Towards a BIM-enabled Facility Management: 
Promises, Obstacles and Requirements 
POURIYA PARSANEZHAD
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Promises, Obstacles and Requirements
Pouria Parsanezhad
Abstract

A substantial share of the organisations’ annual costs is associated with their facilities. A fundamental shift from a reactive facility management (FM) practice to a strategically orchestrated FM profession is thus a prerequisite for increased resource efficiency. One of the requirements for a coordinated facility management practice is information logistics. Building Information Modelling (BIM) is one of the most prominent initiatives frequently addressed by scholars and practitioners as a game-changer in construction industry in general and FM in particular. In order to fully reap the benefits of BIM in FM, however, further research is required. This study aims, therefore, to investigate the challenges against successful implementation and realizing the benefits of BIM in FM.

The primary focus in this study is the FM phase; but the earlier upstream phases have also been studied due to their implications for a BIM-enabled FM. From a spatial-scale perspective, this study is mainly focused on buildings rather than other construction entities. The findings could benefit both academics and practitioners. Overall, a pragmatic research philosophy has been adopted and the main research strategy used here is case study.

The current dissertation is composed of five papers. The focus of knowledge acquisition through papers alternately shifts between the applied and the theoretical. The primary theoretical grounds of the papers are the built environment management model (BEM2) (Ebinger and Madritsch, 2012) and BIM Framework (Succar, 2009). Further theories from the fields of design methodology and cognitive science have also been revisited.

Paper 1 provides a theoretic basis for more focused studies on existing and desired processes in FM and their associated information transactions. In Paper 2, the current status of the building information management technologies used in FM is summarized; the prevailing issues are identified; and a number of technical solutions have been devised. Paper 3 shifts the focus back to the design phase and provides a knowledge base for developing further theoretical frameworks and conceptual models that support IT-implementation for formalized requirements management. Through Paper 4, it has been investigated how beneficial contemporary design-intent BIM deliverables could be to FM and what should be improved. The focus of Paper 5 again shifts back to the FM phase. Here, a methodology has been presented for measuring the benefits of BIM in FM using a proposed benefits realization assessment framework.

Obtaining the full range of the benefits of BIM in FM, however, requires radical organizational changes and introducing new roles. Further research is needed for defining new business models that underpin and motivate such extensive organizational and procedural changes. More research should also be undertaken for enhancing data interoperability among different actors as well as among IT platforms used at different spatial scales namely BIM and GIS applications.

Keywords: Building Information Modelling, facility management, interoperability, BIM, FM
Sammanfattning

En betydande del av organisationernas årliga kostnader utgörs av kostnader för fastigheter. Ett grundläggande skifte från reaktiv fastighetsförvaltning (FM) till strategiskt orkestrerad FM-profession behövs således för att öka resurseffektivitet i branschen. En insiktsfull fastighetsförvaltning kräver, i sin tur, en välväxtrakt form av informationslogistik. Byggnadsinformationsmodellering (BIM) är ett av de mest framträdande initiativen i området. BIM anses som en spelväxlar i byggbranschen som helhet samt FM i synerhet. Ytterligare forskning krävs dock för att kunna nyttja BIM i FM fullt ut. Denna studie syftar därför till att undersöka hinder för implementering och förverkligande av nytto av BIM i FM.

Det främsta fokuset i denna studie ligger på FM-skedet; men de initiala planerings- och projekteringsskedena har också studerats på grund av deras konsekvenser för en BIM-baserad FM. Ur ett rumsligt perspektiv är denna studie främst inriktad på byggnader snarare än andra typer av anläggningar. Resultatena kan gynna både akademi och näringslivet. En pragmatisk forskningsfilosofi har antagits i denna studie och den främsta implementerade forskningsstrategin är fällstudie.


