify barriers and potentially suggest solutions to adoption and further assessment of BIM performance in FM organisations. Furthermore, this research aims to investigate the weakest links and how these can be strengthened, if interoperability between disciplines and phases are hampered by varying commitment and capacity. Moreover, if isolated development and standards can be reasons for poor or no inter organisational involvement in BIM development.

1.6. Scope and Limitations

This research project is limited to organisations delivering FM on university buildings in Australia and Sweden. Universities are large institutions which play a central role in the development of society and the built environment. Furthermore, assets contained within universities are at large generic between countries, meaning that they often contain similar facilities. Thus, the influence of local diversion is limited by studying university FM organisations. Although the outcomes from this thesis might be applicable more broadly internationally, the markets of the two regions investigated might be influenced by local practices. Technology advancement is driven from specific regions but technology accessibility is, more or less, global. Adoption of technology however, is differing between regions for a number of reasons. One of the more pivotal is political incentive and legislation. Furthermore, the study focused on four organisations, which was considered a valid sample size to fulfil the objectives at this introductory stage. To identify and further validate content for assessment, a larger sample size will be needed.

2. Literature review

BIM has become the primary methodology encompassing the digitalisation of the built environment supply chain. BIM is a digital representation of the physical and functional characteristics of a building and serves as a knowledge sharing vehicle for building information (Barlish and Sullivan, 2012). Incentives and use related to BIM have been increasing over the past few years and received considerable recognition for its ability to reduce costs and time as well as improve quality (Juan et al., 2017). Azhar et al. (2015) explains; "BIM has gone from being a buzzword to the centrepiece of AEC[3] technology". Although BIM is applied to many large design and construction projects it is still not common practice throughout the industry. However, design and construction projects are now proving to be more efficient in terms of cost reduction, quality improvement, time schedule adherence and a better work flow between project participants. In addition, project owners have started realising other benefits deriving from BIM as a work method, such as easier quantity take offs, enabling easier calculations and visualisations for promotional purposes and ease of cross-disciplinary collaboration to name a few (Sanchez and Joske, 2016; McGraw Hill Construction, 2014).

In this thesis, Section 2.1 will address the concept of BIM performance as well as the incentives and drivers for BIM. Sections 2.2-2.5 will expand on BIM performance assessment in different geographic regions. Sections 2.6-2.7 addresses prerequisites for assessing BIM performance in FM organisations.

2.1. BIM performance

A common issue when project owners are deciding if they are willing to use BIM in projects is that it will require a significant initial cost. The potential implications of this issue are further magnified if the BIM is primarily intended to be used in the design and construction stages (Motawa and Almarshad, 2013). The barrier of high initial costs combined with inability to foresee or predict positive impact deriving from BIM creates a need to assess performance and capabilities among project participants to ensure a positive project result and prove that BIM is worth the investment. BIM organisational performance assessment refers, in this thesis, to measuring the effect of adopting BIM technologies and their respective processes on the performance of an organisation.

BIM performance can be separated into capabilities and maturity. Assessment of BIM capability defines the minimum requirement for producing a task or delivering a service a project team possesses or is fulfilling. Maturity describes how well an organisation or its members can manage processes and tools (Andersen and Jessen, 2003; Yazici, 2009). The following sections will first explore incentives in various geographical regions and further expand on BIM performance.

2.1.1. Requirements and Drivers: Authorities and Procurement

National guidelines and incentives affect how performance and capability is addressed. For example, from 2016, the European Union Public Procurement Directive (EUPPD) require all European Union (EU) Member States to drive BIM for publicly-funded construction projects by mandating and specifying requirements (Travaglini et al., 2014). While it remains to be seen how this directive will be enforced and followed up, the EUPPD signals how access to public funding will require higher efficiency in the form of better software tools, process transparency, information sharing, and data integration. Such directives also highlight the need for establishing common BIM performance criteria for services procurement. They also focus attention on the challenges facing organisations, private and public alike, as they implement BIM internally or participate in collaborative BIM projects.

[3] AEC: Architectural Engineering and Construction industry is defining the primary disciplines included in a construction project. (Azhar et al., 2012)

This directive is not unique to the EU but has been preceded by the UK, the Netherlands and Nordic countries, which already require the use of BIM on publicly-funded building projects.
Since the 1980s, Nordic countries have possessed a leading position in information management research focusing on the built environment industry. EU-funded research incentives are underway in Denmark, Public sector clients in Norway and Finland are responding to government initiatives to digitise information and digitalise construction processes. In the UK, the government developed a national BIM strategy for the AECO industry in partnership with the private sector and academia. The declared aim of the government is to enable the UK construction industry to become world leaders in BIM use. As a first step, the government is currently mandating Level 2 as illustrated in Figure 2.1 (Hooper, 2015).

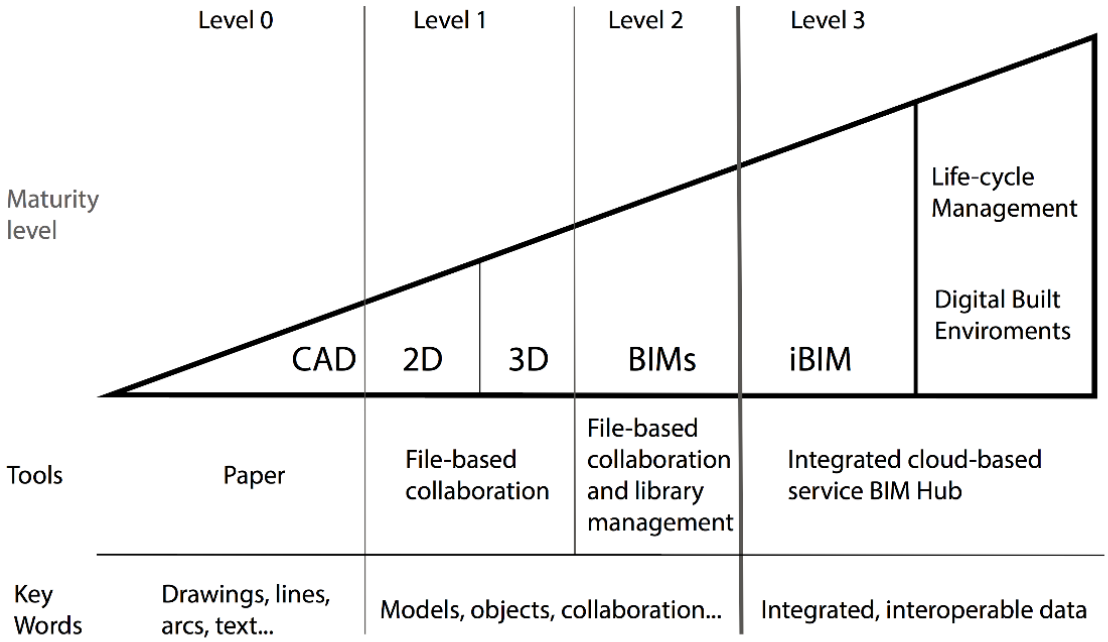

Figure 1. UK iBIM[4], [5] model based on the adaptation made by Barlish and Sullivan (2012) of the original Bew and Richards model.

The application of BIM tools and workflows are not exclusive to buildings and infrastructure, but also applies across the larger urban setting. In this respect, Germany has been leading the development of standardised 3D city models (Kolbe, 2009), and the UK Ordnance Survey has been working on linking BIM models to their national survey map (Morin et al., 2014). In Sweden, the National Board of Housing, Building and Planning (Boverket) have also started to integrate Geographical Information Systems (GIS) with the building permit process (Boverket, 2012).

Since 2014, the Housing Authority in Hong Kong requires the use of BIM on all new development projects. In South Korea, the Public Procurement Service currently requires the use of BIM on all projects over AUD60,000(50 million KRW[6]), since 2016 they are mandating BIM on all publicly-funded projects. Starting in 2010, Singapore is implementing an e-submission system that streamlines

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[4] BIMs – Separate BIM models shared with integration tools (Barlish and Sullivan 2012).

[5] iBIM – Single integrated BIM model used by the entire design team (Barlish and Sullivan 2012).

[6] Exchange rate used for currency conversion 1 AUD = 893 KRW [accessed: 03-10-2017].

the building permissions' process by requiring the submission of models for use by urban planning authorities (Wong and Fan, 2013).

Many authorities around the world are thus driving BIM implementation by encouraging industry stakeholders to investigate and/or adopt new technologies and processes, but even with such encouragements, many challenges remain. From the supply chain perspective, AECO organisations need to both manage their typical workloads and adhere to additional requirements for model generation and information management. From the authorities' perspective, policy makers need to identify how best to prescribe BIM use within tender documents and measure actual BIM use on projects. It is certainly not enough to mandate the adoption of certain software tools and workflows. Even if all companies across the supply chain adopted identical tools and workflows, clients will still need clear metrics or indicators to identify and compare the BIM performance of different stakeholders.

To address supply chain BIM capability issues, it is important to acknowledge that organisations manage their performance, both internally and as part of a project team, in different ways. Some organisations choose not to adopt BIM software tools and workflows but prefer to implement *workarounds* to avoid the costs and challenges of adoption. These workarounds, according to Merschbrock and Figueres-Munoz (2015), reflect insufficient financial resources or inadequate know-how and may lead to confused information exchanges between project participants. Other organisations opt to develop their own workflows, protocols and standards in complete isolation from others. Such an approach is not only costly and time-consuming for these organisations, but signals their hesitance to openly share improvements and promote the spread of compatible protocols across the industry.

To improve performance across the AECO industry, stakeholders must understand the importance of adopting common BIM tools and workflows as well as sharing information and best practices.

2.1.2. Organisational Performance Measurement

While organisations within the AECO industry vary greatly based on the type of business they conduct, it is important to apply unified, reliable and valid metrics that allow the measurement and comparison of their performance. Organisational performance measurement will need to report on whether an organisation increases its overall productivity, delivers better outputs, and meets or even surpasses its target performance improvement objectives. However, the term *performance* is a relatively generic and is thus often replaced with *BIM capability* and *BIM maturity*.

As a term, capability describes what an organisation is able to do and what actions it can take based on its organisational competence. It combines the aspects of knowing what to do with the ability to do it. In other words, capability measurements identify what an organisation can deliver in comparison to what is specified or expected, and reflects its dynamic ability to rethink existing know-how and develop new solutions.

In addition to *capability*, the term *maturity* is often used to describe how well an organisation or its members can manage their processes and tools (Andersen and Jessen, 2003). In more general terms, maturity identifies the performance criteria to be fulfilled by assigning a maturity level or milestone that best describes the use of available knowledge, best practices and innovative techniques within a business or across the whole market (Yazici, 2009).

There are multiple approaches to maturity measurement including those that yield a formal certificate. For example, in the field of project management, there are several specialised entities that offer to certify project managers according to well-defined and commonly-used guidelines. The Project Management Institute (PMI) and the International Project Management Association (IPMA) are two such global organisations providing certification and delivering courses through a network of national associations (IPMA, 2015; PMI, 2015).

Nonetheless, there are several ongoing efforts to measure how construction organisations perform. With increasing demands for construction efficiency and the availability of more detailed procurement protocols, the development of metrics to establish and compare organisational performance is now needed. As mentioned earlier, the development of the EUPPD will necessarily exert transformational pressures on the industry to develop such metrics, and may well drive the generation of common guidelines for assessing and improving organisational performance within the EU.

2.1.3. BIM Performance as Capability and Maturity

As mentioned earlier, in a project context, BIM performance can be separated into capabilities and maturity. Assessment of BIM capability defines the minimum requirement for producing a task or delivering a service a project team possesses or is fulfilling. This can for example be the ability to produce a BIM model with a specific software. BIM maturity on the other hand distinguishes the project teams' quality, repeatability and degrees of excellence in which they perform the task or delivering service (Succar et al., 2012; Sebastian and Van Berlo, 2010). For example, rather than determining what tools are being used, BIM maturity determines how well they are used.

Identifying and collecting performance data is important to motivate and prove the efficiency that can be achieved by BIM implementation. However, many managers within the AECO industry may be reluctant to allow external parties to carry out this assessment. According to Costa et al. (2006), this unwillingness is a significant sign that AECO companies do not emphasise the importance of performance measures and benchmarks enough. This can be a reason why drive and development of BIM assessment is lacking. On the other hand, many organisations control and measure a wide range of other variables (Costa et al., 2006). Since performance data associated with BIM implementation processes and tools is infrequent, the most relevant metrics can be difficult to select when developing a framework for performance measurement. Having established what BIM performance is and why it is important, one should identify what measures are already in use and how suitable they may be to assessing BIM performance in accordance with the performance definition.

In the Information Technology (IT) sector, the advancement of the Capability Maturity Model (CMM) has spawned a development of comparable models for various sectors including manufacturing, healthcare and construction (Curtis et al., 2009; Curtis et al., 2002). As a performance measurement approach, CMM was at the outset designed to distinguish strengths, weaknesses and risks in software development projects (Paulk et al., 1993). Later model adaptations were intended to assess infrastructure projects yet proved less able to address the specific challenges of the construction industry (Jia et al., 2011).

2.2. BIM Performance Assessment Frameworks

There is an increasing number of frameworks which can be referred to as BIM performance assessment frameworks. These include the Interactive Capability Maturity Model (I-CMM, 2009); BIM Proficiency Matrix (Indiana University, 2009); BIM Maturity Levels (Bew and Richards model, see BIM Industry Working Group, 2011); BIM QuickScan (Sebastian and Van Berlo, 2010); BIM Maturity Matrix (Succar, 2009b); Vico BIM Score (Vico, 2011); CPIx-BIM Assessment Form (CPI, 2011); BIM Excellence (BIMe, 2013); bimSCORE (bimSCORE, 2013); BIM Planning Guide for Facility Owners (CIC, 2013); and BIM Competency Assessment Tool (Giel and Issa, 2015). This section addresses these frameworks. A short description of each is provided below:

2.2.1. Interactive Capability Maturity Model

This Interactive Capability Maturity Model (I-CMM) is part of the United States National Building Information Modelling Standard (NBIMS). I-CMM was first published in 2007, slightly modified in 2009 and released as v1.9. However, it has not been updated since then. The I-CMM establishes the maturity of the model/project by assessing eleven topics against ten maturity levels. Using either a static table or an interactive Excel tool, I-CMM generates a single maturity score. This is intended to help "determine the level of maturity of an individual BIM as measured against a set of weighted criteria agreed to be desirable in a Building Information Model" (NIST, 2007; NIBS, 2007a; NIBS 2007b; Suermann et al., 2008; NIST, 2015).

2.2.2. BIM Proficiency Matrix

In 2009, Indiana University developed an interactive Excel matrix to assist their own internal team and other facility owners to pre-qualify the supply chain. The matrix includes eight categories measured against four maturity levels which, upon completion, generates a single BIM Maturity Score (Indiana University, 2009). The matrix is completed by candidate project team members who must provide examples of past projects and address each of the eight BIM proficiency categories. Originally it was designed to assess BIM projects and how it could enhance FM (Indiana University, 2009).

2.2.3. BIM Maturity Levels

The iBIM model or the *Wedge* BIM maturity model (Figure 1) was developed by Mark Bew, Chairman of the HM Government BIM Working Group; and Mervyn Richards, Member of the BuildingSMART UK Managing Board (BIM Industry Working Group, 2011; buildingSMART UK, 2015; BIM Task Group, 2015). In its current form, the model reflects both the UK Government's BIM strategy and many of the industry's ongoing BIM initiatives. The model identifies different levels of market maturity by grouping standards and working methods into three initial BIM Levels. Based on this model, in 2011 the UK Government's BIM Task Group mandated that all publicly-procured construction projects are to meet Level 2 requirements by 2016 (Hooper, 2015). While the terminology, standards and methods linked to the *Wedge* model are mostly UK-specific, it has been used as a guiding framework for BIM policy development in a number of countries.

2.2.4. BIM QuickScan

BIM QuickScan is an online tool developed by the Netherlands Organisation for Applied Scientific Research (TNO). BIM QuickScan is intended to assess the BIM performance of organisations in the Netherlands and generate a performance benchmark at an organisational level through a multiple-choice scorecard based on a series of KPIs. The assessment is conducted against four chapters (categories) and multiple KPIs, and is available in two versions: a free "*self-scan"*, and a more detailed commercial service delivered by a BIM consultant (Sebastian and Van Berlo, 2010; Van Berlo, et al., 2012).

2.2.5. BIM Excellence

BIM excellence, BIMe, further extended by BIM Maturity Index, BIMMI, and BIM Maturity Matrix are all developed by Succar for assessing BIM. They are all developed on the same theoretical framework and complex to apply across disciplines. BIMe is a commercial online platform used for assessing performance of organisations, projects and individuals in relation to BIM (Succar et al., 2013). It is based on the published research of Succar (2009b; 2010) and Succar, Sher and Williams (2013). BIMe includes multiple modules for assessing the performance of individuals, organisations, projects and teams. The basic free assessment generates a simple downloadable report, while the more detailed assessments generate competency profiles for comparison against project requirements, pre-qualification criteria and role definitions (BIMe, 2013).

2.2.6. BIM Maturity Matrix

Developed as part of the same large BIM Framework (Succar, 2009a), the BIM Maturity Matrix is a static self-assessment tool with ten capability sets, three capability stages and five maturity levels.

According to Succar (2009b; 2010), the matrix is intended for assessing the BIM capability and BIM maturity of organisations; where BIM capability refers to minimum ability, and BIM maturity refers to the quality, repeatability and predictability of these abilities.

2.2.7. Vico BIM Score

In 2011, the BIM software tool vendor Vico developed its own scorecard directed towards construction managers. With a focus on clash detection, scheduling and estimating, the declared aim of the tool is to assist organisations to compare their performance against their competitors. Each of these areas is graded based on functionality and capability, best practices and enterprise integration (Vico, 2011).

2.2.8. CPIx-BIM Assessment Form

The CPIx-BIM Assessment Form is a static questionnaire developed by the Construction Project Information Committee in the UK. The questionnaire includes twelve areas grouped under four categories and is based on working documentation provided by Skanska (CPI, 2011).

2.2.9. bimSCORE

bimSCORE is a commercial tool based on the VDC Scorecard, the research effort conducted by Kam, et al. (2014) at Stanford's Center for Integrated Facility Engineering (CIFE). bimSCORE evaluates BIM practices across ten dimensions, grouped under four areas. The scorecard, which also has a free online version, evaluates the maturity of virtual design and construction practices on construction projects. It does this by comparing the performance of new projects against past projects and industry benchmarks (bimSCORE, 2013; CIFE, 2013).

2.2.10. BIM Planning Guide for Facility Owners

The BIM Planning Guide for Facility Owners is a maturity matrix developed by the Computer Integrated Construction (CIC) Research Program at Pennsylvania State University presents an approach in which FM organisations can plan for integrating BIM through strategic, implementation and procurement planning. The Excel matrix is divided into six categories, five maturity levels and is intended for owners to rate their own organisation (CIC, 2013).

2.2.11. BIM Competency Assessment Tool

The BIM Competency Assessment Tool (BIMCAT) is based on research reported by Giel (2013). BIMCAT is targeted towards facility owners and includes 12 competency categories and 66 factors measured against six maturity levels. The assessment is intended to be self-administered by a manager using an interactive offline questionnaire. Upon completing the assessment, the tool generates a single maturity score as well a number of radar charts.

2.2.12. VDC Scorecard

The Virtual Design and Construction (VDC) Scorecard is a framework for evaluating VDC implementation through a series of measures developed with emphasis on the design and construction phases. The scorecard covers four areas of VDC performance; planning, adoption, technology and performance. (CIFE, 2013).

Bassioni et al. (2005) stress the importance of not relying on a single framework and the metrics it includes. Given the diversity of organisations and projects within the AECO industry, it is unlikely that all relevant metrics are included in one framework or that all metrics included in a specific framework are relevant to all organisations and projects. On the other hand, using several frameworks may require a significant investment of resources and there is a risk that the frameworks may not be compatible. The frameworks presented by Succar and Bew/Richards are among the more ambitious ones for assessing BIM performance. However, Bew/Richards iBIM model is considered overly simplistic and unsuitable for comprehensively assessing BIM performance. The model developed by Succar provides a way to assess BIM Maturity, however it is perhaps over complicated and too resource demanding to apply. The methods and availability of data necessary to measure BIM capability and maturity in more depth also require additional development. Further, most of the existing frameworks are not open access tools; they either need to be internally developed based on general guidelines or require investing in a consultant to carry out the assessment. Furthermore, they do not offer the possibility for industry-wide benchmarks and thus limit inter-organisational and industry-wide data sharing.

2.3. Benchmarking BIM Performance Through Self-assessment

According to Bassioni et al. (2005) the AECO industry has been noted by many for being complex, with high levels of conflict, underperforming, and characterised by low levels of productivity (Manderson et al., 2015). There is, seemingly, a need for developing ways of assessment that support improvement of BIM performance. Performance, a broad concept with, no widely accepted industry definition (Rankin et al., 2008), has different meanings between and even within sectoral contexts (Kouzmin et al., 1999). Performance in an organisational context has traditionally been measured through financial parameters such as return on investment (ROI) and is often criticised for providing a too narrow and one-sided focus on organisational productivity and direct profit. In the AECO sector attempts at measuring performance in using BIM has mainly been focusing on measurable financial output in relation to time and quality at the organisational level (Bassioni et al., 2005). In doing so, it fails to take the total performance of BIM use into account with all aspects that contribute to a competitive advantage (Beatham et al., 2004), further it does not address the actual performance of using BIM. Liu et al. (2015) explain performance assessment as a process of quantifying and reporting the efficiency or outcome of an action that is performed in line with an organisation’s goals and objectives. The soft values or benefits generated using BIM such as improved communications between project participants should be included into an assessment of performance to provide more accurate results.

The AECO sector has demonstrated slow productivity improvement historically. An example of this was shown in a case study on the Canadian AECO industry that identified that this industry has historically lagged in labour productivity growth when compared to the rest of the Canadian economy (Rankin et al., 2008). This study further points out that this observation does not necessarily mean that the productivity is lower in the AECO industry. Instead it is suggested that measuring performance is more complex than it is in most other major industries. Additionally, AECO actors often have a more complex output and more versatile and dynamic way of conducting their business than in other industries. This again supports the thesis that traditional KPIs are not necessarily suitable to accurately represent overall performance as they might do in other sectors. (Rankin et al., 2008). When assessing BIM performance only through the above-mentioned financial indicators and other organisational value measures, it presents an incomplete picture. It requires abandoning some traditional methodologies and embracing more appropriate performance assessment to understand and develop business success (Liu et al., 2015). The use of traditional performance measurement indicators and frameworks can therefore be misleading and inaccurate when applied directly or partially to the assessment of BIM performance. It is here proposed that a common understanding of how to define BIM performance assessment is necessary and must be formalised.

2.3.1. BIM Benchmarking

Among the main benefits of assessing performance through common criteria is the possibility to enable benchmarking. Within the context of this research and based on the general definition provided by Costa et al. (2006), BIM benchmarking is a systematic process of measuring and comparing organisational, project team and individual BIM performance with that of competitors or internally between projects;

often with the objective to identify or determine best practices. In addition to assessing its own success internally, each organisation can use the lessons learned from competitors to improve its BIM performance and through this avoid common mistakes as well as unnecessary re-work (Costa et al., 2006). To be able to benchmark externally throughout the industry, an internal assessment must be performed. Internal BIM benchmarking can also be performed as AECO organisations tend to benefit from comparing the performance of their own projects from each other. In that sense, it is difficult to separate internal from external benchmarking since one depends on the other.

If developed from within, initially as a way to assess BIM performance across projects, the size of the organisation can be critical in deciding the capability to assess. Kouzmin et al. (1999) suggest that only large companies can afford to develop their own method of benchmarking and that smaller organisations must rely on frameworks already developed by and specifically for their larger competitors. This can affect the relevance of the metrics involved and potentially lead to misleading performance benchmarking results. However, internally developed frameworks for internal assessment later transformed into external ones, will most likely differ from those developed by others. From this perspective, externally developed unbiased methods for assessing BIM performance is required to make such a tool relevant and applied more broadly throughout the industry. According to Costa et al. (2006) there has been an increasing number of initiatives focused on developing ways of assessing performance of BIM in the AECO sector.

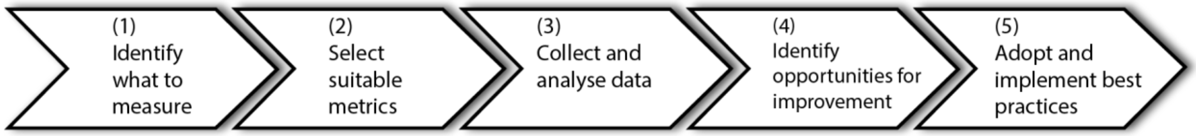

Figure 2. The process of benchmarking (Rankin et al., 2008)

Rankin et al. (2008) defines the process of developing benchmarking as following a step-by-step plan (Figure 2): (1) identification on what to measure, (2) selection of suitable metrics, (3) gathering of data, (4) identification of what can be improved and (5) adoption of best practice (Rankin et al., 2008). The search for valid indicators and methods of data collection are critical elements of this process and can "make or break" the whole process if sub-optimised or poorly executed. While the characteristics of organisations within the AECO industry vary greatly based on the type of business they conduct, it is important to apply unified, reliable and valid metrics that allow a uniform and accurate measurement and comparison of their BIM performance. Assessment of BIM performance will also need to report on how a project team benefits through the utilisation of BIM. Figure 2 illustrates that it is a key activity to identify valid metrics when developing frameworks or methods of assessing or benchmarking performance. But what are the suitable, valid, metrics for a BIM performance benchmark? Can there be a way of overcoming the challenges brought by the fact that sets of metrics will have different level of relevance when comparing organisations?

2.3.2. Self–assessment

A common practice, in the process of assessing organisational performance, is that an external party, often a consultant, is both gathering and analysing the data. The main reason for this might be that organisations want a neutral party, or that it is required for accreditation, but also that the process and most frameworks themselves are too complex for the organisation to manage them or address the challenge of providing knowledge from within. A likely effect of this is that organisations distance themselves from the act of assessing, as responsibility will be more concentrated in the hands of external parties. Through this process the, sometimes, sensitive information used for internal KPIs is exposed to external parties who are likely to have competitors as clients which in turn may be viewed as a business threat (Rankin et al., 2008).

Self-assessment of performance can help make the assessment process faster and less costly, and grow internal 'ownership'. Pun et al. (1999) define organisational self-assessment as "a comprehensive and regular review of an organisation´s activities and results against a systematic model of business excellence". Thus, it is here proposed that applying a self-assessment methodology for performance benchmarks can save time and money while at the same time build ownership. The assessment effort can also be ongoing, enabling continuous improvement processes in line with the dynamic and changing business climate in the AECO industry. Also, the continuous process of assessment and the continually-improving nature of the data may help increasing both the accuracy and the quality of the assessment. This is because parameters are up-to-date and updated as necessary and considered relevant by the users (Rankin et al., 2008).

A significant barrier, when developing a framework for organisational BIM performance assessment, is that the needs of different AECO actors will vary significantly between organisations and even between projects within a single organisation. It is unlikely that there is universal set of metrics for evaluating the BIM performance that is relevant to all actors in all scenarios. By allowing the user to select their own metrics from a default dataset, and add fresh metrics where required, the framework can grow organically, continually improving. This approach and methodology is in a way a type of crowd-sourcing; in this thesis understood as a growing, efficient way of collecting data and by that building multi-variable datasets (Pierce and Fung, 2013; Amsterdamer and Milo, 2015). Therefore, a framework for self-assessed BIM performance constructed through crowd-sourced data gathering is proposed to be a valid way of developing a BIM performance benchmarking system suitable for the diverse and protective AECO industry including FM organisations.

2.3.3. Selecting Valid Indicators

Developing a series of BIM performance indicators, BPIs, is a prerequisite and a paramount cornerstone in the process of creating a method for assessing BIM performance (Sebastian and Van Berlo, 2010). Crowd-sourcing a database of measures means it will grow organically to a certain extent. However, a generic framework with key indicators must be provided initially to drive and support use. It is of great importance to build this first set in collaboration and consensus with industry actors from different disciplines within the AECO industry (Rankin et al., 2008). BPIs need to be (1) valid, (relevant, appropriate and justifiable) (2) quantifiable and (3) realistic (Fang et al., 2004). After the first dataset is created, early users can start selecting the most relevant BPIs from the dataset that represents their view of key indicators of the BIM performance within their core business. In addition, they could request BPIs that do not exist in the dataset to be included. Through this process less used BPIs can be removed, or valued lower and thus the framework would become more relevant.

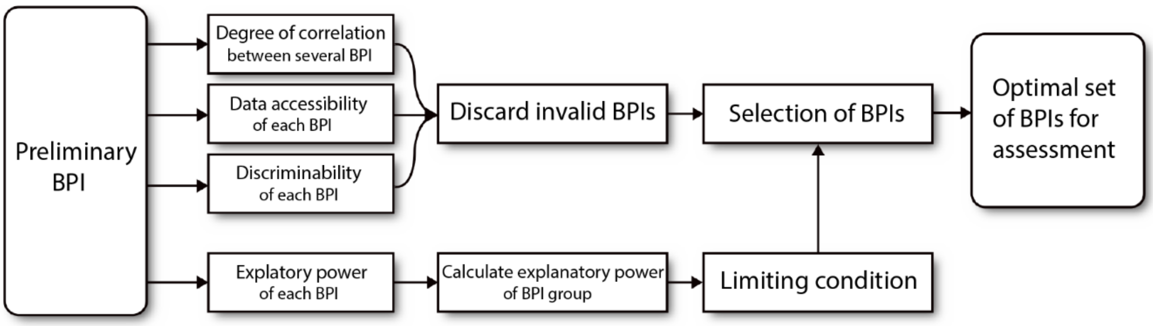

Figure 3. Process of selecting BPIs for assessment of BIM performance - amended version (Fang and Wong, 2015)

To reduce the risk of having deceptive data affecting the tool through the self-assessed benchmarking affecting the dataset, the BPIs should be regulated to some extent and, as noted above, be rooted among the participating industry actors (Rankin et al., 2008). Some administrative control has therefore to be included in a potential tool. Fang and Wong (2015) developed a model for selecting metrics for assessing organisational resilience. Their model, here provided with some minor alterations (Figure 3), is also applicable for the process of selecting BPIs for hosting a self-assessment BIM performance benchmarking tool. This implies that even if the user can add new metrics, there needs to be a managing entity that will validate it in accordance with the process provided in Figure 2. Further, the hierarchy of the importance or value of the metrics as well as whether they are fixed or changeable, must be established.

2.4. BIM as Support for FM Organisations

FM includes use and maintenance during the operations phase of a buildings lifecycle. BIM can function as a reliable basis for management and transfer of data and enables efficient decision making during a building's lifecycle including the operations phase. Kivits and Furneaux (2013) argue that the BIM methodology with a single rich model has the potential for improving the construction and management of a building in a lifecycle perspective including improvement in sustainability. The reality is not always that straight-forward though. FM organisations often have varying qualitative information documentation throughout their portfolios. One asset portfolio can include everything from LOD[7] 500 models to original hand drawn, several decades old blueprints. Developing IT infrastructure to support lifecycle management of digital building information generated in the BIM process will likely result in a vast variety of information handling/accessibility and might also require the use of parallel systems or tools for managing facilities. Pärn et al. (2017) argue that developing, using and maintaining systems able to capture and manage ever expanding involuted information will require high levels of strategic and tactical skill among the FM organisations staff.

Although, a paradigm shift towards a more digitalised information handling, thorough BIM data might entail barriers such as those mentioned above, a transition towards an integrated digital building information principle is likely to be beneficial in the long run. For FM organisations, at current state, efficient day-to-day operations and maintenance are highly dependent on the presence of reliable information, yet the FM sector seems to grapple with information management.

Though the use of BIM as a methodology has been evolving over the past few years, there are distinct barriers to achieving an efficient integration of data transfer from design and construction to FM. A tradition of perceiving the design and construction project as a distinct process entity from FM can be argued to be a reason for this. Combined with the fact that data formats have been varying depending on what specific BIM tool is used and who is populating the model, possibilities for solutions to carry significant project data from design and build to operation and maintenance has been limited. Kiviniemi and Codinhoto (2014) argue that this lack of interoperability combined with difficulties in keeping the information up-to-date are some of the main barriers to successful BIM adoption in FM. Industry Foundation Classes, IFC, a non-proprietary exchange format of building information between software and applications, was developed to represent information over the building's lifecycle. (Volk et al., 2014). Non-proprietary formats, like IFC, enable new possibilities for the development of solutions for handling project data deriving from the BIM process in a lifecycle perspective. If used coherently, non-proprietary formats may therefore be one key pre-requisite for development of new tools and ways of working with building and FM data.

As non-proprietary formats unlock the potential for new technical solutions for interoperable data flows, challenges for development and implementation will emerge. First, the FM organisation must identify

[7] Level of Development, LOD, enables practitioners to specify the content and reliability of BIM models at various stages in the design and construction process (BIMforum, 2017).

and specify what data they will require and develop a BIM Execution Plan[8], BEP, containing a strategy for creating, structuring and handling FM specific information. The Level of Information, LOI[9], and Level of Detail, LoD,[10] contained in model elements of BIM models developed for the design and construction phases of the project is not optimised to be used for FM purposes. Trying to use existing, sub-optimised, BIM models is not ideal for various FM functions and updating them can be difficult. LOD, containing LoD and LOI, is usually determined by the owner at the design phase and executed in the procurement and construction phases of a project (Becerik-Gerber et al., 2011). Project owners should decide these levels before the project is initiated. If over-dimensioning the LOD, they risk spending unnecessary funds and likewise inferior LOD will lead to a sub-optimised model unable to serve its purpose (Bonanomi, 2016).

It may be easy to over-focus on technological solutions as working with digital project information likely will introduce the building managing organisation to a more extensive use and development of software tools. Rather than perceiving the BIM implementation as a technology adoption or development activity, it should be viewed as variation of business routines and procedures. To support this development, an understanding that technology alone cannot deliver business outcomes is needed (Love et al., 2014), stressing the importance for a clear strategy including all organisational dimensions affecting implementation. As stated by Kivits and Furneaux (2013) managing this change will require an extensive management of knowledge, although they explain it as a further extension of current BIM practices. In contrast, it is likely that use or rather adaption of BIM to serve FM or a building's lifecycle will require re-development of the BIM process. Thus, to some extent BIM should be adapted to FM and vice-versa. Organisations working in FM will require different information than the one used for project support, also FM firms may have various capabilities and goals. For example, new parameters and dynamic LOD level matrixes will be required to be clearly stipulated in the design phase.

2.4.1. Identifying Dimensions for Assessing BIM Performance in FM

Assessment of FM organisations' application, use and performance of BIM will be different from assessment of organisations operating in design and construction phases. There may be two main reasons for this. First, the low BIM adoption in FM organisations in general limits the insight into key success factors and, in the long run, variables effecting their performance. Second, the nature of practice differs from that of other actors involved in a project including the time span in which they are operating. It is here proposed that, to gain better insight, new data addressing specific requirement for FM organisations adoption of BIM is needed. Investigated in this thesis are FM organisations owning and managing university buildings. University-focused FM organisations are a suitable niche to investigate since their asset portfolios can contain a variety of building types, ranging from standard office buildings to high-tech laboratories. Furthermore, it is likely that universities have incentives for improving FM efficiency through digitalisation considering that it is likely beneficial for universities to be perceived as innovative as well as acting innovatively. Lastly, efficient management of university buildings may contribute with a positive impact on education and research quality, making this field suitable and attractive to investigate. The following sections will explore BIM as support for FM and prerequisites for assessment of BIM performance specific for these organisations.

[8] BIM Execution Plan, BEP, is a document developed by the suppliers explaining how the information modelling aspects of a project will be carried out (NBS, 2017).

[9] Level of Information, LOI, defines the amount of non-graphical information is added to a model element (BIMForum, 2017).

[10] Level of detail, LoD, defines the amount of graphical information contained in a model element (BIMForum, 2017).

2.4.2. Assessing BIM Performance in FM Organisations

To prove the efficiency of BIM projects or evaluate an organisation's BIM deliverables and use, the performance should be assessed. In terms of object-based model information, the FM side is far from being as developed as actors working with executing design and construction. FM includes use and maintenance during the operations phase of a building's lifecycle. Van Berlo et al. (2012) presents a case study, evaluating and comparing the BIM performance of all actors in the AEC industry and operations (AECO). Here, actors with client/owner and FM roles had the lowest BIM performance levels out of all primary AECO stakeholders. A major reason for this is that traditionally the operations of a building have been perceived as something separate from its design and construction. Following that pattern, the process of generating a BIM model is often divided in the same fashion as the physical asset which creates illogical hurdles for the information flow between project stages. This leads to a low level of inclusion of FM actors in design and construction and subsequently low involvement in the development and adoption of BIM methodology during operations.

The approach presented in Section 2.4 includes a self-assessment methodology using a crowd-sourcing approach to populate and autonomously refine the inclusion of parameters for assessing BIM performance of projects. The methodology would require a series of default BPIs to serve as a foundation for continuous improvement. To enable this methodology, parameters for adequate performance assessment are needed. Generally, the process of refining parameters as shown in Figure 3 requires a preliminary set of BPIs followed by meticulous analysis and validation.

To assess an organisation's BIM performance there are several different methods of collecting data required to do so. One efficient way is to perform interviews with employees directly involved with the organisation's operation. Furthermore, various analyses and surveys can serve as efficient self-assessment tools for assessing the organisation's performance (CIC, 2013). BIM in FM is not yet significantly established, consequently there is a lack of methodologies and parameters to assess the performance of actors in this field.

As addressed in Section 2.2 there are a number of models and frameworks that have been developed to measure BIM performance by assessing the capabilities and maturity of individuals, teams or organisations. These have been developed in an ad-hoc fashion and are, if not organisation-specific, likely influenced by the context in which they were developed (Bassioni et al., 2005). Furthermore, they are applied differently and have different levels of applicability to include FM organisations. These frameworks for measuring performance are still evolving and are applied differently across the market. The development of some of them has been driven by the industry while others have been driven by government or academic actors. Similarly, some have been developed for a specific project or organisation while some are intended for a broader audience. These create different areas of focus regarding metrics and methods used.

3. Research methodology

During the initial phase of the research project it was identified that the field of BIM performance assessment, and in particular within FM organisations, was novel. Regarding performance assessment, it was found that the amount of published academic literature was low. Furthermore, there was a lack in coherence in how the topics were addressed between the few but different studies that had been done. There was also a little amount of research and results identifying industry understanding and adoption. Hence, development of this thesis has been conducted as an exploratory research comprising secondary data through literature reviews and formal qualitative research through an interview-based case study. This has provided insight into current practices and requirements for future implementation of BIM in FM organisations and subsequently led to the development of a methodology concerning how to self-assess performance and capabilities. The following sections describe how the research was conducted.

3.1. Literature Review

The research presented in the literature review has been developed as a descriptive review of literature based on academic publications. In addition, this thesis has gathered new data through a case study. As performance assessment within the AECO industry in general and BIM specifically are relatively under-developed, parallels to different sectors and their frameworks have been analysed and described to map the context for such development. The literature review has been conducted in three phases with an initial scoping review (Arksey and O'Malley, 2005) focussing on establishing a general knowledge of BIM performance. This initial study was followed by the phases described below.

3.1.1. Phase 1

The first phase of literature review aimed at gathering general information related to BIM performance assessment and initiatives driving the development of this in different regions globally. Initially this was done by using a scoping research approach to gain necessary overview and map knowledge in the field. The literature search was mainly done through Google Scholar and Curtin University library catalogue initially utilising the following scoping keywords; BIM performance, BIM Maturity, BIM Capability and BIM Assessment. Key authors processed and mapped were; Bilal Succar and Leon Van Berlo. These were chosen since they were the most quoted authors per the keywords. Furthermore, various frameworks for measuring, evaluating and assessing BIM performance, BIM Efficiency, BIM Capability and BIM Maturity were reviewed in terms of structure, content and methods used for assessment. The meaning and overlap of and between these terms was also studied.

3.1.2. Phase 2

This phase aimed to contribute to the development of a tool for benchmarking BIM performance. This section of the research aimed to answer the following questions: (i) Is self-assessed benchmarking a relevant and reliable approach for assessing BIM performance at the project level; (ii) Is crowd-sourcing a valid and relevant method to populate a potential prototype BIM performance benchmarking tool? If so, how should the most appropriate metrics for benchmarking performance of the use of socio-technical systems such as BIM be selected? (iii) What methods can be used to ensure the comparability, accuracy and consistency of the data input by users?

3.1.3. Phase 3

The aim of this phase was to gather insight concerning BIM performance assessment of and in FM organisations. Initially a literature review was carried out to establish a knowledge base about the ways scholars addressed BIM adoption in FM organisations. It was found that literature concerning BIM performance assessment applicable to FM organisations, with a comprehensive understanding, were few. To address this, a comparison between frameworks and tools for measuring and assessing various aspects related to BIM performance and value was made. A preliminary comparison focused on how these frameworks and scales divided their metrics into categories, particularly on those that seemed most relevant to the study. The categories, here referred to as dimensions, were validated in terms of their use in the reviewed frameworks and relevance to the FM sector judged empirically through a series of six interviews with four different university FM organisations in Australia and Sweden.

3.2. The Case Study Approach

Efficient implementation and use of digital data, deriving from the project, in FM organisations requires effective implementation strategies. To identify these strategies, key factors affecting the BIM progression need to be identified. A self-assessment approach to this will enable a way of evaluating implementation progress and efficiency. The BPIs needed for such a method needed to be identified and validated. Since information related to this is very limited, new data to create a general framework for BPIs and long-term success factors specific to FM organisations was necessary. Furthermore, complex processes and issues can be better understood as new data is gathered and evaluated. An efficient way of doing this is by conducting a case study (Dooley, 2002). By applying a case study methodology when gathering and testing data, a deeper insight and understanding for complex issues will be possible to obtain. In addition, a case study can contribute to a greater confidence for what is already proven or identified in past studies (Dooley, 2002).