Att nyttja BIM i FM fullt ut kräver dock radikala organisatoriska förändringar och införande av nya roller. Ytterligare forskning behövs för att uppföra nya affärsmodeller som underbygger och motiverar sådana förändringar. Mer forskning behövs även för att öka datainteroperabilitet mellan olika aktörer samt mellan IT-plattformer som används för olika rumsliga nivåer nämligen BIM- och GIS-applikationer.
Acknowledgements

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Pouria Parsanezhad
Stockholm, April 2019
## Abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Full Form</th>
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<tbody>
<tr>
<td>Aff</td>
<td>Avtal för fastighetsförvaltning</td>
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<tr>
<td>AI</td>
<td>Artificial Intelligence</td>
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<tr>
<td>API</td>
<td>Application programming interface</td>
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<td>BAS</td>
<td>Building automation system</td>
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<td>BCF</td>
<td>BIM collaboration format</td>
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<td>BEM2</td>
<td>The built environment management model</td>
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<td>BIM</td>
<td>Building information modelling</td>
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<tr>
<td>BMS</td>
<td>Building management system</td>
</tr>
<tr>
<td>BSAB</td>
<td>Byggandens samordning AB</td>
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<tr>
<td>bSDD</td>
<td>buildingSMART data dictionary</td>
</tr>
<tr>
<td>CAD</td>
<td>Computer-aided design</td>
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<tr>
<td>CAFM</td>
<td>Computer-aided facility management</td>
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<tr>
<td>CIB</td>
<td>Conseil international du bâtiment</td>
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<tr>
<td>CIFE</td>
<td>Center for integrated facility engineering</td>
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<tr>
<td>CMMS</td>
<td>Computerized maintenance management system</td>
</tr>
<tr>
<td>COBie</td>
<td>Construction operation building information exchange</td>
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<tr>
<td>CPPM</td>
<td>Capital project portfolio management</td>
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<tr>
<td>DMS</td>
<td>Document management system</td>
</tr>
<tr>
<td>ECPPM</td>
<td>European conference on product and process modelling</td>
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<tr>
<td>EUL</td>
<td>Expected useful life</td>
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<td>EPD</td>
<td>Environmental product declarations</td>
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<td>EPIC</td>
<td>Electronic product information cooperation</td>
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<td>EuroFM</td>
<td>European facility management network</td>
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<td>FM</td>
<td>Facility management</td>
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<td>GDP</td>
<td>Gross domestic product</td>
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<tr>
<td>GFA</td>
<td>Gross floor area</td>
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<tr>
<td>GIS</td>
<td>Geographic information system</td>
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<tr>
<td>GTIN</td>
<td>Global trade item number</td>
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<tr>
<td>GUID</td>
<td>Global unique identifiers</td>
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<tr>
<td>HVAC</td>
<td>Heating, ventilation and air-conditioning</td>
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<tr>
<td>IAI</td>
<td>International alliance for interoperability</td>
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<td>IAM</td>
<td>Institute of asset management</td>
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<tr>
<td>ICT</td>
<td>Information communication technology</td>
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<tr>
<td>IDM</td>
<td>Information delivery manual</td>
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<td>IEC</td>
<td>International electrotechnical commission</td>
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<tr>
<td>IFC</td>
<td>Industry foundation classes</td>
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<tr>
<td>IFD</td>
<td>International framework for dictionaries</td>
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<td>IFMA</td>
<td>International facilities management organization</td>
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<tr>
<td>IoT</td>
<td>Internet of things</td>
</tr>
<tr>
<td>Abbreviation</td>
<td>Definition</td>
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<tr>
<td>IPD</td>
<td>Integrated project delivery</td>
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<tr>
<td>IRR</td>
<td>Internal rate of return</td>
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<tr>
<td>ISO</td>
<td>International organization for standardization</td>
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<tr>
<td>IT</td>
<td>Information technology</td>
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<tr>
<td>IWFM</td>
<td>Institute of Workplace and Facilities Management</td>
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<tr>
<td>KPA</td>
<td>Key process area</td>
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<td>KPI</td>
<td>Key performance indicator</td>
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<tr>
<td>KTH</td>
<td>Royal Institute of Technology</td>
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<tr>
<td>LOD</td>
<td>Level of detail</td>
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<tr>
<td>MVD</td>
<td>Model view definition</td>
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<tr>
<td>NPV</td>
<td>Net present value</td>
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<tr>
<td>OCCS</td>
<td>OmniClass construction classification system</td>
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<tr>
<td>PLCS</td>
<td>Product lifecycle support</td>
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<tr>
<td>PP</td>
<td>Payback period</td>
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<tr>
<td>ROI</td>
<td>Return on investment</td>
</tr>
<tr>
<td>SQL</td>
<td>Structured query language</td>
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<tr>
<td>STEP</td>
<td>Standard for the exchange of product model data</td>
</tr>
<tr>
<td>U.K.</td>
<td>United Kingdom</td>
</tr>
<tr>
<td>U.S.</td>
<td>United States</td>
</tr>
<tr>
<td>XML</td>
<td>Extensible markup language</td>
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1 INTRODUCTION