Developing a theoretical framework is central when performing a case study focusing on organisational research. Eisenhardt (1989) stresses that a weak theory can result in weak ties between the theory and the test results due to an overly widespread accumulation of case study methods. There are different approaches to conducting a case study research with varying approaches, all of which strive to explore an area/issue and seek to reveal patterns, aspects and core structures of it. As the theory and examples from practice is novel and limited in this field, this research focused on combining available theory with qualitative semi structured face to face interviews. Ultimately a case study approach will enable yielding a default series of BPIs specifically suitable for assessing the performance of BIM use in FM firms.

The following table includes the organisations participating in this research.

Organisation	**A**	**B**	**C**	**D**
Country	Sweden	Sweden	Australia	Australia
Description	One of Sweden's largest building owners and FM organisation with a market share of 60% in the university segment and a project portfolio of AUD2.8 billion (SEK18 billion)	B, itself owned by the university it owns, manages and develops assets	C owns, manages and develops their own assets in coherence with guidelines from Tertiary Education Facilities Management Association, TEFMA, who provide strategic and operational infrastructure and services in support of tertiary education throughout Australia and parts of Asia (TEFMA, 2016).	Owned by the university, D manages, owns and develops assets on two university campuses.
Portfolio	University buildings spread out across Sweden. Property value is 10.6 billion AUD (67.5 billion	Manages assets on two university campuses Gothenburg and a space observatory outside	University buildings spread out across eight campuses in Australia and one in Malaysia. The main campus is situated in	University buildings spread out on three campuses in Western Australia.

	SEK[11]). Annual turnover is 0.9 billion AUD (5.7 billion SEK)	Gothenburg. Property value is AUD400 million (SEK2.7 billion). Annual turnover is AUD78.7 million (SEK500 million).	Perth, Western Australia.	
Ownership	A is publicly-owned and manages its own buildings.	Private institution owning, operating and strategising for their own properties.	TEFMA is a privately owned, non-profit membership organisation functioning as a strategic advisory board for Australasian universities managing their own buildings in line with TEFMAs directives, one of those are C. However, strategic input from TEFMA is limited to a few benchmark indicators.	Private institution owning, operating and strategising for their own properties.

Figure 4. Organisations participating in the case study

3.2.1. Interviews

Interview-based case studies aims to collect qualitative information from people with connection to or likely valuable knowledge or opinion about the researched topic for further analyse. Interview outcomes can also serve as benchmarks to compare non-connected knowledge or opinions with connected ones to validate the significance of the information. Since using BIM in FM organisations is quite novel, it is expected that detailed knowledge of its present or future use is difficult to obtain directly from respondents. Interviews sought to obtain a general image of the organisation's present status, future use and perception of the implications connected to BIM use in FM.

Furthermore, knowledge gained through interviews can help, by adding insight, when developing and evaluating the importance of specific BPIs deriving from analysis of the interview outcomes. This can then enable the development of prerequisites for further research and development of BPIs relevant for assessing organisations working with BIM in FM. An interview based case study is set to mirror reality, but there is a trade-off between level of control and degree of realism (Runeson and Höst, 2008). As FM organisations have different levels of development practice and adoption, it is challenging to foresee the outcomes of such interviews. Therefore, the interviews consisted of open-ended questions aiming to cover a wide variety of topics. Also, the respondents partaking in the case study were working in strategic level functions or specifically with building information. As part of this case study, interviews and follow up questionnaires with representatives from four university facilities organisations in Sweden and Australia was conducted this is presented in the following section.

The intention with the interviews, conducted for this thesis, was to map out the importance of the dimensions presented in Section 4.1.1 with regards to using BIM in FM organisations. This is a logical step towards obtaining a deeper knowledge and a positive way forward. The interviews included representatives from four FM organisations managing university buildings. The exploratory case study

[11] Exchange rate used for currency conversion 1 AUD = 6.35 SEK [accessed: 06-09-2017]

is based on five organisational dimensions in which a series of BPIs can be further developed. The case study comprised interviews with participants appointed by the organisation based on following selection criteria:

- At least three years' experience within the organisation.
- Strategic or production staff working with operations.
- A position in which BIM adoption for FM is relevant.

The case study material was interrogated and analysed to answer following questions which were derived from the literature review as being significant:

- Are there any capabilities they look for internally related to BIM or handling of digital building information?
- Are there any capabilities they look for when procuring and purchasing? If so, are they applying some sort of scale or protocol for this?
- How do they perceive digitalisation of the built environment and use of information exchange between project and FM?
- What prerequisites or organisational dimensions do they perceive as important for implementing this exchange?
- Are there any uses enabled or enhanced through use of digital project information that they view as possible or more important?
- Is there any difference if the building managing organisation also owns the project or just manages the building?
- Do they consider the country they are operating in affect the result?

3.2.2. Categorising, Transcribing and Analysis

The interviews were audio recorded (with permission) and sections that were considered pertinent to the research question were transcribed and later categorised into 12 sections addressing different discussion topics. The respondents were anonymised in accordance with the approved research ethics, HRE2017-0707.

A general summary of each topic was written and, where applicable, quotes and/or individual summaries were used to outline the respondents' answers. Each section compiled replies from the respondents on similar topics to carry out a cross-case comparison following the methodology outlined by Yin (2013). These were then mapped against the outcomes of the literature review in the discussion section.

4. Results and Discussion

This section presents the main results from the case study using cross-case analysis method outlined by Yin (2013). The second part of this chapter presents the discussion which compares the empirical findings to the literature review.

4.1. Literature Review Outcomes

Although, none of the existing frameworks addressed is specifically designed for FM-based activities, some of them present indicators that can be used to assess the performance of FM-related organisations. By comparing how these frameworks treat the different factors affecting the overall performance, perspectives on how to map factors for assessing performance of organisations or activities in a FM context can be identified. Following are summaries of how some of the frameworks are addressing organisational dimensions in relation to BIM performance assessment.

BIM Excellence is an online tool that assesses the performance of organisations, projects and individuals in relation to BIM. This commercial tool is based on the research of Succar et al. (2013), and divides the assessment subject into eight main dimensions: technical, operational, functional, implementation, administration, supportive, research and development, and managerial. *BIM Excellence* is developed in coherence with the more extensive tool *BIM Maturity Index*, BIMMI dividing the BIM implementation into stages from object-based modelling to an integrated project delivery. Dimensions in which organisational BIM maturity is sought is divided into technology, processes and policies (Succar et al., 2013).

BIM Quick Scan developed by Sebastian and Van Berlo (2010) is intended for generating a performance benchmark. It divides the organisation into four categories consisting of series of parameters: organisation and management; mentality and culture; information structure and flow; and tools and applications.

The *BIM Planning Guide for Facility Owners* developed by CIC (2013) at Penn State University divides the organisation into six categories: strategy, BIM uses, process, information, infrastructure, and personnel.

Azhar et al. (2015) describes BIM as a combination of technologies and processes. However, when adapting the BIM methodology to FM, processes and technologies will change. Furthermore, FM organisations should consider dimensions, considered to be soft, such as knowledge, communication and culture.

Dimension	BIM Excellence and BIMMI	BIM Quick Scan	BIM Planning Guide for Facility Owners	Azhar et al.
Technology	x	x		x
Knowledge			x	
Communication		x	x	
Processes	x		x	x
Culture and Motivation	x	x		

Figure 5. Summary of dimensions addressed in existing frameworks

4.1.1. Five Organisational Dimensions for Assessing BIM Performance

After comparing the above-mentioned frameworks and methods, this research adopts five organisational dimensions as a foundation for identifying relevant BPIs suitable for assessing FM oriented organisations. These are: (1) Technology; (2) Knowledge, (3) Communication; (4) Processes; and (5) Culture and Motivation. These dimensions are detailed in the following sections.

4.1.1.1 Technology

The technology dimension includes technical solutions serving and performing data management and use. Specifically addressing BIM technology refers to hardware and mainly software solutions as addressed by Van Berlo et al. (2012) in BIM Quick Scan as tools and applications, further addressed in BIMe, BIMMI (Succar et al., 2013) and by Azhar et al. (2015). Technology assessment has two main approaches, first technology available for a specific need and secondly, technology obtained by the organisation. While technology available may indicate, the possibilities open to supplier capability, technology obtained can indicate the organisation's maturity comparing the deviation between the availability and the technology obtained. The dimension concerns firstly, what capacity organisations possesses to use the technology and secondly, what technology they are using. These can be related to financial indicators (CIFE, 2013). FM organisations should make sure that the tools they are currently using will be compatible with the building information deriving from the BIM process. They also must ensure that structure and formats of the building information can be used to serve operational needs. BPIs developed within this dimension should be able to assess whether the firm or team has all technical capabilities necessary to perform or receive required BIM services or products.

4.1.1.2 Knowledge

The knowledge dimension reflects the organisation's collective knowledge primarily in terms of competent staff members, information held and use of information addressed by CIC (2013) in the BIM Planning Guide for Facility Owners. BIM Quick Scan also addresses information as a category (Van Berlo et al., 2012). New organisational development such as integration or further utilisation of project data in FM often requires rapid and effective knowledge integration throughout the organisation. This also includes strategies for knowledge integration over time and how implementation will be aided by the organisation's preparedness for change (Marsh and Stock, 2006). A critical factor can be a lack of competent staff to employ which can become a significant barrier to implementation of new methodologies. In short, what strategy does the organisation possess to obtain and manage knowledge? When implementing BIM, a new way of working with building information, FM organisations require hiring new staff as well as educating its employees. Supportive assessment of knowledge possessed and required related to BIM enables this. BPIs developed within this dimension should be able to assess whether the firm or team possess the knowledge necessary to perform or receive required BIM services or products.

4.1.1.3 Communication

This dimension includes the capacity to retain and share knowledge between projects and participants. It also addresses the efficiency of information flows between projects, project participants and organisational departments. BIM Quick Scan emphasises information structure and flow as an important dimension to assess (Van Berlo et al., 2012). For a business knowledge sharing is capturing, organising, reusing and transferring the vast and unique knowledge that resides within the organisation and making that knowledge available to others in the business (Reid, 2003). When implementing BIM in FM, effective communication between design and construction actors is key, as well as between FM actors. The required model content must be established before the project is initiated. Furthermore, disciplines within the FM organisation may find new ways of internal collaborating through digitalisation of building information stressing the importance of good knowledge sharing. BPIs developed within this dimension should be able to assess how capable the firm or team is in communicating and sharing knowledge supporting their performance and receiving required BIM services or products.

4.1.1.4 Processes

A good understanding of and a clear strategy for the causal relationships between organisational entities affecting new implemented methodologies is required for a successful implementation and use (Marsh and Stock, 2006). Furthermore, clarity about which events occur and what resources are used is needed. Processes are included as assessment categories in BIMMI (Succar et al., 2013), BIM Planning Guide for Facilities Owners (CIC, 2013) and by Azhar et al., 2015) If processes are not specified and followed, it may hamper change and adoption of new business methodologies. As new technologies and management of knowledge and communication will change through BIM integration in FM, processes in which to apply these must be designed and followed. To make sure that they are effective, they should be properly assessed. BPIs developed within this dimension should be able to assess how well the firm or team is supported by processes specifying how to perform and receive required BIM services or products.

4.1.1.5 Culture and Motivation

This dimension refers to openness and responsiveness for change of business procedures and adoption of new methodologies as well as willingness and capability to drive change. Organisational culture is described by Martins and Terblanche (2003) to be deeply-seated values and beliefs shared by the members of an organisation which will manifest its characteristics and affect the ability to change business methodologies. BIM Quick Scan addresses culture and mentality as dimensions for assessment (Van Berlo et al., 2012). BIM in FM may include a dramatic change in how building organisations conduct their business, stressing the importance of implementing and testing new practices and tools. An environment in which risk taking through innovative and creative development is encouraged is necessary as business methodology changes and develops into new areas. Organisations need to consider that some initial problems might occur when new procedures are implemented in the business and communicate a culture in which errors and initial mistakes are not discouraged (Martins and Terblanche, 2003). BPIs developed within this dimension should be able to assess how well the firm or team is supported by the organisational culture and motivation to develop, perform and receive BIM services or products. This could either relate to financial indicators such as, money spent on R&D tied to BIM, or to the employees' experience of support from the organisation.

4.2. Empirical Research Outcomes

Table 4.1 provides information about the respondents participating in the case study. Their actual names and those of their organisations have been substituted with acronyms for privacy reasons. The following sections will explore their answers following the 12 categories described in the methods section.

Respondent acronym	Position/role	Country	Background	Organisation
SA1	IT Development Manager	Sweden	IT, GIS, Land-surveyor	A
SA2	Construction Engineer	Sweden	Civil Engineer	A
SB1	Vice President	Sweden	Civil Engineer	B
AC1	IT and Data Manager	Australia	Project Management	C
AC2	Space Optimisation Manager	Australia	None of relevance	C
AD1	Buildings and Services Manager	Australia	Facilities Management	D

Figure 6. Interview respondents

4.2.1. Definition of BIM

The respondents were first asked to define the acronym BIM. Their answers showed that they had a varying basic knowledge of BIM but all the respondents were familiar with the term. They however defined it in different ways. Some choose to describe the acronym BIM as Building Information Management while some used the more conventional Building Information Modelling. One respondent had only heard of the acronym before but did not even know what it stood for. Following are quotes from each respondent's definition of BIM:

> IT Development Manager [SA1] - "Building Information Management is an all-encompassing work methodology with affiliated information models and technological support".
>
> Construction Engineer [SA2] - "Building Information Management is about processes rather than a method of working with 3D models".
>
> Vice President [SB1] – "Building Information Modelling is a way to manage data or information concerning buildings in terms of drawings, materials and operational aspects".
>
> IT and Data Manager [AC1] – "Building Information Management is a concept in which attributed data, elements and intelligence are applied to a virtual world, the BIM model."
>
> Space Optimisation Manager [AC2] – The respondent was not comfortable enough to define it but said he had heard of it before.
>
> Buildings and Services Manager [AD1] – "Building Information Modelling is information presented in a dynamic manner representing all services (mechanical, electrical, hydraulic, fire, structural information) included in a single application. Used to assist and help FM practitioners understand construction and operation of a building."

4.2.2. Benefits with BIM in General

Respondents were asked to list what they perceived as the main benefits from using BIM in design and construction projects. In the cases the respondents did not have any experience using BIM, they were asked what makes them interested when they hear others speak about BIM.

The benefits that were mentioned were:

- Clash detection
- Information orderliness
- Information for FM
- 5D planning
- Easier visualisations and energy calculations
- Better logistics and material handling
- Easier refurbishments due to detailed information access.

Two respondents were not able to name any. Three of the respondents named clash detection as a main benefit stressing the benefits with detecting and correcting errors and omissions at the design stage. SB1 named information orderliness over a projects lifecycle as the main benefit. Information for FM was mentioned by SA1 and AC1 who stated:

> "BIM will allow us to change space information during FM without having to update on several instances. This will reduce labour and errors." [AC1]

Specifically, AC1 said that the benefits depend on the stakeholders' role. For instance, construction would benefit mostly from clash detection, a mechanical engineer from speed of installation, plumbing would avoid conflict with structural engineers and structural engineers have been working with BIM for years. Furthermore, SA1 listed 5D planning, easier visualisations, energy calculations and better logistics and material handling as important benefits with BIM. AD1 mentioned that BIM use will assist in developing and progressing building refurbishment projects where a clear understanding is required when redesigning and modifying existing services.

4.2.3. BIM Practice and Experience in the Organisation

According to the respondents replies, only one of the responding organisations, A, had an elaborate BIM work practice in design and build projects. Organisation C had done a few BIM projects but they had relied on external BIM coordinators to plan the BIM execution, they were merely the silent observers in these projects. A problem they encountered was that the BIM deliverables did not contain the data they required for their FM operations.

Organisations A and C had begun investigations and preparation for future BIM adoption in their respective FM organisations but had varying approaches to strategy development. Organisation C has initiated a BIM project (medical school) in which they are developing a BEP that they intend to use as a standard for upcoming BIM projects. This, they expect, will enable them to obtain data from earlier lifecycle phases that they can use for their FM operations.

Respondents SB1 and AD1 did not have any experience from BIM projects that had been conducted by their respective organisations.

SA2 stated that organisation A is largely using BIM in their design and construction projects, both in terms of planning and support for production.

> "In some projects employees are using iPads to track production progress for instance. In other projects, they are using BIM as support for quality control where a certain amount and structure of the information has to be fulfilled in accordance to plan and time." [SA2]

However, the organisation itself does not have a strict BIM policy to be followed. Rather, this is stipulated at an individual project level. SA1 also added how they plan on using the data for FM purposes.

> "We try to use BIM in the projects where it seems relevant. We have just implemented a new FM system where we work with adding more information from design and build projects automatically. Primarily essential systems. In the long run, we will work with databases with information of our assets that will be able to communicate with other systems. It is important with a willingness and interest to change and gain knowledge. Also, you will need to test live in projects." [SA1]

Organisation C has, together with a design contractor, developed a preliminary BEP they refer to as BEP1 to establish a broad overview of what they needed in terms of data. They are now working on BEP2 in which they are specifying how to, efficiently, feed information into the various disciplines without over-spending on excessive data gathering.

> "We could ask for LOD 500 down to every single bolt or lighting fixture, however we cannot use all this data thus it has no value to us. The tricky part is to define our real future requirements." [AC1].

Furthermore, AC1 explained that a problem with their current processes, software and standards is that it becomes highly resource-consuming when the physical asset is altered.

> "It must be adapted to our current pre-requisites which is very resource consuming and it does not matter if it is a new development or just refurbishment of one single room, the information still needs to go through these steps" (referring to that data needs to be changed in several instances). [AC1]

4.2.4. Experiences with BIM in Facilities Management

The respondents were asked what their respective organisations experience or practice was regarding BIM in FM and how they perceive the concept. Organisations B and D did not have any stipulated plans for adopting a BIM practice into their FM practices. They both could see the potential and respondent SB1 stated that:

> "Digitalisation of the built environment, through BIM, is a trend that cannot be ignored." [SB1]

SB1 further explained that the discourse is often dominated by technically-oriented people who focus on "cool" features that one does not always understand the direct benefits from.

> "It is very important to be precise in how the different concepts and terms are defined. Initially BIM, created in the design and construction process, will constitute an additional source in which building managers will access the data required for their operations. The major challenge future on is utilising and draw benefit from this information. If done properly, it will change the whole way that we are building and managing buildings." [SA1]

Organisations A and C had progressed somewhat and started to plan for FM BIM. Organisation C had done six BIM projects and now had initiated a pilot project for FM which adopted BIM in a new development hospital school project. As part of this they are developing a BEP including FM operation-based parameters.

SA2 stressed the importance of avoiding vast changes and instead promoted an incremental approach towards implementing new procedures. Furthermore, that change needs to be benefit driven.

> "To achieve an unbroken chain of information, between design and build projects and FM operations, the key is to take small steps and successively implement them, otherwise we risk ending up with nothing happening." [SA2]

> "I believe that when it comes to BIM uses in FM one should first look at the potential benefits and what aspects are mature enough to realise the benefit. How far has development come to realise these benefits? On the other hand, a potential benefit that is not yet achievable but can serve a great benefit could also be worth looking in to by mapping out the progress of research and other industry innovation projects. But mainly one should look at the direct benefits and understand that it is unlikely to come with a large catalogue of benefits" [SA2]

4.2.5. Benefits with Integrating BIM in FM

The respondents were asked to name what they perceived as the main benefits for FM organisations adopting BIM. All the respondents answered this question.

Benefits that were addressed were:

- Space and object information
- Reactive maintenance
- Proactive maintenance
- Compatibility with IoT data enables broader information sets
- Better track of product information and smarter documentation
- Information accessibility for end-users and sales.

SA1 began with listing four major benefits with integrating BIM in FM:

- Space and room information such as square meters, base information for planning, lease and economic follow up on these areas.
- Reactive maintenance. Managing significant installations and systems. Enabling more efficient processes.
- Proactive maintenance. Maintenance plan from project.
- IoT inclusion will grant a larger information set. This can enable self-adjusting systems in the future that can adjust adaptively.

SA1 stressed that FM organisations need to keep better track of their product information and that the industry is very document-heavy. Today information about all objects is collected such as operation and how maintenance should be carried on through documents.

> "In the future, we will work more with objects and properties attached to them. This will result in that the documents will eventually disappear. However, this will take time, the industry will live in mixed worlds for a while but the direction of the industry and therefore the goal of Organisation A is to get there eventually." [SA1]

AC1 named maintenance as an avenue to gain the largest benefits from working with BIM through easier information sharing via efficient issue reporting. Furthermore, AC1 addressed the benefit of data accessibility.

> "Up until recently, at project delivery, no one considered the operations or cared about the customer. In many cases even the customer did not care. As of now the potential benefits are increasing along with technology. For instance, now consumers want to track their energy usage directly in their phones. All of this requires data which no one is thinking about. BIM is always considering the data as you progress the building. With BIM, we can get data in a good format, in a synchronised way from the people who are managing the actual design or construction of the object and that is part of their thought process. You don't have to go back for information, the original is accessible. The model becomes the single source of truth." [AC1]

SA2 highlighted information accessibility as support for sales as an important benefit. This in terms of enabling more precise calculations. SB1 said that the largest benefits will be held by space planners, project managers and maintenance. Further that the most important benefit is that the data is correct in structural changes in refurbishments. AC2 did not have any experiences working with BIM but was interested in possibilities to improve his work practice.