1.1 Research background

Facility management (FM) costs make for the third largest tier of the costs of organizations after the costs of personnel and production assets. FM costs account for 5 to 10 percent of the gross domestic product (GDP) of advanced industrialized countries (Brandt, 1994). In order to increase resource efficiency, a fundamental shift from an unorganized and reactive FM practice to a coordinated and disciplined FM profession is required (Irizarry et al., 2014). An essential prerequisite to this is more automated processes which – in turn – demand a robust infrastructure for information management (Teicholz, 2013a; Gallaher et al., 2004). Such information logistics would guarantee that the right set of information required for organizations’ business processes is available in the right format, at the right time and in the right place and is supplied to the right actor(s) through smooth transactions (Schevers et al., 2007). In practice, however, administration of facility information quite often involves erratic, slow and costly procedures which are, to a great extent, based on printed handover documents (Parsanezhad and Tarandi, 2013) (fig. 1).

FIG. 1: Traditional repositories of facility information
Parallel to lean and agile methodologies, Building Information Modelling (BIM) is one of the most prominent initiatives frequently addressed by scholars and practitioners as a game-changer in construction industry in general (Jylhä and Suvanto, 2015; Eastman et al., 2011; Azhar, 2011; Arayici et al., 2011). There is also an abundance of research that suggest immense potentials for increased efficiency accrued by implementing BIM in FM (Love et al., 2014; Teicholz, 2013a; Eastman et al., 2011; Love et al., 2013; Jason Lucas et al., 2013; Motawa and Almarshad, 2013; Becerik-Gerber et al., 2012). Numerous efforts have been made for investigating the promises of a BIM-enabled FM. Such efforts range from hands-on experiments for developing data transfer plugins (Pärn and Edwards, 2017) and simulating FM tasks in BIM environments (Yusuf Arayici et al., 2012) through developing BIM-implementation frameworks for supporting specific use cases in maintenance (Wetzel and Thabet, 2015), to such abstract studies as proposing research frameworks for future researchers in the field of BIM-enabled FM (Pishdad-Bozorgi et al., 2018).

Despite all promises and forecasts and the massive amount of buzz that has been created about BIM, however, its perceived benefits have yet not been fully realized in FM (Teicholz, 2013a; Becerik-Gerber et al., 2012; Ashurst et al., 2008). Another plausible scenario is that the contingent benefits of BIM in FM have not been sufficiently researched or documented yet (Kiviniemi and Codinhoto, 2014). In fact, FM is – as a new field of study – under-researched itself. Regardless of which of these two conjectures is true, there is a need for further studying BIM-implementation in FM in order to fill in the knowledge gap addressed above as well as to develop guidelines for action.

Through the following sections, the overall aim, objectives, scope and target audience of this study have been explained. In chapter 2, the overall outline and design of this research have been presented. Different research philosophies, research approaches, research strategies and methods have also been introduced as contextual information. Moreover, the specific choices made through this study are presented, justified and discussed in relation to one another. In chapter 3, the basic concepts deployed here are introduced as a prelude to a brief presentation of the theoretical grounds of this study. Chapters 4 and 5 provide contextual information about the two major subjects that are addressed through the included papers i.e. requirements management and BIM standards. A summary of the papers is then provided in chapter 6. Through chapter 7, the findings of the papers are presented in more details and the three research questions introduced in chapter 1 have been revisited and addressed. Through chapter 8, the academic contributions of this study have been presented. The limitations faced throughout this study have also been addressed here. In chapter 9, some further relevant insights that are not covered through the included papers have been presented. Chapter 10 provides a number of suggestions for further research in the field.