> "I would obviously be interested in any way of recording a space or how it is communicated. That would be my area of interest. Something that we struggle with very much is keeping track of materials and fixtures within the facilities. With BIM, I see a potential to keep better track of future maintenance costs and backlog liability in a lifecycle perspective. I see a great value with that." [AC2]

AC2 also mentioned how BIM combined with Virtual Reality, VR, can enhance space planning and improve customer engagement.

> "I can see a benefit using BIM together with VR for training of academic staff, how to use teaching spaces so that they are ready to use it when they become available. Over the last few years we have been developing a few high-tech collaborative distributed teaching spaces with a lot of advanced technology in them. The room is round and has no main entrance, this will be a completely new type of space for academics to teach. What we found was that we delivered the space but the academics were not ready to teach in that way. So, the possibility to enter a space before it actually exists would be very beneficial in this matter." [AC2]

According to AD1 the main benefits with BIM in FM is that it enables investigation, identification and solving of all operational problems. This could include construction defects arising during and after a defect liability period, such as hydraulics and mechanical failures. Furthermore, AD1 named Technical Operational Managers, Space Planners and Asset Managers as the main beneficiaries.

4.2.6. Industry-wide Adoption of BIM

The respondents were asked to name their perception of how the AECO sector could improve its efficiency from an industry-wide adoption of BIM; including adoption from FM organisations. Furthermore, they were asked how the built environment and society might benefit. All respondents except AC2 and AD1 answered this question.

SA1 described a scenario where cities have information models in 3D of the whole city. In that scenario SA1 said that project owners can feed their detailed building models into a larger city model.

> "This would enable easier planning and increase the information exchange compared to today when actors work in isolated environments. All actors can produce a much more detailed representation of their own assets, this will lead to a much more sustainable future." [SA1]

Further SA1 added that to reach an industry broad implementation of BIM it is important that all stakeholders use the same standards.

> "The forms of collaboration also need to be changed so that everyone works together from an earlier stage than we do today and that everyone has, at least an idea of the vision you want to achieve." [SA1]

SA2 named increased information flow and avoiding re-work as a potential benefit from object-based collaboration. SB1 reinforced this by saying that BIM will enable good knowledge transfer between stakeholders and enable a holistic overview of activities.

> "A continuous flow of information between several disciplines is a big potential for the whole sector. Typical for the construction industry is that a lot of re-work is done between

> the different stages. If there is a digital way of handling and communicate information a lot of time can be saved. It could be to register material types." [SA2]

For society as a whole, CM said that BIM will enable better resource optimisation. This will lead to less waste and less environmental damage. Furthermore, it will decrease working hours since planning is more optimised. In the long run, it will lead to faster production of housing which is a public and thus societal benefit.

AC1 said that, globally, the AECO sector is no longer only concerned with producing a concrete product (a building). Instead they are now interested in how that product exists through its life including disposal or replacement. In that sense, AC1 means that lifecycle thinking has entered the international market. In Australia however, AC1 said that the major industry actors are more reluctant towards digitalisation through BIM even though it is probably slightly better on the east coast than Western Australia.

> "All actors would probably agree to all the potential benefits but in WA the market is slow. I think it is because there is a lack of guidance in Australia. UK and US for instance are further developed since their governments are mandating BIM. In Australia, the government is letting the industry drive the development for FM organisations to buy. The result is that only the major firms will adopt to BIM and the smaller organisations will probably slowly die. However, the customers are getting smarter. Hence, the lifecycle desire for that is coming from the customer." [AC1]

4.2.7. Barriers Towards Integrating BIM in FM

The respondents were asked what they perceived as the main barriers with FM organisations adopting BIM. Their answers showed a variety of perceptions but knowledge was the barrier mentioned most often.

The barriers that were mentioned were:

- Diverse language and definitions
- System incompatibility
- Lack of specification from FM practitioners
- Format diversification
- Knowledge.

SA1 was focusing on detailed challenges they will face as they move towards integration with BIM and digital building information. The first was that standardised languages and definitions are an important pre-requisite so that all stakeholders and systems can produce and interact with the data and each other. Their current FM systems are not compliant with BIM data and the FM-side work on a higher granularity data level. SA2 said that even though they have good prerequisites for integrating the BIM data into FM through their experiences with BIM in design and construction projects one main limitation is a lack of request or specification from the FM side. This results in low demand for this type of data at organisation A. SA1 and SA2 agreed in that system integration is a challenge.

> "Therefore, the change has been so slow but there is a big potential, especially for a FM organisation like ours with a long-term value perspective. It is likely that we must adapt the information in accordance to the client's needs and the complexity of their business procedures which will require varying levels of information content." [SA1]

Furthermore, SA1 stressed that common standards and non-propriety formats, automatisation and user-friendliness are key. Also, one cannot wait around for new discoveries and solutions, rather develop based on technology available. SA2 said that LOD is hard to define and that they do not want to risk spending unnecessary funds on excessive information or end up with a sub-optimised information model. In addition, SA2 said that a main barrier is lacking knowledge among AECO organisations combined with strict public procurement regulations, LOU[12], prohibiting them from accessing the whole market. SB1 said that knowledge and varying data or systems are their main barriers towards digitalising their portfolio.

> "Our organisation does not have the proper knowledge and this is hard to come by. Furthermore, our portfolio contains several existing buildings that are not documented coherently. It would be very resource consuming to digitalise the whole portfolio." [SB1]

AC1 perceived that the main limiting factors lies within the FM contractor's mentality. Mainly, that there are varying levels of maturity among contractors and consultants.

> "If there is only one specialist contractor able to fulfil a service, the procurement price is going up. The solution must be to change the mentality so that contractors do not perceive modelling as hard and time consuming.

Also, AC1 implied that easily updating information is essential and, as of now, one critical barrier not developed enough to suit organisation C. AC2 also mentioned this through the following example:

> "At the moment, our spaces at the campus is changing dramatically and rapidly. For instance, we are now in the process of moving from traditional offices to open-plan working spaces. The teaching spaces and informal spaces for students and the outside spaces are changing as well. We can see this transformation everywhere. The way of working, teaching and interacting is changing along with new technology and so is the way we are planning for our spaces. A problem for us is that our system for recording and capturing space does not have the capacity to keep up with the rate of change." [AC2]

Further AC2 said that, for organisation C, the barriers do not lie within lack of knowledge or competencies. Rather, that implementation time will be an obstacle.

AD1 named individual capability to use and apply application in real-time through training and development of software and applications required as one main barrier. Furthermore, for Organisation D, funding to purchase the software and time to transfer information into BIM software were the main barriers.

4.2.8. Key Enablers for Integrating BIM in FM

The respondents were asked to name one or more key stakeholders driving and enabling BIM for FM. All the respondents named one or several stakeholders however they differed. SA2 and AD1 both named senior directors at FM organisations as the key enablers stressing the importance for top down implementation and elaborate strategies to be initially stated. SB1 also believed top down decision making to be key but emphasised the need for BIM consultants to coordinate accordingly. AC1 named the project manager as the key driver in driving BIM thinking to project participants and in the long run throughout the organisation. SA1 and AC2 both mentioned bottom-up innovation flows as key. SA1 believed people with IT background, or BIM knowledge, will be the main drivers. In contrast, AC2 named the end-user as the key driver, in AC2's example drawing services.

SA1 explained that the likely champions within FM organisations would come from IT backgrounds.

> "For people experienced in working with IT, the step towards understanding efficiency in which information is captured by its source and later used and re-used in other parts of the organisation and its systems is not large." [SA1]

[12] LOU – Law on public procurement regulating how publicly-owned organisations in Sweden can procure services and products. (Sveriges Riksdag, 2017)

SA2 said that it is important that top management decide long term goals concerning our BIM adoption, if they do so, it is more likely that the policies will penetrate the organisational culture and thus we can see an increased level of demand for the information within the organisation.

SB1 said that competencies from consultants are essential to produce the data, but also the knowledge from the FM side that must define what information they are requiring.

AC1 said that the project manager possesses the largest responsibility to create good prerequisites for BIM adoption in FM.

> "They don't even have to know what a mechanical duct is for example, but they must be able to enforce that design thinking and the data management up front. After project delivery if there is anything wrong/incorrect or missing in your model you are going to play catch-up forever. Thus, you will not get excellent benefits down the line. The only one who can control all this information is the lead consultant/project manager. Hence, they are the ones who will have to drive this mentality from start to finish." [AC1]

Furthermore, AC1 emphasised that the project manager must be strong, confident and preferably BIM-oriented to begin with. If one of the consultants/contractor refuses to document in the model accordingly, he/she should make sure they will.

AC2 said that building services would be the main driving stakeholder for FM BIM in their organisation.

AD1 said that the introduction of BIM would be part of a broad technology strategy for the University Faculty of Science. A preferred partner would be identified, selected, integrated with a strategic plan to introduce across the asset portfolio over time. Furthermore, that a business case supporting the investment would be a prerequisite and project champion would be the Director of Facilities.

4.2.9. Assessment of Competencies

The respondents were asked what competencies one should look for, from whom and in which scenario in a BIM process. All respondents except AC2 addressed this question. Following are quotes representing their answers.

> "It is hard for us to assess anything other than the quality of the data that is delivered to us. In BIM projects, we always appoint a BIM Coordinator and it is important to assess his/her competencies." [SA1]

> "We had a competency specification when we procured BIM Coordinators these were mostly focusing on merit through previous experiences." [SA2]

> "The competencies we are looking for when we recruit, procure and purchase are professional expertise, system expertise, ability to cooperate in team, respect for and insight in sustainability, quality and time." [SB1]

> "We are not assessing the competencies of project participants we didn't set the standard of our six projects that we have done in BIM so we cannot judge them based on that. We set the standard for documentation delivery. What would be sought from the project participants would probably vary on their involvement." [AC1]

> "Ability to read and interpret construction and building services drawings, navigate and use software, follow process. In specific projects, the process is like the following: introduce application, deliver training sessions, explain value, adopt a test model building, identify skill gaps, then provide training." [AD1]

4.2.10. How are you Assessing your own Competencies?

Respondents were asked if they are assessing their own competencies and if so, whether they were using any framework to support this. In general, they had little opinion about this, only three respondents commented on this question. SB1 said that the organisation did not have enough knowledge to assess their competencies as they still are using traditional FM systems that are not compatible with BIM data. AC1 stated that they are aiming at putting assessment of BIM competencies into practice but are focusing more on assessing documentation of data. AC1 further stated that they are currently developing a standard for this. SA1 said that they do not have any specific support to assess competencies within the organisation. However, that they have been discussing the iBIM model to benchmark where they stand compared with industry. As of now they require support to assess competencies from external parties. The three remaining respondents did not answer this question.

4.2.11. Capability and Maturity Assessment

The respondents were exposed to the following two terms with definitions:

1. BIM Capability - Ability to generate BIM deliveries and services.
2. BIM Maturity - Range, depth, quality, predictability and repeatability of BIM deliveries and services.

They were then asked: Regarding BIM, in what situations should capability and maturity be assessed? Furthermore, what qualities their respective organisation is seeking? Lastly how their organisations are assessing their own capabilities and maturity? All the respondents replied that they did not have any strategy for internal assessment regarding BIM performance. Two of the respondents chose not to elaborate. SA1 stressed that it is hard for them to assess anything other than the quality of data delivered to them but that they are trying to relate to the iBIM model.

> "In design and construction projects we always appoint a BIM Coordinator and it is important to assess his/her capabilities. Our organisation has not delved very much in BIM maturity and capability but we try to relate to the iBIM Model to assess and approximate where we stand in relation to the FM sector in general. The assessment we made concluded that our organisation is around Level 1 at present." [SA1]

AC1 answered that it is most important to assess capabilities in the procurement stage. They are assessing capabilities of project managers and their organisations based on merit through past experiences. AC1 also exemplified how they have been assessing their own capabilities.

> "Five years ago, when we were introducing an online maintenance reporting tool, our main indicator was take-up by our customers, in this case the maintenance staff. We tracked how many of them were logging in to the tool to see mechanical drawings and how many people were not but performing their tasks indicating that they were still using old drawings. One guy was still doing this. Our conclusion was that we had not communicated its benefits properly." [AC1]

SB1 underlined that their organisation was still quite far from being ready to use BIM on full scale but stated that assessment of internal capability in terms of knowledge by employees would be the first step. The next step would be assessing the capabilities of their FM systems to identify the magnitude of a potential BIM adoption.

> "Do we need to replace our FM systems or can we piece out our current ones?" [SB1]

In contrast to SB1, AC2 believed internal assessment of capabilities at an individual level was unimportant and difficult to do. However, agreed on the importance of internal capability assessment at the organisational level, above all, to identify technical requirements for using BIM data.

4.2.12. The five Dimensions' Significance

The respondents were shown a list of the five organisational dimensions presented in Section 2.8 of this thesis and asked how important they are to BIM adoption in FM organisations. Some respondents gave elaborate answers about how these dimensions are relating to each other while some named which ones are more important. SB1 only named knowledge as the most paramount prerequisite but underlined that all of them are important.

> "I have chosen to only specify one. It is obvious that the other dimensions have to be functioning for BIM to be beneficial." [SB1]

AC2 also said that all of them are important and necessary. The other responses are compiled per dimensions.

4.1.12.1Technology

AC2 said that, technology is critical since all existing data and systems need to be applicable to BIM which would be challenging initially. Furthermore, that BIM would be the main repository of information for all other systems. In contrast, AC1 said that, from a data management perspective, raw non-intelligent data is better than any application on the market.

> "A spreadsheet made by a 10-year old is better than any application that you can give me. The data underpins solutions, consumables, waste reporting etcetera that's all it is. So, you got to get your data absolutely "nailed". Off course if you can use technology to input data, I am all for it, but the data is key. Technology falls outside of that it is just a thing you use either to consume or input data. The level of technology that we got to capture building data is already there, thus it is not a significant barrier." [AC1]

SA2 said that before applying or developing any technology there needs to be a concrete solution that can be proven beneficial from a business point of view. AD1 said that technology needs to be sourced from a supplier with local support. Furthermore, that all new technology needs to be compatible with their existing IT infrastructure.

4.1.12.2 Knowledge

SB1 said that knowledge of the FM organisations´ end-user is the most important aspect. Critical knowledge would be how, and why BIM is used as well as what the benefits are. AC1 also mentioned the end-users' knowledge as critical but rather referred to instructions on what they need to do, not mentioning understanding of why.

AC2 said that it is important for organisation C to have competent staff with the right knowledge. Since the FM sector does not have a tradition in working with BIM data they will need to source from consultants until their own staff have the required knowledge and competencies. AD1 only perceived sourcing as an option mentioning that consultants need to be able to provide consistent technical support, reliable training and resolve problems quickly.

4.1.12.3 Communication

SA2 said that all aspects of the change in business procedures needs to be communicated to the employees/management. AC2 said that it is paramount to communicate the ambitions and long-term strategies to all actors affected by BIM integration to make sure they understand what the impact and relevance is between what they do and the new methodology. AD1 implied that a local key point of communication as important in all major changes. AC1 believed communication is important although, it is not a cornerstone of a methodical change.

> "You could set a really good process and then not speak to anyone for six months and still get a good outcome. But if you try to speak to everyone every day and they don't follow process you will get nowhere." [AC1]

4.1.12.4 Processes

SA1 said that certain processes create information, while some use it, implementation of BIM in FM organisations will require re-arrangement of how they look at processes where traditional organisational structures are no longer interesting.

> "A process that takes one from A to B can include multiple roles, which in turn requires both knowledge and the exchange of information and knowledge. Thus, I perceive all five points as important." [SA1]

Both respondents from Organisation C seemed to value process-thinking. AC1 said that change needs to be driven by process and thus is the most important dimension when adopting BIM in FM.

> "A chain is only as strong as its weakest link, if someone is not following the process. The process and protocols needs to be standardised, if it is loose nothing else matters." [AC1]

AC2 also said that processes are very important and that they have a very good level of understanding their processes through documentation.

4.1.12.5 Motivation and Culture

SA1 said that culture and motivation plays a huge role in providing dedication and a willingness to change business procedures. SA2 said that top management need to enforce BIM adoption and mandate it through decision making. Only then can the ideas and insight driven from within the organisation take effect. SA2 also stressed that it is difficult to value which dimension is more important. The primary issue is that there needs to be a clear benefit and the solution needs to work flawlessly. Otherwise no one will be interested.

> "The risk with putting the BIM ambition level to high is that people/users will not understand it fully, also that it will take too long to develop. Its key to deliver functioning easy-to-use solutions that will be most beneficial for the user." [SA2]

AC1 said that innovation and special competencies happen close to the benefit, bottom up, but nothing will change if there is no culture for driving innovation. This can only be done if the management has a willingness to go down the BIM track. AC2 said that it is paramount to have an innovative workforce that is open to change as implementing a BIM methodology would require.

4.2.13. The Five Dimensions in Terms of Organisational Readiness for BIM

The respondents were asked: Within the same five areas, where do you consider your organisation to be, at present, in terms of readiness to a BIM adaption/implementation? Organisations B and D answered that they were not currently planning on such adoption. SB1 gave their implementation plan if they were to adopt a BIM in FM methodology in their organisation:

> "We are unfortunately quite far from being ready to use BIM on full scale. The first step towards getting there is knowledge possession of key personnel, we are not there yet. The next step would be to find a solution I which this methodology can be used with portfolios with a large proportion of existing buildings that lack the proper documentation. Furthermore, how this would be coordinated with our current building management systems? Do we need to replace or can we piece out our current systems?" [SB1]

> "The organisation is constantly changing but the information should be constant." [SA1]

4.1.13.1 Technology

Organisation A had a problem with their current IT infrastructure since it is designed and thus, not capable of handling BIM data. Exchanging or piecing out their systems would be necessary. SA2 said that existing tools for BIM integration in FM available on the market are not good enough. SA1, who was working more with IT-systems in the organisation, said that they recently had acquired a system that can read non-propriety BIM formats and thus are prepared to integrate it future on.

> "Our previous FM system did not have the capacity to import BIM information. Now we have acquired a new system that can read neutral formats. This means that we are prepared to this new information management future on." [SA1]

> "We lack a lot of technical tools. Our current IT systems do not comply with BIM data. In general, I think that there are currently no good tools for FM to work in a BIM environment." [SA2]

Organisation C was testing a third-party software linking with Revit. They came across a few problems with it. One example being that it could only read files from Revit 2014. AC1 said that, technology from a consumer point of view must be better. But that in terms of data, they are prepared. Furthermore, AC1 said that non-propriety formats would bridge the problems they have with system integration.

> "We have a myriad of different systems where information is flowing between. It gets a bit messy. So, we are going for a data warehouse. Rather than having all the systems speak to each other. All the information is pushed into a data warehouse containing any standard formatted data." [AC1]

AC2 said that Organisation C is currently not ready in terms of technology obtained, but could not recognise that as a problem if the technology is available. Organisations D and B did not have BIM adoption in FM as part of their current strategic plan.

4.1.13.2 Knowledge

FM strategists in Organisation A participate in industry and innovation projects in which they gain knowledge and try to enforce BIM adaption among other AECO actors according to SA1. SA2 said that they have started to educate their project managers in BIM. FM employees however have not had any education which means there is a diversity in knowledge between production and FM. AC1 said that they still are in the process of learning what they want, what they are going to report on, what tools they are going to use and what solutions can they can employ. AC2, working with space management, stated not possess sufficient knowledge about BIM in FM.

> "I have no idea how capable the work force is in terms of BIM knowledge. I do not have enough knowledge myself and I can see that this will be a barrier." [AC2]

4.1.13.3 Communication

Only two of the respondents commented on this dimension, both of which from Organisation C. AC1 said that since they have standard communication lines anyway, so this will only be another element of what we do already. Hence, AC1 had the opinion that Organisation C had sufficient communication for successful BIM adoption in their FM practices. In contrast AC2 implied that communication will be a likely barrier.

> "Since I suspect that the workforce has as little knowledge as I have, communication is going to be a barrier." [AC2]

4.1.13.4 Processes

Organisation A had begun developing processes for BIM in FM. They were focusing on identifying direct benefits and through that develop logic processes. They were still early in development and none of the respondents from Organisation A could specify what the processes would look like but their ambition was to create an unbroken chain of information between design and FM, meaning that all relevant information created in the design and construction phases can be integrated into their FM IT infrastructure.

AC1 said that Organisation C had a minimal level of process development. Like Organisation A they are working on specifying their requirements. This is done by internally developing a BEP for medicine new medical facility. They are currently specifying what LOI they will require for their FM. AC2 said that processes are important but that Organisation C have a good process practice. Hence, this will unlikely be an issue in the future.

4.1.13.5 Motivation and Culture

Only one of the respondents chose to answer this question could even though most of them said that it is important. AC2, did not perceive motivation and culture to be a barrier for Organisation C. This, due to that they just had undergone a major company re-structuring which had gone well.

> "I think that our organisation is very open to these types of improvement so I do not think that this will be a significant barrier. We have been through a period of very rapid change a couple of years ago, and the people who are still here are likely to be used of it." [AC2]

4.3. Discussion

The frameworks for assessing performance in design and construction projects presented in Section 2.2 are still evolving as BIM adoption increases and are applied differently across the market. In some countries, governments drive the adoption of BIM while in others, industry groups take the lead. While the frameworks presented by Succar and Bew/Richards are among the most ambitious, the methods necessary to measure BIM capability and maturity in more depth still require additional development.

If maturity is monitored through a framework such as the iBIM model, it can illustrate and show a historic process and describe to the outside world which steps the construction sector or company has taken. Industry organisations can position themselves according to what systems they use. However, this does not say anything about what they are capable of doing, placing the definition of capability in the limelight. If it is used to describe an organisation's capability to deliver specific outcomes, it will then relate to the ability to deliver projects according to pre-set specification.

Viewed in a more dynamic way, it would then inform how an organisation adapts and changes with the use of information sharing through BIM. This is reflected in Succar's capability stages and maturity levels which allow the assessment of organisational processes and business models. However, such qualitative indicators may not be sufficient and provide an opportunity to develop quantitative metrics for establishing an organisation's BIM competence in a detailed and measurable way.

There are several metrics identified as appropriate and valid when scrutinising methods of measuring BIM performance. However, since the AECO industry consists of actors from many different fields, sometimes using BIM in different ways, aiming to select an ultimate series of these metrics to serve as valid for all actors within the industry seems is impractical. Established frameworks and models for assessing BIM performance are either too simplistic (e.g. iBIM) or overly detailed (e.g. BIM Maturity Matrix) and therefore somewhat ill-suited for self-assessment. The self-assessed benchmarking approach instead enables an easy, accessible, dynamic and customised set of metrics for performance measurement to be developed. This will enable a "relevant only" approach for assessment.

It can be argued that self-assessed crowd-sourcing methodology will contribute to the gathering of relevant data; organisations select what is relevant to them for internal benchmarking purposes. More users successively will lead to a better database, with more valid metrics and more precise measurements which will benefit all users. Furthermore, this approach to benchmarking BIM performance will reduce the risk of leaking sensitive information to a third party since data considered sensitive is regulated in its exposure. Existing frameworks applicable for assessing BIM performance, as mentioned earlier, will either require help from expert consultants or the development of possibly costly in-house know-how and thus are more troublesome to get started with.

An obstacle to overcome when applying this methodology of assessment over the whole AECO industry, is the probability for some metrics being easier to score high or fulfil than others. This since there is a risk that the performance of actors in a certain sector will be shown, or indicated, as more mature than others as a result of what metrics are closer to the core business and the characteristics for this type of organisation, and thus more likely to be used. Hence, it seems reasonable that this methodology and approach for developing BIM performance benchmarks may be a practical way forward. As a methodology for comparing organisations with different abilities and focus throughout the whole industry however, it is unlikely to be applicable in the same way. Rather, it can be used to give a rough estimation, an indication, between the fields which in the long-run can provide valuable information about how well a sector is performing in BIM application in the industry context. Hence, this thesis is promoting the term BIM performance Indicators, BPIs, as a suitable designation for FM assessment rather than metrics.

As the system is used more frequently, the database will grow in terms of additional new BPIs and get more refined and precise as the users automatically validate the BPIs. Early adopters or pilot organisations risk suffering inaccurate assessment results as the dataset is developing. This is likely to create barriers to developing the database and pose a threat towards convincing industry actors to adopt it. However, setting up a tool with relevant and versatile default BPIs developed through case studies and expert consultation will reduce the chance of this occurring.

The BIM methodology has become fairly established in design and construction projects and has contributed to a more efficient way to execute the process (He et al., 2016). Still, there are many ways in which BIM can be used more extensively in FM. The information created in the design and construction phase of a project holds many possibilities to serve FM in terms of maintenance and more effective use of buildings. In the empirical part of this thesis, the respondents mentioned several main benefits with BIM in FM. These were mostly focusing on developing smarter information flows, combining data sources and increasing communication. An impediment is that the information created in BIM projects often lacks essential data as it is not produced for FM purposes to begin with. Therefore, the required LOD should be extended and clearly defined by the FM organisation, who is often also the project owner. This issue was addressed in the empirical part as two of the respondents said that a main challenge for FM organisations is to define what data they require. This does not necessarily mean that LoD needs to be enhanced, rather LOI should be enhanced to suit those who are likely to require additional data from BIM models than what is usually included for design and construction purposes. This may enable a more standardised and repetitive structure of BIM models making it more relevant for FM practitioners. FM organisations naturally have different needs and abilities from those of organisations involved in the production of the constructed asset. Improved development of BIM models, through a higher involvement by FM practitioners when the BEP is made, may increase the potential in which they can be used for FM purposes.

A more elaborate and inclusive engagement of FM organisations in the construction project delivery process will enable a better insight into what information and functions are needed and valuable through the BIM model. This will require a more precise requirement specification necessary to identify needs and further develop solutions to meet these needs. One of the organisations participating in the case study has initiated such a development by specifying its present and future needs in a standard BEP including FM content. This is a factor showing that FM practitioners are starting to have a more mature position towards BIM use in FM.

Possible adoption, or rather, use of BIM data in FM organisations will create further challenges. There is no unanimous need stated for what aspects of BIM, FM organisations demand, possibly since there has not been any service use presented to them or that possibilities for using digital project information has not previously been applicable. A starting point is that non-propriety formats such as IFC has been established enough in terms of content and applicability to major BIM software, enabling a good integration between software and development of new ones serving FM. This was addressed in the empirical part as respondents mentioned that a reason for not implementing BIM has been due to uncertain data coming from a variety of tools and their specific formats. IFC is a step towards standardisation and is a good prerequisite for developing data integration between systems. In addition, the use of IFC models may enhance data interoperability throughout the building lifecycle and collaboration between project stakeholders. However, other factors should be considered such as those related to processes, knowledge and communication and motivation and culture.

The empirical part showed that, respondents with a more elaborate understanding of BIM and its potential for the FM sector stressed the importance of having support from the organisation to pursue new innovative work practices. Benefits through BIM adoption is likely identified by the potential user. However, BIM adoption is perceived as a major organisational strategy change and can only be decided by top management. An organisational culture in which innovative ideas from employees is promoted can be crucial for successful BIM adoption, especially since the respondent’s answers showed that they do not perceive BIM to come with a clear series of benefits, rather they should find uses relevant for them. This cannot be achieved through top-down nor bottom up decision making alone. Rather, the organisation must promote innovative thinking and make sure to follow up on recommendations made by the employees.

Traditionally FM organisations have low support in digital building information handling since this has never been applied before. Hence, they will likely need to acquire new staff, programmers, digitalisation strategists for example. Also, these respondents addressed that the key benefit from BIM would have little to do with geometrical representations of building but rather unlock valuable sources of raw data. Further, that solutions targeting FM actors often focus largely on graphical representation through advanced 3D viewers. However, the respondents seemed more focused on data accessibility.

The research objectives were also aimed at comparing whether there are regional differences between Australia and Sweden. The interviews did not show any distinct differences in the ambition and understanding among the FM practitioners. However, the markets in which they were operating had very varying maturity according to the respondent's answers. Furthermore, incentives from their respective public agencies seems to affect their respective maturity. It can be argued that FM practitioners in Australia have a more difficult time to adapt to the BIM methodology from those in Sweden due to the inference that there is less interest from public agencies driving BIM in design and construction. While the long-term effect of national BIM mandates is still to be seen, they will certainly challenge clients to be more diligent in identifying and stating their BIM requirements during the procurement process. By clearly identifying their requirements, they would encourage industry actors to adopt technological solutions and develop innovative ways to fulfil these requirements. As innovation through digitalisation diffuses across the market, the need to assess and compare performance levels become paramount. This is where facility owners and other industry actors need to collaborate to adopt, adapt or develop a common BIM performance framework. This is also where they will need to join forces to communicate the benefits of performance assessment across the broader FM sector.

Furthermore, it is important that researchers and industry actors follow and engage in the development of digital data integration in FM and strive to use the digital building data from a lifecycle perspective and support performance assessment in the built environment. Through this, it should be possible to develop a better understanding of how actors are performing and how some hamper greater industry efficiency and the reasons behind the different approaches.

5. Conclusions and recommendations

As digitalisation of the FM sector through BIM adoption implies additional initial costs and efforts for the organisations affected, optimisation of implementation and ongoing use needs to be assessed. This thesis is promoting a methodology for self-assessed benchmarking of BIM performance through crowd-sourcing as a viable method for refining and further populating BPIs. This methodology may reduce unnecessary cost and lead-times as well as avoid sensitive information being exposed to third parties. It can also serve for efficient comparison between projects given that their performance is likely reflected by similar BPIs. To reduce or remove misguiding user influence, potential tools must be developed on the foundation of some default BPIs. Also, there should be a certain amount of administrative control to adjust possible misguiding data. The dataset hosting these tools is suggested to be developed in accordance with the structure shown in Figure 3.

5.1. Conclusions

The literature review showed that there are gaps in knowledge of BIM uptake in the FM sector will create benefits and what constitutes a level of performance specific for these organisations. Also, through applied research efforts with FM organisations it was found that there is a lack of insight as to how the companies themselves perceive benefits in relation to critical success factors for BIM adoption. Performance literature and assessment tools related to BIM performance in FM organisations tend to focus largely on technology aspects which naturally is a major initial factor.

Scrutinising the data collected in this research, it becomes clear that there is an ambition among FM practitioners to change their business procedures towards a more digitalised approach. BIM serves as a good platform for data in its current state but it has its limitations. First, BIM data needs to be adapted to suit FM needs. This can be done through earlier FM engagement in the planning process so that their requirements can be identified. Further inclusion of FM practitioners throughout the design and construction phase will incorporate valuable input from the end user ensuring appropriate content in the BIM model enabling it to better serve facility managers over buildings' lifecycles. Second, building information needs to be made more future proof and up-to-date, covering current needs and encompass room for growth without being excessive.

Non-propriety formats such as IFC can serve as reliable formats not affected by future external changes made by BIM software developers. Also, IFC can be a good base format to develop tools for transferring, handling and updating BIM data between the project delivery and FM systems. BIM adoption for FM purposes demands interoperability between different systems. IFC, needs to be easily adjusted and continuously updated. This will require adaptable and dynamic systems that can cope with significant and rapid changes. A risk with developing comprehensive, non-agile systems is that they can be expensive and quickly run out-of-date as technology evolves. The empirical study of this research showed that FM practitioners understand that new systems must be able to adapt to new information flows. However, it was also shown that their current systems cannot comply with this since they are not developed for this type of data integration. It is therefore paramount that FM organisations develop long term strategies to adapt or even re-develop their current IT infrastructure to create data interoperability to achieve the benefits from a BIM integrated system.

BIM should be adapted to suit the needs of FM in a similar manner that FM organisations must adapt to BIM methodologies. Bridging the gap between the, often, separate entities will inevitably require a proactive stance and change. A starting point is that non-propriety formats such as IFC enables development of technical solutions addressing BIM in building operations. This is an important cornerstone in the development of BIM practices that cover FM (and indeed all sectors of the construction supply chain). A problem with IFC models created as design and construction support, is that they are seldom populated to meet FM requirements. Therefore, requirement specifications should be clear, inclusive and developed in consensus with the FM organisation at a project's early phases.

Aside from the technical aspects, there are several other factors affecting BIM implementation and use for FM that needs to be taken into consideration when developing strategies for implementation. Assessment of performance among FM organisations is essential to evaluate performance and develop strategies for implementation. What should be assessed, however, must be identified and defined. The first step in identifying what to assess is to identify and map what dimensions of the respective organisations are the most important in relation to BIM implementation, as well as the level of maturity for these dimensions. This will help specifying in which areas they are ready for implementation as well as areas in which they, and in the long run the whole sector, need to improve. The literature review identified, besides technology, there are a number of other dimensions affecting BIM implementation in FM. These were identified as knowledge, communication, processes and culture and motivation.

Respondents with a more elaborate understanding of BIM and its potential for the FM sector stressed the importance of having support from the organisation to pursue new innovative work practices. Also, these respondents addressed that the key benefit from BIM would have little to do with geometrical representations of building but rather unlock new and valuable sources of raw data. Decisions are made at top levels but the study also showed that innovation can be driven from within. FM organisations must drive digitalisation by enforcing an innovative culture and motivate new ideas. Firstly, through establishment of a culture in which employees are encouraged to seek new innovative solutions to their current work practice and organisational changes. Secondly through creation, or support of, motivation to engage in change if new practices are proven and show higher degrees of efficiency, i.e. new work practices should be tested rather than questioned.

5.2. Recommendations for Future Research

This thesis has presented prerequisites for FM practitioners to implement and use BIM as a way for digitalising their work practices. Self-assessment of BIM performance through crowd-sourcing was identified as a suitable way of benchmarking and prepare for this adoption. For the self-assessment methodology presented to be efficient more research must be conducted on a detailed industry case studies. As mentioned in this thesis, a starting point in developing such a methodology for BIM performance assessment will require default BPIs. To be useful for the FM sector as well as being internationally applicable, these will be developed through case studies with diverse sectoral as well as regional participants. Another challenge is to define if and, further, how weighting of the BPIs should be considered.

Furthermore, this research has investigated how the effective use of BIM for FM can be assessed. A review of recent literature found that while there are several methodologies for evaluating BIM practices in design and construction, there are few for assessing performance of BIM in FM organisations. Furthermore, it is clear that at least some knowledge of BIM benefits has encouraged the uptake of BIM by the AECO professions. To address the absence of BIM evaluation methodologies for FM, the thesis proposes a program of further research to identity appropriate measures in five key dimensions of FM practice. These are listed below together with assessment specification identified in the thesis:

(1) Technology.

BPIs developed within this dimension should be able to assess whether the firm or team has the technical capabilities necessary to perform or receive required BIM services or products.

(2) Knowledge.

BPIs developed within this dimension should be able to assess whether the firm or team possess the knowledge necessary to perform or receive required BIM services or products.

(3) Communication.

BPIs developed within this dimension should be able to assess how capable the firm or team is in communicating and sharing knowledge supporting its performance and receiving required BIM services or products.

(4) Processes.

BPIs developed within this dimension should be able to assess how well the firm or team is supported by processes specifying how to perform and receive required BIM services or products.

(5) Culture and Motivation.

BPIs developed within this dimension should be able to assess how well the firm or team is supported by the organisational culture and motivation to develop, perform and receive BIM services or products. This could either relate to financial indicators such as money spent on R&D tied to BIM, or to the employees' experience of support from the organisation.

Based on the dimensions identified, the aim would be that future research contributes to identification of a selection of relevant BPIs and enable future comparison between a wide selection of FM actors. University FM organisations often manage large portfolios centralised on one or several campuses containing a myriad of different buildings, ranging from standard office spaces to complex laboratories. Also, FM organisations connected to universities are likely to be willing to integrate innovative solutions due to their propinquity to education and research making this segment suitable and attractive to investigate. To investigate this methodology's applicability to the broader FM sector, this needs to be validated through investigation on a larger scale with various FM organisations with more building portfolios and business procedures.

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Appendix 1

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BIM Performance and Capability

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Starting Point

A concept that is constantly evolving and adapting to new ways of usage within the Architectural, Engineering, Construction and Operations (AECO) industry, is Building Information Modelling (BIM). BIM is defined in varied ways across literature; from being solely perceived as a software tool for visual information-sharing by project participants; to an elaborate methodology for integrating data-rich, object-based models across the whole project life-cycle (Succar, 2009). An elaboration of this definition has been provided in Chapter 1.

When using BIM software tools, data and information associated with an object upon its creation can be later referenced across several views or representations. When the source information is later altered, objects linked to the source are changed and are instantly visible. Through such interconnectedness, design problems and re-work are greatly reduced thus saving time and money (Lee and Sexton, 2007). By adding time and cost attributes to 3D elements – referred to as 4D and 5D respectively - organisations can reduce resources needed and streamline project execution. In addition to 4D and 5D, there are additional dimensions such as 6D (sustainability) and 7D (facilities management) which help extend the benefits of using BIM tools and methods. Also, multi-dimensional modelling or “nD” provide avenues for including additional data (Jung and Joo, 2011) and can integrate several additional benefits such as using models to assess energy use, materials re-cycling and operations’ logistics. Using this multi-dimensional understanding, the BIM term can be expanded to cover additional analysis areas (Lee and Sexton, 2007).

From a different perspective, BIM represents the future of integrating processes through model-based information sharing. As BIM software tools evolve, the boundaries of BIM will continuously expand and allow the creation of new applications and utilisations. However, in such a rapidly expanding technological environment, many questions arise including how best to measure the levels of BIM use and establish stakeholders’ capability beyond the simple use of BIM software tools.

As technologies continuously evolve and authorities release more detailed BIM directives, the AECO industry thus faces significant challenges. These challenges are exasperated by the absence of an agreed BIM framework for assessing and comparing basic BIM capabilities across organisations and measuring their respective BIM maturity. Developing such a framework is not a simple undertaking due to the wide range of construction industry stakeholders, their multitude of disciplines and specialties, and their varied perceptions of expected BIM benefits. To date, very little effort has been exerted to develop formal guides and tools that can be used to establish and compare organisational BIM capability and maturity.

Requirements and Drivers: Authorities and Procurement

National guidelines and incentives affect how performance and capability must be addressed. For example, by 2016, the European Union Public Procurement Directive (EUPPD) will require all 28 European Union (EU) Member States to encourage, specify or mandate the use of BIM for publicly funded construction and building projects (Travaglini et al., 2014). While it remains to be seen how this directive will be enforced and followed up, the EUPPD signals how access to public funding will require higher efficiency in the form of better software tools, process transparency, information sharing, and data integration. Such directives also highlight the need for establishing common BIM performance criteria for services procurement. They also focus attention on the challenges facing organisations, private and public alike, as they implement BIM internally or participate in collaborative BIM projects.

This directive is not unique to the EU but, as discussed in previous chapters, has been preceded by the UK, the Netherlands and Nordic countries, which already require the use of BIM on publicly funded building projects.

Since the 1980s, Nordic countries have been leading the world in information management research. Major research efforts are currently underway in Denmark (EU social funds), Norway and Finland (under the direction of public sector clients) responding to government initiatives to digitise construction processes. In the UK, the government developed a national BIM strategy for the AECO industry in partnership with the private sector and academia. The declared aim of the government is to enable the UK construction industry to become world leaders in BIM utilisation. As a first step, the government is currently mandating Level 2 as illustrated in Figure 3.1 (Hooper, 2015).

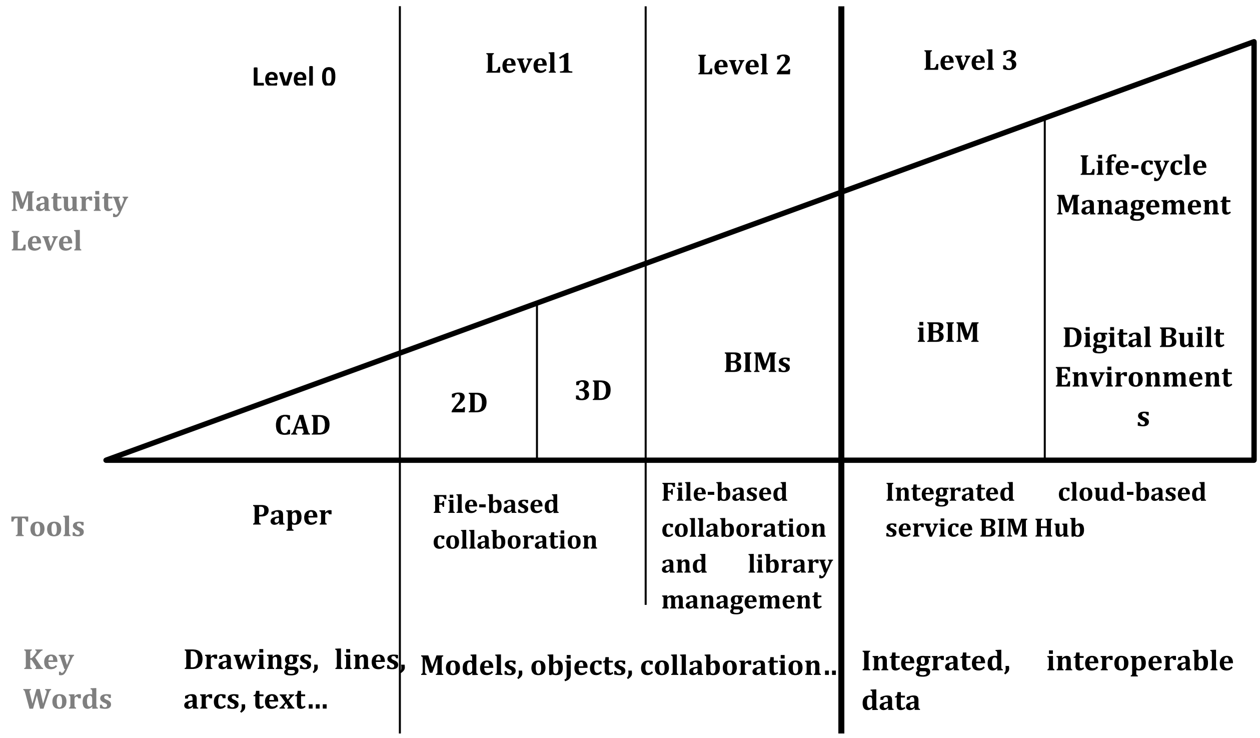

Figure 3.1: Illustration of the UK iBIM model based on the adaptation made by Barlish and Sullivan (2012) of the original Bew and Richards model.

The application of BIM tools and workflows are not exclusive to buildings and infrastructure, but also applies across the larger urban setting. In this respect, Germany has been leading the development of standardised 3D city models (Kolbe, 2009), and the UK Ordnance Survey has been working on linking BIM models to their national survey map (Morin et al., 2014). In Sweden, the National Board of Housing, Building and Planning (Boverket) have also started to integrate Geographical Information Systems (GIS) with the building permit process (Boverket, 2012).

In Hong Kong, the Housing Authority requires the use of BIM on all new projects since 2014. In South Korea, the Public Procurement Service currently requires the use of BIM on projects over SKW50 million, and on all public sector projects by 2016. Starting in 2010, Singapore developed an e-submission system that streamlines the building permissions' process by requiring the submission of models for use by planning authorities (Wong and Fan, 2013).

Many authorities around the world are thus driving BIM implementation by encouraging industry stakeholders to investigate and/or adopt new technologies and processes, but even with such encouragements, many challenges remain. From the supply chain perspective, AECO organisations need to both manage their typical workloads and adhere to additional requirements for model generation and information management. From the authorities' perspective, policy makers need to identify how best to prescribe BIM use within tender documents and measure actual BIM use on projects. It is certainly not enough to mandate the adoption of certain software tools and workflows. That is, even if all companies across the supply chain adopted identical tools and workflows, clients/employers will still need clear metrics to identify and compare the BIM performance of different stakeholders.

To address supply chain BIM capability issues, it is important to acknowledge that organisations manage their performance, both internally and as part of a project team, in different ways. Some organisations opt not to adopt BIM software tools and workflows but prefer to implement workarounds to avoid the costs and challenges of adoption. These workarounds, according to Merschbrock and Figueres-Munoz (2015), reflect insufficient financial resources or inadequate know-how and may lead to messy information exchanges between project participants. Other organisations opt to develop their own workflows, protocols and standards in complete isolation from others. Such an approach is not only costly and time-consuming for these organisations, but signals their hesitance to openly share improvements and allow the spread of incompatible protocols across the industry.

To improve performance across the AECO industry, stakeholders must understand the importance of adopting common BIM tools and workflows as well as sharing information and best practices.

Organisational Performance Measurement

Organisational performance measurement refers, in this chapter, to measuring the effect of adopting BIM technologies and their respective processes on the performance of an organisation. While organisations within the construction industry vary greatly based on the type of business they conduct, it is important to apply unified, reliable and valid metrics that allow the measurement and comparison of their performance. Organisational performance measurement will also need to report on whether an organisation actually increases its overall productivity, delivers better outputs, and meets or even surpasses its target performance improvement objectives. However, the term *performance* is a relatively generic and is thus often replaced with BIM capability and BIM maturity.

As a term, capability describes what an organisation is able to do and what actions it can take based on its organisational competence. It combines the aspects of knowing what to do with the ability to do it. In other words, capability measurements identify what an organisation can deliver in comparison to what is specified or expected, and reflect its dynamic ability to rethink existing know-how and develop new solutions.

In the Information Technology (IT) sector, the development of the Capability Maturity Model (CMM) has spawned a number of similar models applied in varied industries including manufacturing, healthcare and construction (Curtis et al., 2009; Curtis et al., 2002). As a performance measurement approach, CMM was originally developed to identify strengths, weaknesses and risks of software projects (Paulk et al., 1993). Later model adaptations were intended to assess infrastructure projects yet proved less able to address the specific challenges of the construction industry (Jia et al., 2011).

In addition to *capability*, the term *maturity* is often used to describe how well an organisation or its members can manage their processes and tools (Andersen and Jessen, 2003; Yazici, 2009). In more general terms, maturity identifies the performance criteria to be fulfilled by assigning a maturity level or milestone that best describes the utilisation of available knowledge, best practices and innovative techniques within a business or across the whole market.

There are multiple approaches to maturity measurement including those that yield a formal certificate. For example, in the field of project management, there are a number of specialised entities that offer to certify project managers according to well-defined and commonly-used guidelines. The Project Management Institute (PMI) and the International Project Management Association (IPMA) are two such global organisations providing certification and delivering courses through a network of national associations (IPMA, 2015; PMI, 2015).

Nonetheless, there are a number of ongoing efforts to measure how construction organisations perform. With increasing demands for construction efficiency and the availability of more detailed procurement protocols, the development of metrics to establish and compare organisational performance is now needed. As mentioned earlier, the development of the EUPPD will necessarily exert transformational pressures on the industry to develop such metrics, and may well drive the generation of common guidelines for assessing and improving organisational performance within the EU.

BIM Performance Frameworks

There is an increasing number of frameworks which can be referred to as BIM performance frameworks. These include the Interactive Capability Maturity Model (I-CMM, 2009); BIM Proficiency Matrix (Indiana University, 2009); BIM Maturity Levels (Bew and Richards model, see BIM Industry Working Group, 2011); BIM QuickScan (Sebastian and Berlo, 2010); BIM Maturity Matrix (Succar, 2010a); Vico BIM Score (Vico, 2011); CPIx-BIM Assessment Form (CPI, 2011); BIM Excellence (BIMe, 2013); bimSCORE (bimSCORE, 2013); BIM Planning Guide for Facility Owners (CIC, 2013); and BIM Competency Assessment Tool (Giel and Issa, 2015). A short description of each is provided below:

Interactive Capability Maturity Model

This Interactive Capability Maturity Model (I-CMM) is part of the United States National Building Information Modeling Standard (NBIMS). I-CMM was first published in 2007, slightly modified in 2009 and released as v1.9. However, it has not been updated since then. The I-CMM establishes the maturity of the model/project by assessing eleven topics against ten maturity levels. Using either a static table or an interactive Excel tool, I-CMM generates a single maturity score. This is intended to help *determine the level of maturity of an individual BIM as measured against a set of weighted criteria agreed to be desirable in a Building Information Model* (NIST, 2007; NIBS, 2007; Suermann et al., 2008; NIST, 2015).

BIM Proficiency Matrix

In 2009, Indiana University developed an interactive Excel matrix to assist their own internal team and other facility owners to pre-qualify the supply chain. The matrix includes eight categories measured against four maturity levels which, upon completion, generates a single BIM Maturity Score (Indiana University, 2009). The matrix is completed by candidate project team members who must provide examples of past projects and address each of the eight BIM proficiency categories.

BIM Maturity Levels

The iBIM model or the *Wedge* BIM maturity model (**Error! Reference source not found.**) was developed by Mark Bew, Chairman of the HM Government BIM Working Group; and Mervyn Richards OBE, Member of the BuildingSMART UK Managing Board (BIM Industry Working Group, 2011; buildingSMART UK, 2015; BIM Task Group, 2015). In its current form, the model reflects both the UK Government's BIM strategy and many of the industry's ongoing BIM initiatives. The model identifies different levels of market maturity by grouping standards and working methods into three initial BIM Levels. Based on this model, in 2011 the UK Government's BIM Task Group mandated that all publicly-procured construction projects are to meet Level 2 requirements by 2016 (Hooper, 2015). While the terminology, standards and methods linked to the *Wedge* model are mostly UK-specific, it has been used as a guiding framework for BIM policy development by other policy makers in a number of countries.

BIM QuickScan

BIM QuickScan is an online tool developed by the Netherlands Organisation for Applied Scientific Research (TNO). BIM QuickScan is intended to assess the BIM performance of organisations in the Netherlands and generate a performance benchmark. The assessment is conducted against four chapters (categories) and multiple Key Performance Indicators, and is available in two versions: a free *self-scan*, and a more detailed commercial service delivered by a BIM consultant (Sebastian and Berlo, 2010; Van Berlo, et al., 2012).

BIM Maturity Matrix

Developed as part of a larger BIM Framework (Succar, 2009), the BIM Maturity Matrix is a static self-assessment tool with ten capability sets, three capability stages and five maturity levels. According to Succar (2010a; 2010b), the matrix is intended for assessing the BIM capability and BIM maturity of organisations; where BIM capability refers to minimum ability, and BIM maturity refers to the quality, repeatability and predictability of these abilities.

Vico BIM Score

In 2011, the BIM software tool vendor VICO developed its own scorecard directed towards construction managers. With a focus on clash detection, scheduling and estimating, the declared aim of the tool is to assist organisations to compare their performance against their competitors. Each of these areas is graded based on functionality and capability, best practices and enterprise integration (Vico, 2011).

CPIx-BIM Assessment Form

The CPIx-BIM Assessment Form is a static questionnaire developed by the Construction Project Information Committee in the UK. The questionnaire includes twelve areas grouped under four categories and is *based on working documentation provided by Skanska* (CPI, 2011).

BIM Excellence

BIM Excellence (BIMe) is a commercial online platform for performance assessment. It is based on the published research of Succar (2010a; 2010b) and Succar, Sher and Williams (2013). BIMe includes multiple modules for assessing the performance of individuals, organisations, projects and teams. The basic free assessment generates a simple downloadable report, while the more detailed assessments generate competency profiles for comparison against project requirements, pre-qualification criteria and role definitions (BIMe, 2013).

bimSCORE

bimSCORE is a commercial tool based on the VDC Scorecard, the research effort conducted by Kam, et al. (2014) at Stanford's Center for Integrated Facility Engineering (CIFE). bimSCORE evaluates BIM practices across ten dimensions, grouped under four areas. The scorecard, which also has a free online version, evaluates the maturity of virtual design and construction practices on construction projects. It does this by comparing the performance of new projects against past projects and industry benchmarks (bimSCORE, 2013; CIFE, 2013).

BIM Planning Guide for Facility Owners

The BIM Planning Guide for Facility Owners is a maturity matrix developed by the Computer Integrated Construction (CIC) Research Program at Pennsylvanya State University. The Excel matrix is divided into six categories, five maturity levels and is intended for owners to rate their own organisation (CIC, 2013).

BIM Competency Assessment Tool

The BIM Competency Assessment Tool (BIMCAT) is based on research reported by Giel (2015). BIMCAT is targeted towards facility owners and includes 12 competency categories and 66 factors measured against six maturity levels. The assessment is intended to be self-administered by a manager using an interactive offline questionnaire. Upon completing the assessment, the tool generates a single maturity score as well a number of radar charts.

For a more comprenhensive comparison between these frameworks, please refer to Giel (2013), Azzouz, et al. (2015) and NIST (2015).

The Way Forward

These frameworks for measuring performance are still evolving and are applied differently across the market. In some countries, governments drive the adoption of BIM while in other countries, industry groups take the lead. While the frameworks presented by Succar and Bew/Richards are among the most ambitious, the methods necessary to measure BIM capability and maturity in more depth still require additional development.

If maturity is monitored through a framework such as the iBIM model, it can possibly describe a historic process and describe to the outside world which steps the construction sector or company has taken. Industry organisations can position themselves according to what systems they use. Unfortunately, this does not say anything about what they are capable of doing, placing the definition of capability in the limelight. If it is used to describe an organisation's capability to deliver specific outcomes, it will then relate to the ability to deliver projects according to pre-set specification.

If it is viewed in a more dynamic way, it would then inform how an organisation adapts and changes with the use of information sharing through BIM. This is reflected in Succar's capability stages and maturity levels which allow the assessment of organisational processes and business models. However, such qualitative indicators may not be sufficient and provide an opportunity to develop quantitative metrics for establishing an organisation's BIM competence in a detailed and measurable way.

Conclusion

While the effect of national BIM mandates is still to be seen, they will certainly challenge clients to be more diligent in identifying their BIM requirements during the procurement process. By clearly identifying their requirements, they would encourage industry actors to adopt technological solutions and develop innovative ways to fulfil these requirements. As innovation diffuses across the market, the need to assess and compare performance levels become paramount. This is where authorities and industry actors need to collaborate to adopt, adapt or develop a common BIM performance framework. This is also where they will need to join forces to communicate the benefits of performance assessment across the construction industry.

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Appendix 2

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Assessing BIM performance through self-assessed benchmarking

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Abstract

This paper describes research investigating what measures of performance of Building Information Modelling adoption can be standardised in creating an international benchmarking tool for self-assessment. By applying crowd-sourcing methodology to populating a prototype benchmarking tool, the research team aims to break down barriers of data and know-how ownership to encourage industry innovation to flow more freely. In particular, this research aims to answer the following questions: (i) Is self-assessed benchmarking a reasonable approach in assessing the performance of BIM at the project level?; (ii) Is crowd sourcing a valid method to populate the prototype? If so, how should the most appropriate metrics for benchmarking performance of BIM be selected?; (iii) What methods can be used to ensure the comparability, accuracy and consistency of the data input by users? The research described addresses these questions through an extensive literature review to build a foundation for future research combining the development and testing of a prototype tool with case studies and expert consultation in Australia and Sweden. This paper discusses key concepts used to develop the prototype and the requisite research being undertaken.

Keywords: BIM, performance, benchmarking, crowd-sourcing, self-assessment, selecting metrics, construction, capability, maturity

1. Introduction

Errors and omissions during design and construction phases in built environment projects are often the result of inefficient communication processes involving numerous stakeholders (Sebastian and van Berlo, 2010). These projects are characterised by being information intensive, putting pressure on enabling participants to have easy access to accurate and up-to-date information (Matthews et al., 2015). Hence, successful project delivery within the built environment industry requires accurate, effective and timely communication methods including inter-organisational communication and information exchange (Becerik and Pollaris, 2006). This pushes organisations to move away from traditional inter-organisational communication and delivery methods towards implementing more effective contemporary digital methods, such as Building Information Modelling (BIM).

BIM can be viewed as a socio-technical system that is expected to contribute to a vast and rapid change in the built environment industry similar to that experienced by the automotive industry when Information and Communication Technologies (ICT) were introduced (Sanchez et al., 2016). BIM is considered to take the entire Architecture, Engineering, Construction and Owner-operated (AECO) sector to a new era in integrating data and communication and is in that regard perceived to be the future methodology of the industry (Tuohy and Murphy, 2015). The industry-wide and organisational changes, required to implement BIM more effectively and broadly, have already required significant capital and time investments from early adopters. It will also, most certainly, pose a challenge to the whole sector, equivalent to the move from pens to Computer-Aided Design (CAD); from main frames to hand-held devices. These investments need to be justified by measuring organisational value-added Key Performance Indicators (KPIs) monitored in terms of the effectiveness of the chosen investment strategy.

Other sectors that have undergone a digital revolution in previous years, such as the finance and banking sector, have been successful in documenting efficiency improvement through benchmarking indicators (Tuohy and Murphy, 2014), an example being cost per transaction. However, the built environment industry has a high level of inter-organisational relationships, which are different to many other industries and provide industry-specific challenges and opportunities. Even though a collective goal may be defined within the context of a single project, actors contributing to it may have particular interests that are not shared with other stakeholders as well as diverting perspectives and internal organisational goals. It follows that within a single project, different stakeholders may have different approaches to implementing BIM and different ways of thinking about and measuring performance. However, implementing BIM effectively, requires a collaborative and integrated approach in order to maximise efficiencies across stakeholders and life-cycle phases (Sanchez et al., 2016). As noted by Sebastian and Berlo (2010); "BIM comprises collaboration frameworks and technologies for integrating process- and object-oriented information throughout the life cycle of the building in a multi-dimensional model". Benefits expected from implementing BIM include more effective, efficient, fast and error-free collaborative processes (Sebastian and van Berlo, 2010). Nevertheless, implementation and value monitoring strategies that have not been well defined and optimised through evidence-based processes can quickly lead to efficiency losses and cost overruns.

One of the main reasons for ineffective implementation and monitoring strategies to happen is the lack of standard frameworks to assess and benchmark performance within and across organisations (Sebastian and van Berlo, 2010). Although this area is progressing quickly, there is often a lack of appropriate guidelines that help organisations and project teams identify and prioritise performance requirements (Succar, 2010). At the same time, while there is a market-driven pressure for organisations to invest in implementing these kinds of technologies and processes, they may not be able to access sufficient information to justify such investment and evaluate the effects of its implementation (Van Grembergen, 2002). Although organisational performance deriving from utilisation of BIM is important to justify investment, assessing the actual BIM performance at the project level is as important to understanding the effectiveness of the investment strategy. BIM performance is identified by Succar (2012) as being divided into BIM capability, the ability to generate deliverables and services, and BIM maturity, the extent, depth, quality, predictability and repeatability of the capabilities. Founded upon the above definition of BIM performance, this research proposes an internationally applicable open access system for project teams to develop internal BIM performance benchmarks while also providing the industry as a whole with cross-firm or industry benchmarks.

Research methodology

The research presented in this paper has been developed as a descriptive review of literature based on academic publications and therefore based on secondary data. As performance assessment within the AECO industry in general and BIM specifically are relatively under-developed, parallels to different sectors and their frameworks have been analysed and described. This study has been conducted with the aim of contributing to the development of a tool for benchmarking BIM performance. Future research on the topic will possibly include development of new data and methodological considerations necessary for developing an actual tool. This research aims to answer the following questions: (i) Is self-assessed benchmarking a reasonable approach in assessing the performance of BIM at the project level; (ii) Is crowd sourcing a valid and relevant method to populate the prototype? If so, how should the most appropriate metrics for benchmarking performance of the use of socio-technical systems such as BIM be selected?; (iii) What methods can be used to ensure the comparability, accuracy and consistency of the data input by users? Future research will include testing the prototype tool through case studies and expert consultation in Australia and Sweden. This will provide insight into the potential application across international markets with different economic and implementation contexts.

2. Assessment of BIM performance

According to Bassioni et al. (2005) the AECO industry has been noted by many for being complex, with high levels of conflict, underperforming, and characterised by low levels of productivity (Manderson et al., 2015). There is, seemingly, a need for developing ways of assessment that support improvement of BIM performance. Performance, a broad concept with, no widely accepted industry definition (Rankin et al., 2008), has different meanings between and even within sectoral contexts (Kouzmin et al., 1999). Performance in an organisational context has traditionally been measured through financial parameters such as return on investment (ROI) and is often criticised for providing a too narrow and one sided focus on organisational productivity and direct profit. In the AECO sector attempts at measuring performance in using BIM has mainly been focusing on measurable financial output in relation to time and quality at the organisational level (Bassioni et al., 2005). In doing so, it fails to take the total performance of BIM use into account with all aspects that contribute to a competitive advantage (Beatham et al., 2004), further it does not address the actual performance of using BIM. Liu et al. (2014) explain performance assessment as a process of quantifying and reporting the efficiency or outcome of an action that is performed in line with an organisation's goals and objectives. The soft values or benefits generated through the use of BIM such as improved communications between project participants has to be included into an assessment of performance in order to provide more accurate results.

A case study on the Canadian AECO industry showed that this industry has historically lagged in labour productivity growth when compared to the rest of the Canadian economy (Rankin et al., 2008). This study further points out that this observation does not necessarily mean that the productivity is lower in the AECO industry. Instead it is suggested that measuring performance is more complex than it is in most other major industries. Additionally, AECO actors often have a more complex output and more versatile and dynamic way of conducting their business than in other industries. This again supports the thesis that traditional KPIs are not necessarily suitable to accurately represent overall performance as they might do in other sectors. (Rankin et al., 2008). When assessing the performance of BIM performance measured only through the above-mentioned financial indicators and other organisational value measures, it presents an incomplete picture It requires abandoning some traditional methodologies and embracing more appropriate performance assessment to understand and develop business success (Liu et al., 2014). The use of traditional performance measurement indicators and frameworks can therefore be misleading and inaccurate when applied directly or partially to the assessment of BIM performance. A common understanding of how to define BIM performance assessment is necessary and has to be formalised.

In a project context BIM performance can be separated into capabilities and maturity. Assessment of BIM capability defines the minimum requirement for producing a task or delivering a service a project team possesses or is fulfilling. This can for example be the ability to produce a BIM model with a specific software. BIM maturity on the other hand distinguishes the project teams' quality, repeatability and degrees of excellence in which they perform the task or delivering service (Succar et al., 2012; Sebastian and van Berlo, 2010). This means that rather than determining what software is used, the BIM maturity determines how well it is used.

Identifying and collecting performance data is important in order to motivate and prove the efficiency that can be achieved by BIM implementation. However, many managers within the AECO industry may be reluctant to allow external parties to carry out this assessment. According to Costa et al. (2006), this unwillingness is a significant sign that AECO companies do not emphasise the importance of performance measures and benchmarks enough. This can be a reason why drive and development of BIM assessment is lacking. On the other hand, many organisations control and measure a wide range of other variables (Costa et al., 2006). Since performance data associated to BIM implementation processes and tools is infrequent, the most relevant metrics can be difficult to select when developing a framework for performance measurement. Having established what BIM performance is and why it is important, one has to identify what measures are already in use and how suitable they may be to assessing BIM performance in accordance with the performance definition.

2.1 Existing frameworks for BIM performance measuring and assessment

There are a number of models and frameworks that have been developed to measure BIM performance by assessing the capabilities and maturity of individuals, teams or organisations (Månsson and Lindahl, 2016). These have been developed in an ad-hoc fashion and are, if not organisation-specific, likely influenced by the context in which they were developed (Bassioni et al., 2005). Frameworks that have been identified include the Interactive Capability Maturity Model (I-CMM, 2009); BIM Proficiency Matrix (Indiana University, 2009); BIM Maturity Levels (Bew and Richards, 2010); BIM QuickScan (Sebastian and van Berlo, 2010); BIM Maturity Matrix (Succar, 2010); Vico BIM Score (Vico, 2011); CPIx-BIM Assessment Form (CPI, 2011); bimSCORE (bimSCORE, 2013); BIM Planning Guide for Facility Owners (CIC, 2013); and BIM Competency Assessment Tool (Giel and Issa, 2015). These frameworks for measuring performance are still evolving and are applied differently across the market. The development of some of them has been driven by the industry while others have been driven by government or academic actors. These create different areas of focus regarding metrics and methods used.

Bassioni et al. (2005) stress the importance of not relying on a single framework and the metrics it includes. Given the diversity of organisations and projects within the AECO industry, it is unlikely that all relevant metrics are included in one framework or that all metrics included in a specific framework are relevant to all organisations and projects. On the other hand, utilising several frameworks may require a significant investment of resources and there is a risk that the frameworks may not be compatible. Månsson and Lindahl (2016) suggest that the frameworks presented by Succar and Bew/Richards are among the more ambitious frameworks for assessing BIM performance. However, Bew/Richards iBIM model is overly simplistic and by that unsuitable for comprehensively assessing BIM performance. The model developed by Succar grants a way to assess BIM Maturity, however it is perhaps over complicated and too resource demanding to apply.

The methods and availability of data necessary to measure BIM capability and maturity in more depth also require additional development. Further, most of the existing frameworks are not open access tools; they either need to be internally developed based on general guidelines or require investing in a consultant to carry out the assessment. Furthermore, they do not offer the possibility for industry-wide benchmarks and thus limits inter-organisational and industry-wide data sharing.

3. BIM benchmarking

Among the main benefits of assessing performance through common criteria is the possibility to enable benchmarking. Within the context of this research and based on the general definition provided by Costa et al. (2006), BIM benchmarking is a systematic process of measuring and comparing organisational, project team and individual BIM performance with that of competitors or internally between projects; often with the objective to identify or determine best practices. In addition to assessing its own success internally, each organisation can use the lessons learned from competitors in order to improve its BIM performance and through this avoid common mistakes as well as unnecessary re-work (Costa et al., 2006). In order to be able to benchmark externally throughout the industry, an internal assessment has to be performed. Internal BIM benchmarking can also be performed as AECO organisations tend to benefit from comparing the performance of their own projects from each other. In that sense it is difficult to separate internal from external benchmarking since one depends on the other.

If developed from within, initially as a way to assess BIM performance across projects, the size of the organisation can be critical in deciding the capability to assess. Kouzmin et al. (1999) state that only large companies can afford to develop their own method of benchmarking and that smaller organisations have to rely on frameworks already developed by and specifically for their larger competitors. This can affect the relevance of the metrics involved and potentially lead to misleading performance benchmarking results. However, internally developed frameworks for internal assessment later transformed into external ones, will most likely differ from those developed by others. From this perspective, it would appear that externally developed un-biased method for assessing BIM performance is required to make such a tool relevant and applied more broadly throughout the industry. According to Costa et al. (2006) there has been an increasing number of initiatives focused on developing ways of assessing performance of BIM in the AECO sector.

Rankin et al. (2008) defines the process of developing benchmarking as following a step-by-step plan (Fig 1): (1) identification on what to measure, (2) selection of suitable metrics, (3) gathering of data, (4) identification of what can be improved and (5) adoption of best practice (Rankin et al., 2008). The search for valid indicators and methods of data collection are critical elements of this process and can "make or break" the whole process if sub-optimised or poorly executed. While the characteristics of organisations within the AECO industry vary greatly based on the type of business they conduct, it is important to apply unified, reliable and valid metrics that allow a uniform and accurate measurement and comparison of their BIM performance. Assessment of BIM performance will also need to report on how a project team actually benefits through the utilisation of BIM. Figure 1 illustrates that it is a key activity to identify valid metrics when developing frameworks or methods of assessing or benchmarking performance. But what are the suitable, valid, metrics for a BIM performance benchmark? Can there be a way of overcoming the challenges brought by the fact that sets of metrics will have different level of relevance when comparing organisations?

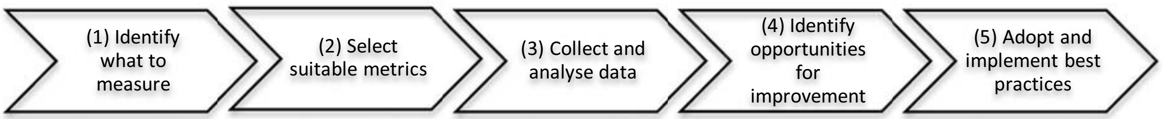

Figure 1: The process of benchmarking (Rankin et al., 2008)

3.1 Self–assessing

A common practice, in the process of assessing organisational performance, is that an external party, often a consultant, is both gathering and analysing the data. The main reason for this might be that organisations want a neutral party, or that it is required for accreditation, but also that the process and most frameworks are too complex for the organisation itself to manage and the challenge of providing knowledge from within. A likely effect of this is that organisations distance themselves from the act of measuring, as responsibility will be more concentrated in the hands of external parties. Through this process the sometimes sensitive information used for internal KPIs is exposed to external parties who are likely to have competitors as clients which in turn may be viewed as a business threat (Rankin et al., 2008).

Self-assessment of performance can help make the assessment process faster and less costly, and grow internal 'ownership'. Pun et al. (1999) define organisational self-assessment as "a comprehensive and regular review of an organisation´s activities and results against a systematic model of business excellence". Thus, it is proposed that applying a self-assessment methodology for performance benchmarks can save time and capital while at the same time build ownership. The assessment effort can also be ongoing, enabling continuous improvement processes in line with the dynamic and changing business climate in the AECO industry. Also, the continuous process of assessment and the continually-improving nature of the data may help increasing both the accuracy and the quality of the assessment. This is because parameters are up-to-date and updated as necessary and considered relevant by the users (Rankin et al., 2008).

3.2 Crowd sourcing

A significant barrier, when developing a framework for organisational BIM performance assessment, is that the needs of different AECO actors will vary significantly between organisations and even between projects within a single organisation. It is unlikely that there is universal set of metrics for evaluating the BIM performance that is relevant to all actors in all scenarios. By allowing the user to select their own metrics from a default dataset, and add non-existing metrics where needed, the framework can grow organically, continually improving. This approach and methodology is in a way a type of crowd sourcing; here understood as a growing, efficient way of collecting data and by that building multi-variable datasets (Pierce and Fung, 2013; Amsterdamer and Milo, 2014). Therefore, a framework for self-assessed BIM performance constructed through crowd-sourced data gathering is proposed to be a valid way of developing a BIM performance benchmarking system suitable for the diverse and protective AECO industry.

3.3 Selecting valid metrics

Developing a series of BIM performance metrics is a prerequisite and a paramount cornerstone in the process of creating a method for assessing BIM performance (Sebastian and van Berlo, 2010). Crowd sourcing a database of measures means it will grow organically to a certain extent. However, a generic framework with key metrics has to be provided initially to drive and support use. It is of great importance to build this first set in collaboration and consensus with industry actors from different disciplines within the AECO industry (Rankin et al., 2008). Metrics need to be (1) valid, (relevant, appropriate and justifiable) (2) quantifiable and (3) realistic (Fang et al., 2004). After the first dataset is created, early users can start selecting the most relevant metrics from the dataset that represents their view of key indicators of the BIM performance within their core business. In addition, they can request metrics that do not exist in the dataset to be included.

Through this process less used metrics can be removed, or at least valued lower and thus the framework will become more relevant.

To reduce the risk of having deceptive data affecting the tool through the self-assessed benchmarking affecting the dataset, the metrics have to be regulated to some extent and, as noted above, be anchored among the participating industry actors (Rankin et al., 2008). Some administrative control has therefore to be included in a potential tool. Fang and Wong (2015) developed a model for selecting metrics for assessing organisational resilience. Their model, here

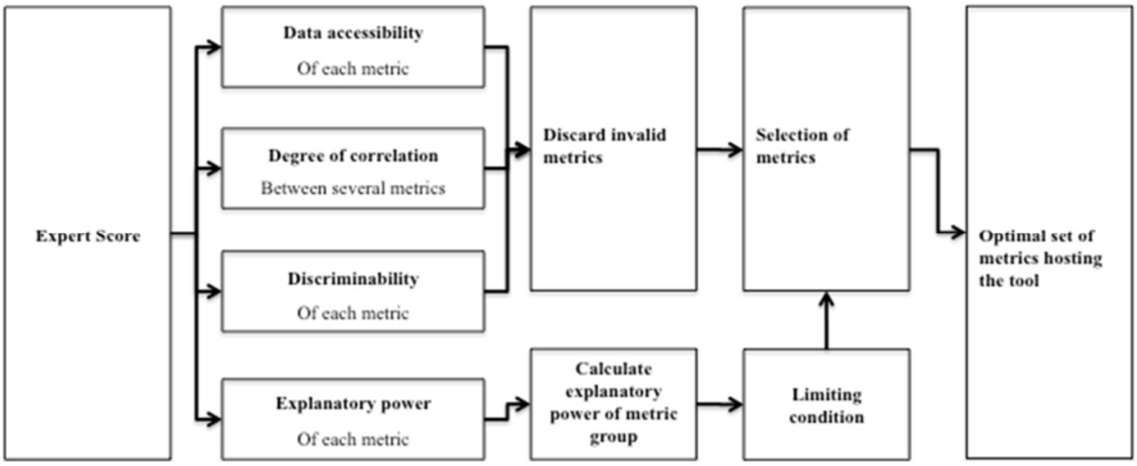

Figure 2: Process for selecting metrics for hosting the benchmarking tool- altered version (Fang and Wong, 2015)

provided with some minor alterations (Fig. 2), is also applicable for the process of selecting metrics for hosting a self-assessment BIM performance benchmarking tool. This implies that even if the user can add new metrics, there needs to be a managing entity that will validate it in accordance with the process provided in Figure 2. Further, the hierarchy of the importance or value of the metrics as well as whether they are fixed or changeable, has to be established.

4. Discussion

There are many metrics identified as appropriate and valid when scrutinising methods of measuring BIM performance. However, since the AECO industry consists of actors from many different fields, using BIM in sometimes different ways, it is impractical aiming to select an ultimate series of these metrics to serve as valid for all actors within the industry. Established frameworks and models for assessing BIM performance is either too simplistic (e.g. iBIM) or overly detailed (e.g. BIM Maturity Matrix) and therefore somewhat ill-suited for self-assessment. The self-assessed benchmarking approach instead enables an easy, accessible, dynamic and customised set of metrics for performance measurement to be developed. This will enable a "relevant only" approach for measuring. The crowd sourcing approach will eventually enable the development of dataset groups and categories, what Succar et al. (2012) refers to as filters that will incrementally guide validation and valuation of metrics.

By this we argue that self-assessed crowd sourcing methodology will contribute to the gathering of relevant data; organisations select what is relevant to them for internal benchmarking purposes.

More users successively will lead to a better database, with more valid metrics and more precise measurements which will benefit all users. Furthermore, this approach to benchmarking BIM performance will reduce the risk of leaking sensitive information to a third party since data considered sensitive is regulated in its exposure. Existing frameworks applicable for measuring BIM performance, as mentioned earlier, will either require help from expert consultants or the development of possibly costly in-house know-how and thus are more cumbersome to get started with.

An obstacle to overcome, when applying this methodology of assessment over the whole AECO industry, is the probability for some metrics being easier to score high or fulfil than others. This since there is a risk that the performance of actors in a certain sector will be shown, or indicated, as more mature than others as a result of what metrics are closer, and thus more likely to be used, to the core business and the characteristics for this type of organisation. Hence, it seems reasonable that this methodology and approach to developing BIM performance benchmarks may be a way forward. As a tool for comparing organisations with different abilities and focus throughout the whole industry however, it is unlikely to be applicable in the same way. Rather, it can be used to give a rough estimation, an indication, between the fields which in the long run can provide valuable information about how well a sector is performing BIM in industry context.

As the system is used more, the database will grow in terms of additional new metrics and get more refined and precise as the users automatically validate the metrics. Early adopters or pilot organisations risk suffering inaccurate measuring results as the dataset is developing. This is likely to create barriers to developing the database and pose a threat towards convincing industry actors to adopt it. However, setting up a tool with relevant and versatile default metrics developed through case studies and expert consultation will reduce the chance of this occurring.

5. Conclusions

Development of a framework for self-assessed benchmarking of project based BIM performance with utilisation of crowd sourcing as a method for populating the tool is proposed to be an accessible and cost effective way of evaluating BIM performance. This methodology may reduce unnecessary cost and lead-time as well as avoid sensitive information being exposed to third parties. It can also serve as an efficient tool for comparison between projects given that they will have similar ways of conducting their business and thereby are using similar key metrics. As a method for comparing organisations in varying fields within the AECO industry however, it seems more likely to provide a rough comparison which can be valuable for pin-pointing the weakest capabilities in terms of BIM performance throughout the AECO industry.

To reduce or remove misguiding user influence, the tool has to be developed on the foundation of some default metrics. Also, there has to be a certain amount of administrative control in order to adjust eventual misguiding data. The dataset hosting the tool is suggested to be developed in accordance with the structure shown in Figure 2.

6. Future research

For this methodology to be efficient in procurement situations more research has to be conducted on a foundation of industry case studies. As mentioned earlier in this paper, a starting point and platform of BIM performance default metrics is needed. In order to be useful for the AECO industry as well as internationally applicable, these will be developed through case studies with diverse sectorial as well as regional participants. Another challenge is to define if and by that how weighting of the metrics should be considered. A metric or factor frequently used or assessed might be less important than one of lesser frequency.

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Appendix 3

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Assessing BIM performance in building management organisations

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Abstract

This paper presents a literature review into issues related to Building Information Modelling (BIM) performance assessment in building management organisations and proposes an agenda for future research addressing how such an approach can be further developed. Performance in use of BIM can be described as a measure or description of how capable and mature a project team or organisation is in terms of developing, using, evaluating or receiving BIM products or services. Although BIM is a well-known and established methodology in building design and construction organisations, when procuring and executing projects, the building management side, encompassing building operations and maintenance, usually lags. Adoption of BIM in building management has become a challenge addressed in discussions on what the next step for BIM uptake will be. By adapting and using solutions that, to an extent, have already been developed for other stages in the construction delivery process, BIM can contribute to benefits for the operations/management phase of buildings. To prove efficiency and applicability of BIM as a methodology in building management operations, approaches to assess actual performance are necessary.

This paper describes development of a possible approach of assessing BIM performance through self-assessment. It is identified that pre-requisites in the form of default performance indicators, referred to as BIM Performance Indicators (BPI) must be established for such methodology to be possible. To distinguish these BPIs, new data through input from practitioners must be gathered. This paper suggests that a case study aiming to gather data from practitioners for this development is a suitable vehicle for identifying these indicators underpinning assessment of BIM performance specific to organisations within the building management sector. The paper concludes that appropriate dimensions in which significance for BIM use in building management organisations should be sought in a case study are (1) Technology, (2) Knowledge, (3) Communication, (4) Processes and (5) Organisational culture and motivation.

Keywords: BIM performance, building management, self-assessment, capability, BIM performance indicators, BIM maturity

1. Introduction

BIM has become the primary methodology encompassing the digitalisation of the built environment supply chain. BIM is a digital representation of the physical and functional characteristics of a building and serves as a knowledge sharing vehicle for building information (Barlish and Sullivan, 2012). Incentives and use related to BIM have been increasing over the past few years, as explained by Azhar et al. (2012), "BIM has gone from being a buzzword to the centrepiece of AEC[1] technology". Although BIM is applied to many large design and construction projects it is still not common practice throughout the industry. However, design and construction projects are now proving to be more efficient in terms of cost reduction, quality improvement, time schedule adherence and a better work flow between project participants. In addition, project owners have started realising other benefits deriving from BIM as a work method, such as easier quantity take offs, enabling easier calculations and visualisations for promotional purposes and ease of cross-disciplinary collaboration to name a few (Sanchez and Joske, 2016; McGraw Hill Construction, 2014).

In terms of object-based model information, the building management side is far from being as developed as actors working with executing design and construction. Building management includes use and maintenance during the operations phase of a building's life cycle. Van Berlo et al. (2012) presents a case study, evaluating and comparing the BIM performance of all actors in the AEC industry and operations [AECO]. This study addresses that actors with client/owner and building manager roles have the lowest BIM performance levels out of all primary AECO stakeholders. A major reason for this is that traditionally the operations of a building have been perceived as something separate from the production of it - construction. Following that pattern, the process of generating a BIM model is often divided in the same fashion as the physical asset which creates illogical hurdles for the information flow between project stages. This leads to a low level of inclusion of building management actors in design and construction of projects and subsequently low involvement in the development and adoption of BIM methodology as a whole.

At the same time, the degree of competitiveness on the market amongst building owners and managers has increased the need for optimisation of processes delivering a streamlined building operation (Zhang et al., 2009). Consequently, implementation of BIM in building management organisations may constitute an effective platform for long-term strategic business outcomes (Love et al., 2013). BIM performance can be described as how capable and mature the project team or organisation is in terms of their BIM use and can mirror efficiency (Månsson and Lindahl, 2016; Månsson et al., 2016; Succar et al., 2012). Assessment of BIM performance can contribute to both preparation for efficient implementation and streamlining future use of BIM in building management. To realise this, a base methodology for assessing the BIM performance of the organisation is required.

To enable a methodology in which assessment of BIM performance of all stakeholders involved in and affected by BIM projects can be possible, potential ways of assessing the weakest link, building management, will need to be investigated. The research presented in this paper, will compile information related to BIM performance in building management organisations to build a foundation on which BIM Performance Indicators, BPIs, can be further developed.

2. Methodology

The aim of this paper is to gather insight concerning BIM performance assessment of building management organisations. Initially a literature review was carried out to establish a knowledge base about the ways scholars are addressing BIM adoption in building management organisations. It was identified that literature concerning BIM performance assessment of building management organisations, with a comprehensive understanding was a scarce resource. To address this, a comparison between frameworks and tools for measuring and assessing various aspects related to BIM performance and value was made. A preliminary comparison addressing how these frameworks and scales divided their metrics into categories was made by addressing those that seemed most relevant for the study. The dimensions addressed related to frequency, within the reviewed frameworks, and estimated importance

[1] AEC: Architectural Engineering and Construction industry is defining the primary disciplines included in a construction project. (Azhar et al., 2012)

for BIM adoption in building management. Furthermore, a combination of interviews and follow up questions via email correspondence with four different building management organisations was made to verify that these categories were relevant for the study as mentioned above. The input gathered set the foundation in which a default set of BPIs can be developed and further tested empirically.

3. Literature review

BIM capability refers to the ability project teams or organisations must deliver a service or product related to BIM. BIM maturity addresses the quality, repeatability and depth in which these services and products are or can be delivered (Månsson et al., 2016; Succar et al., 2012). To prove the efficiency of BIM projects or evaluate an organisation's BIM deliverables and use, the performance should be assessed.

There are several frameworks that aim to assess or measure benefits and performance related to implementation and readiness of BIM in design and construction of projects. BIM excellence, BIMe, further extended by BIM Maturity Index, BIMMI, and BIM Maturity Matrix are all developed by Succar for assessing BIM. BIMe is an online tool used for assessing performance of organisations, projects and individuals in relation to BIM (Succar et al., 2013). BIM Quick Scan (Sebastian and Van Berlo, 2010) is intended for generating a performance benchmark at an organisational level through a multiple-choice scorecard based on a series of KPIs. The BIM Quick Scan is performed by an external consultant comprising information from interviews and observations. The *BIM Planning Guide for Facility Owners* developed by Computer Integrated Construction (CIC) at Penn State University presents an approach in which building management organisations can plan for integrating BIM through strategic, implementation and procurement planning. (CIC, 2013). BIM Value is an online tool identifying metrics to evaluate BIM value and benefit outcomes achieved through BIM projects. The methodology is presented by Sanchez and Joske (2016) in a benefits dictionary published in *Delivering Value with BIM A Whole-of-life Approach* by Sanchez et al. (2016). Interactive Capability Maturity Model, I-CMM, a simplified version of Capability Maturity Model, CMM, measures the maturity of BIM when being implemented. The focus is on project level and mostly concerns technical aspects (National Institute of Building Sciences NIBS, 2007). The Virtual Design and Construction, VDC, Scorecard is a framework for evaluating VDC implementation through a series of measures developed with emphasis on the design and construction phases (CIFE, 2013). The BIM proficiency matrix is an excel-based matrix scorecard created to assess the proficiency in which a BIM model is developed. It was developed by Indiana University originally to assess BIM projects and thus enhance building management (Indiana University, 2009).

An approach presented by Månsson et al. (2016) includes a self-assessment methodology using a crowd-sourcing approach to populate and autonomously refine the inclusion of parameters for assessing BIM performance of projects. The methodology includes the need for a series of default BPIs to serve as a foundation for continuous improvement. To enable this methodology, parameters for adequate performance assessment are needed. Generally, the process of refining parameters as shown in Figure 1 requires a preliminary set of BPIs followed by meticulous analysis and validation.

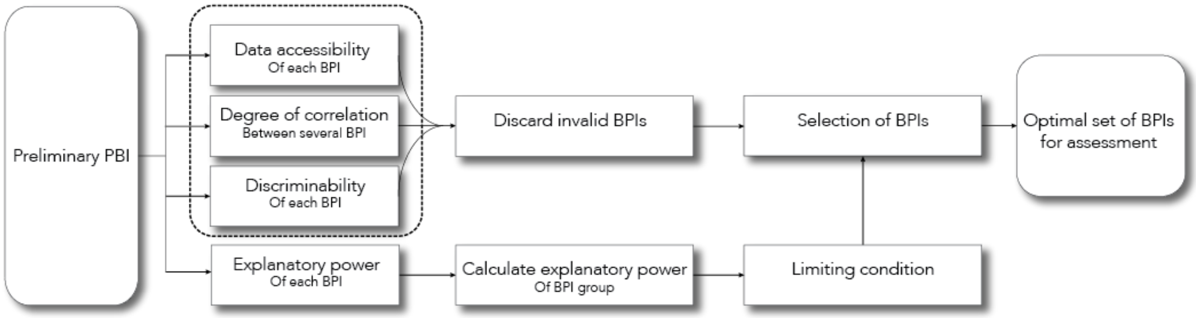

Figure 1: *Process of selecting BPIs for assessment of BIM performance, edited version (Mansson et al., 2016)*

Assessment of building management organisations' application, use and performance of BIM will be different from assessment of organisations operating in design and construction phases. There may be two main reasons for this. First, the low BIM adoption in building management organisations in general limits the insight into key success factors and, in the long run, variables effecting their performance. Second, the nature of practice differs from that of other actors involved in a project including the time span in which they are operating. To gain better insight, new data addressing specific requirement for building management organisations adoption of BIM is needed. A suitable niche to investigate is building management organisations owning and managing university buildings. University-focused asset portfolios can contain a variety of building types, ranging from standard office buildings to high-tech laboratories. Furthermore, it is likely that universities have high ambitions or willingness in improving building management efficiency through digitalisation considering that it is likely beneficial for universities to be perceived as innovative as well as acting innovatively. Lastly, efficient management of university buildings may contribute with a positive impact on education and research quality, making this field suitable and attractive to investigate. The following sections will explore BIM as support for building management and prerequisites for assessment of BIM performance specific for these organisations.

3.1 BIM as support for the built environment industry

Building management includes use and maintenance during the operations phase of a buildings life cycle. BIM can function as a reliable basis for management and transfer of data and enables efficient decision making during a building's life cycle including the operations phase. Kivits and Furneaux (2013) argues that the BIM methodology with a single rich model has the potential for improving the construction and management of a building in a life cycle perspective including improvement in sustainability.

Though the use of BIM as a methodology has been evolving over the past few years, there are distinct barriers to achieving an efficient integration of data transfer from design and construction to building management and operation. A tradition of perceiving the design and construction project as a separate entity from building management can be argued to be a reason for this. Combined with the fact that data formats have been varying depending on what specific CAD tool is used and who is populating the model, possibilities for solutions to carry significant project data from design and build to operation and maintenance has been limited. Kiviniemi and Codinhoto (2014) argue that this lack in interoperability combined with difficulties in keeping the information up-to-date are some of the main barriers to successful BIM implementation in building management. Industry Foundation Classes, IFC, a non-proprietary exchange format of building information between software and applications, was developed to represent information over the building's life cycle. (Volk et al., 2014). Non-proprietary formats, like IFC, enable new possibilities for the development of solutions for handling project data deriving from the BIM process in a life cycle perspective. If used coherently, non-proprietary formats may therefore be one key pre-requisite for development of new tools and ways of working with building and building management data.

As non-proprietary formats unlock the potential for new technical solutions for interoperable data flows, challenges for development and implementation will emerge. First, the building management organisation must identify and specify what data they will require. The Level of Information, LOI[2], and Level of Detail, LoD,[3] contained in model elements of BIM models developed for the design and construction phases of the project is not optimised to be used for building management purposes. Trying to utilise already existing, sub-optimised, BIM models is not ideal for various building management functions. LoD and LOI is usually determined by the owner at the design phase and executed in the procurement and construction phases of a project (Becerik-Gerber et al., 2011). Project owners should decide these levels before the project is initiated. If over-specifying the LoD and LOI, they risk spending unnecessary funds and likewise inferior LoD and LOI will lead to a sub-optimised model unable to serve its purpose (Bonanomi, 2016).

It may be easy to over focus on technological solutions as working with digital project information likely will introduce the building managing organisation to a more extensive use and development of software tools. Rather than perceiving the BIM implementation as a technology adoption or development activity, it should be viewed as variation of business routines and procedures. To support this development, an understanding that technology alone cannot deliver business outcomes is needed (Love et al., 2014), stressing the importance for a clear strategy including all organisational dimensions affecting the implementation. As stated by Kivits and Furneaux (2013) managing this change will require an extensive management of knowledge, although they explain it as a further extension of current BIM practices. In contrast, it is likely that use or rather adaption of BIM to serve building management or a building's life cycle will require re-development of the BIM process. Thus, to some extent BIM should be adapted to building management and the other way around. Organisations working in building management will require different information than the one used as project support, also building management firms may have various capabilities and goals. For example, new parameters and dynamic LoD level matrixes will be required to be clearly stipulated in the design phase.

3.2 Assessing BIM performance

To assess an organisation's BIM performance there are several different methods of collecting data required to do so. One efficient way is to perform interviews with employees directly involved with the organisation's operation. Furthermore, various analyses and surveys can serve as efficient self-assessment tools for assessing the organisation's performance (CIC, 2013). BIM in building management is not yet significantly established, consequently there is a lack of methodologies and parameters to assess the performance of actors in this field.

Månsson and Lindahl (2016) posit that there are several existing frameworks for measuring or assessing the performance of organisations or project teams tied to construction projects operating a BIM practice. None of which is specifically addressing building management-based activities. Although, some of them host parameters that can be used to assess the performance of building management-related organisations. By comparing how these frameworks are treating the different factors affecting the overall performance, perspectives on how to map factors for assessing performance of organisations or activities in a building management context can be identified.

[2] Level of Information, LOI, defines the amount of non-graphical information is added to a model element
[3] Level of detail, LoD, defines the amount of graphical information contained in a model element (BIMForum, 2017).

BIM Excellence is an online tool that assesses the performance of organisations, projects and individuals in relation to BIM. This commercial tool is based on the research of Succar et al. (2013), and divides the assessment subject into eight main dimensions: technical, operational, functional, implementation, administration, supportive, research and development, and managerial. *BIM Excellence* is developed in coherence with the more extensive tool *BIM Maturity Index*, BIMMI dividing the BIM implementation into stages from object-based modelling to an integrated project delivery. Dimensions in which organisational BIM maturity is sought is divided into technology, processes and policies (Succar et al., 2013).

BIM Quick Scan developed by Sebastian and Van Berlo (2010) is intended for generating a performance benchmark. It divides the organisation into four categories consisting of series of parameters: organisation and management; mentality and culture; information structure and flow; and tools and applications.

The *BIM Planning Guide for Facility Owners* developed by CIC (2013) at Penn State University divides the organisation into six categories: strategy, BIM uses, process, information, infrastructure, and personnel.

Sanchez et al. (2016) have documented metrics for assessment of organisational BIM value. It has divided the organisation into four main categories: people, process, procurement and sustainability. *BIM Value* identifies possible metrics for evaluation of value deriving from BIM use not addressing BIM performance but rather the benefit outcomes of BIM activities.

Azhar et al. (2012) describes BIM as a combination of technologies and processes. However, when adapting the BIM methodology to building management, processes and technologies will change. Furthermore, organisations should consider dimensions, considered to be soft, such as knowledge, communication and culture.

After comparing the above-mentioned frameworks and methods, this research will adopt five organisational dimensions as a foundation for identifying relevant BPIs suitable for assessing building management oriented organisations. These are: technology; knowledge, communication; processes; and organisational culture and motivation. These dimensions are described in the following sections.

3.3 Technology

The technology dimension includes technical solutions serving and performing data management and use. Specifically addressing BIM technology refers to hardware and mainly software solutions as addressed by Van Berlo et al. (2012) in BIM Quick Scan as tools and applications, further addressed in BIMe, BIMMI (Succar et al., 2013) and by Azhar et al. (2012). Technology assessment has two main approaches, first technology available for a specific need and secondly technology obtained by the organisation. While technology available may indicate, the possibilities open to supplier capability, technology obtained can indicate the organisation’s maturity comparing the deviation between the availability and the technology obtained. The dimension concerns firstly, what capacity organisations possesses to use the technology and secondly, what technology they are using. These can be related with financial indicators (CIFE, 2013). Building management organisations should make sure that the tools they are currently using will be compatible with the building information deriving from the BIM process. They also must ensure that structure and formats of the building information can be used to serve operational needs. BPIs developed within this dimension should be able to assess whether the firm or team has all technical capabilities necessary to perform or receive required BIM services or products.

3.4 Knowledge

The knowledge dimension reflects the organisation's collective knowledge mainly in terms of competent staff members, information held and use of information addressed by CIC (2013) in the BIM Planning Guide for Facility Owners. BIM Quick Scan also addresses information as a category (Van Berlo et al., 2012). New organisational development such as integration or further utilisation of project data in building management often requires rapid and effective knowledge integration throughout the organisation. This also includes strategies for knowledge integration over time and how implementation will be aided by the organisation's preparedness for change (Marsh and Stock, 2006). A critical factor can be a lack of competent staff to employ which can become a significant barrier to implementation of new methodologies. In short, what strategy does the organisation possess to obtain and manage knowledge? When implementing BIM, a new way of working with building information, building management organisations require hiring new staff as well as educating its employees. Supportive assessment of knowledge possessed and required related to BIM enables this. BPIs developed within this dimension should be able to assess whether the firm or team possess the knowledge necessary to perform or receive required BIM services or products.

3.5 Communication

This dimension includes the capacity to retain and share knowledge between projects and participants. It also addresses the efficiency of information flows between projects, project participants and organisational departments. BIM Quick Scan emphasises information structure and flow as an important dimension to assess (Van Berlo et al., 2012). For a business knowledge sharing is capturing, organising, reusing and transferring the vast and unique knowledge that resides within the organisation and making that knowledge available to others in the business (Reid, 2003). When implementing BIM in building management, effective communication between design and construction actors is key, as well as between building management actors. The required model content must be established before the project is initiated. Furthermore, disciplines within the building management organisation may find new ways of internal collaborating through digitalisation of building information stressing the importance of good knowledge sharing. BPIs developed within this dimension should be able to assess how capable the firm or team is in communicating and sharing knowledge supporting their performance and receiving required BIM services or products.

3.6 Processes

A good understanding of and a clear strategy for the causal relationships between organisational entities affecting new implemented methodologies is required for a successful implementation and use (Marsh and Stock, 2006). Furthermore, clarity about which events occur and what resources are used is needed. Processes are included as assessment categories in BIMMI (Succar et al., 2013), BIM Planning Guide for Facilities Owners (CIC, 2013), BIM Value (Sanchez et al., 2016) and by Azhar et al., 2012) If processes are not specified and followed, it may hamper change and adoption of new business methodologies. As new technologies and management of knowledge and communication will change through BIM integration in building management, processes in which to apply these must be designed and followed. To make sure that they are effective, they should be properly assessed. BPIs developed within this dimension should be able to assess how well the firm or team is supported by processes specifying how to perform and receive required BIM services or products.

3.7 Organisational culture and motivation

This dimension refers to openness and responsiveness for change of business procedures and adoption of new methodologies as well as willingness and capability to drive change. Organisational culture is described by Martins and Terblanche (2003) to be deeply seated values and beliefs shared by the members of an organisation which will manifest its characteristics and affect the ability to change business methodologies. BIM Quick Scan addresses culture and mentality as dimensions for assessment (Van Berlo et al., 2012). BIM in building management may include a dramatic change in how building organisations conduct their business, stressing the importance of implementing and testing new practices and tools. An environment in which risk taking through innovative and creative development is encouraged is necessary as business methodology changes and develops into new areas. Organisations need to consider that some initial problems might occur when new procedures are implemented in the business and communicate a culture in which errors and initial mistakes are not discouraged (Martins and Terblanche, 2003). BPIs developed within this dimension should be able to assess how well the firm or team is supported by the organisational culture and motivation to develop, perform and receive BIM services or products. This could either relate to financial indicators such as, money spent on R&D tied to BIM, but also on the employees' experience of support from the organisation.

4. The case study approach

Efficient implementation and use of digital data, deriving from the project, in building management organisations will require effective implementation strategies. To identify these strategies, key factors affecting the BIM progression need to be identified. A self-assessment approach to this will enable a way of evaluating implementation progress and efficiency. The BPIs needed for such a method must be identified and validated. Since information related to this is very limited, new data to create a general framework for BPIs and in the long run success factors specific for building management organisations will be necessary. Furthermore, complex processes and issues can be better understood as new data is gathered and evaluated. An efficient way of doing this is by conducting a case study (Dooley, 2002). By applying a case study methodology when gathering and testing data, a deeper insight and understanding for complex issues will be possible to obtain. In addition, a case study can contribute to a greater confidence for what is already proven or identified in past studies (Dooley, 2002).

Developing a theoretical framework is central when performing a case study focusing on organisational research. Eisenhardt (1989) stresses the importance that a weak theory can result in weak ties between the theory and the test results due to an overly widespread accumulation of case study methods. There are different approaches to conducting a case study research with varying approaches, all of which strive to explore an area/issue and seek to reveal patterns, aspects and core structures of it. As the theory and examples from practice is novel and limited in this field, this paper is suggesting that a case study approach should focus on combining available theory with qualitative interviews with representatives of industry actors.

4.1 Interviews

Interview-based case studies aim to collect qualitative information from people with connection to or likely valuable knowledge or opinion about the researched topic for further analyse. Interview outcomes can also serve as benchmarks to compare non-connected knowledge or opinions with connected ones to validate the significance of the information. Since using BIM in building management organisations is quite novel, it is expected that detailed knowledge of its present or future use is difficult to obtain directly from interviewees. An initial interview with each interviewee can be performed for obtaining a general image of the organisation's present status, future use and perception of the implications connected to BIM use in building management. This paper suggests that a case study including interviews intended to map out the importance of the above-mentioned dimensions in regards to using BIM in building management organisations is a logical step towards obtaining a deeper knowledge and a positive way forward.

Furthermore, knowledge gained through interviews can help when developing and evaluating the importance of specific BPIs deriving from analysis of the interview outcomes. Ultimately a case study approach will enable yielding a default series of BPIs specifically suitable for assessing the performance of BIM use in building management firms. This can then enable the development of prerequisites for further research and development of BPIs relevant for assessing organisations working with BIM in building management. A case study is set to mirror reality, but there is a trade-off between level of control and degree of realism (Runeson and Höst, 2008). Since it is unlikely that building management organisations, suitable to partake in such case study already have an elaborate BIM practice, it is challenging to foresee the outcomes of such interviews. Therefore, the interview should consist of open-ended questions aiming to cover a wide variety of topics. Also, the interviewees sought for such case study should be working in strategic level functions or specifically with building information.

5. Discussion

The BIM methodology has become fairly established in design and construction projects and has contributed to a more efficient way to execute the process (He et al., 2016). Still, there are many ways in which BIM can be used more extensively in the building management process. The information created in the design and construction phase of a project holds many possibilities to serve building management in terms of maintenance and more effective use of buildings. An impediment is that the information created in BIM projects often lacks essential data as it is not produced for a building management purpose to begin with. Therefore, the required LoD and LOI should be extended and clearly defined by the building management organisation, who is often also the project owner. This may enable a more standardised and repetitive structure of IFC models. Building management organisations naturally have different needs and abilities from those of organisations involved in the production of the asset. Improved development of IFC models may increase the potential in which they can be used for building management purposes. In addition, it may enhance data interoperability throughout the building life cycle and collaboration between project stakeholders.

Possible implementation, or rather, use of digital project data in building management organisations will create further challenges. There is no unanimous need stated for what aspects of BIM building management organisations demand, possibly since there has not been any service use presented to them or that possibilities for using digital project information has not previously been applicable. A starting point is that non-propriety formats such as IFC has been established enough in terms of content and applicability to major BIM software, enabling a good integration between software and development of new ones serving building management. However, other factors should be considered such as those related to processes, knowledge and communication and motivation and culture.

A more elaborate and inclusive engagement of building management organisations in the construction project delivery process will enable a better insight into what information and functions are needed and valuable through the BIM model. This will require a more precise requirement specification necessary to identify needs and further develop solutions to meet these needs.

Furthermore, it is of importance that researchers and industry follow and engage in the development of digital data integration in building management and strive to use the digital building data from a life cycle perspective and support performance assessment of the built environment. Through this, it should be possible to develop an understanding of how actors are performing and how some hamper greater industry efficiency and the reasons behind the different approaches.

6. Future research methodology

This paper has investigated how the effective use of BIM for building management can be measured. A review of recent literature found that whilst there are several methodologies for evaluating BIM practices in design and construction, there are few for assessing performance of BIM in building management organisations. Furthermore, it is clear that at least some knowledge of BIM benefits has encouraged the uptake of BIM by the AEC professions. To address the absence of BIM evaluation methodologies for building management, the research team proposes a program of research to identity appropriate measures in five key areas of building management practice, namely: (1) Technology, (2) Knowledge, (3) Communication, (4) Processes and (5) Organisational culture and motivation.

Future research will include interviews with building management organisations operating within a university segment in two countries, Sweden and Australia. The objective is to establish a deeper insight in the actual prerequisites and needs these organisations have related to digitalisation through BIM adoption. These organisations often have large portfolios centralised on one or several campuses containing buildings with a variety of complexity.

Based on the dimensions identified in this paper, the aim is that future research will contribute to identification of a narrow selection of relevant BPIs and enable future comparison between the approach taken in two countries, Sweden and Australia. University building management organisations often mange large portfolios centralised on one or several campuses containing a myriad of different buildings, ranging from standard office spaces to complex laboratories. Also, building management organisations connected to universities are likely to be willing to integrate innovative solutions in due to their propinquity to education and research making this segment suitable and attractive to investigate.

7. Conclusions

BIM should be adapted to suit the needs of building management in a similar manner that building management organisations must adapt to BIM methodologies. Bridging the gap between the, often, separate entities will inevitably require proactive change. A starting point is that non-propriety formats such as IFC enables development of technical solutions addressing BIM in building operations. This is an important cornerstone in the development of BIM practices that cover building management. A problem with IFC models created as design and construction support, is that they seldom are populated in accordance to meet building management requirements. Therefore, requirement specifications should be clear, inclusive and developed by the building managing organisation in a project's early phases. In addition, further inclusion of building managers throughout the design and construction phase will incorporate valuable input from the end user ensuring the appropriate content in the BIM model to serve a building over its life cycle.

The literature review showed that there are gaps in terms of how a common knowledge of BIM uptake in building management will create benefits and what constitutes a level of performance specific for these organisations. Also, through correspondence with building management organisations it was found that there is a lack of insight as to how the companies themselves perceive benefits in relation to critical success factors for BIM adoption. Performance literature and assessment tools related to BIM performance in building management organisations tend to focus largely on technology aspects which naturally is a major factor.

Aside from the technical aspects, there are several other factors affecting BIM implementation in building management that needs to be taken into consideration when developing strategies for implementation. Assessment of performance among building management organisations is essential to evaluate performance and develop strategies for implementation. A self-assessment approach to this will enable user-friendly assessment that does not require potentially threatening external supervision and external knowledge. What should be assessed, however, must be identified and defined. The first step in identifying what to assess is to identify and map what dimensions of the respective organisations are the most important in relation to BIM implementation, as well as the level of maturity for these dimensions. This will help specifying in which areas they are ready for implementation as well as areas in which they, and in the long run the whole sector, need to improve. The dimensions in which the importance of BPIs will be sought in planned future research are (1) Technology, (2) Knowledge, (3) Communication, (4) Processes and (5) Organisational culture and motivation.

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Appendix 4

Table of Respondents

Table of interview participants.

Acronym	Organisation	Role	Country	Background	Years in org.
SA1	Akademiska Hus	IT development	SWE	IT/ GIS Civ. Engineer	17
SA2	Akademiska Hus	BIM strategist in projects	SWE	Projects Civ. Engineer	9
AC1	Curtin University Properties	IT/data mgmt	AUS	Design and Construction Projects	5
AC2	Curtin University Properties	space optimization manager. – TEFMA coordinator	AUS	Space management. No relevant education	15
AD1	Edith Cowan University Properties	Manager Buildings and Services	AUS	FM	4
SB1	Chalmers Properties	Vice President	SWE	Civ. Engineer	7

Appendix 5

Permission Letters

Permission for paper in Appendix 1

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Fri 15/09, 4:48 PM
Daniel Månsson

Reply all

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Tue 15/08, 3:17 PM

Dear Daniel Månsson,

Thank you for your message and your interest to take advantage of your WBC paper as a part of your thesis. Permission granted for this purpose with pleasure.
Best success to you for the named thesis work.

Kindly,

____

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