1.2 Research aim and objectives

This study aims to investigate the challenges against successful implementation and realizing the benefits of BIM in FM. As a prerequisite to this, corresponding promises, obstacles and requirements
would be identified. In order to fulfil this aim, the following objectives have been developed and pursued:

Firstly, to perform an inventory of the current status of the building information management technologies and processes deployed in FM;
Secondly, to investigate implications of a BIM-enabled FM for the upstream planning and design phases;
And thirdly, to develop a framework for measuring the benefits of BIM-implementation in FM.

The three objectives above do, however, not cover all different aspects of the phenomenon addressed in section 1.1 i.e. BIM implementation in FM. The first objective addresses a basic prerequisite for fulfilling the two following objectives. The second and third objectives reflect the urge for a lifecycle approach towards BIM implementation as uttered in the literature. Kiviniemi and Codinhoto (2014) and Liu and Issa (2013), for instance, remark the need for BIM deliverables that are aligned with the needs of FM. This aspect is addressed in the second objective. The urge for measuring the benefits of BIM in FM – as addressed within the third objective – corresponds to the other side of the supply chain of the buildings i.e. the FM phase. Also this aspect has been highlighted by Kiviniemi and Codinhoto (2014) as an area where further research is required.

The above objectives could be reformulated as the following research questions:

What is the current status of the building information management technologies and processes deployed in FM?
What are the implications of a BIM-enabled FM for the upstream planning and design phases?
How could the benefits of BIM-implementation in FM be measured?

1.3 Delimitation of scope

The principles of object-oriented information management underpinning BIM could eventually be applied to the entire built environment at all spatial scales, across all disciplines and through all lifecycle phases (Hallberg and Tarandi, 2011; Parsanezhad, 2015). The literature and cases studied here are, however, mainly focused on buildings rather than other construction entities i.e. infrastructure facilities.

From a lifecycle perspective, the study has its focus on the FM phase. However, the earlier upstream phases have also been studied with regard to their implications for a BIM-enabled FM (as presented in papers 3 and 4; see table 4). From a technological point of view, the scope of this study is limited to BIM. Other relevant technological initiatives in the field such as Internet of Things (IoT), big data, laser scanning and 3D-printing have merely been touched upon or avoided altogether for the sake of clarity of focus.
1.4 Target audience

The results of this study would complement the body of knowledge in the field of construction informatics. From a practitioners’ point of view, the outcomes could be beneficial to all actors in the construction industry across different phases from planning and design to FM who are involved or interested in information management. The intended practical outcomes of this study pertain, however, primarily to the downstream field of FM.
2 RESEARCH OUTLINE

There are a wide variety of research doctrines each encompassing a partially distinct set of principles and guidelines. Through any delimited and time-bound research, the researcher faces numerous philosophical, strategic, tactical and methodological choices. In the following sections, some of the concepts framing such choices have been shortly introduced. Different alternatives associated with each concept have been presented and the choices made through this work have been addressed and justified. Saunders et al. (2009) provide a hierarchical representation of such concepts and their corresponding taxonomies – the so called research onion (fig. 2). The most essential concepts for defining the research outline as articulated in the research onion are research philosophies, research approaches, research strategies and methodological approaches. These concepts have been briefly addressed in the following sections. Prior to that, the overall design of the research work has been presented.

FIG. 2: The research onion (drawn after Saunders et al., 2009)

2.1 Research design

This work is a diverse and transdisciplinary collection of research sequences undertaken in the pursuit of the overall research aim explained in section 1.2. The current dissertation is composed of five papers introduced in table 1. The focus of the knowledge acquisition process through the constituent papers shifts from applied and practical to theoretical and fundamental and vice versa. None of the papers is though utterly theoretical or empirical. All papers contribute to fulfilling the overall aim of the research i.e. to investigate the challenges against successful implementation and realizing the benefits of BIM in FM.
TABLE 1: Index of the constituent papers and their focus

| Paper 1: An overview of information logistics for FM&O business processes |
| Author: Parsanezhad, P. |
| Published in | Overall focus | Lifecycle focus | Published |
| Proceedings of ECPPPM | Theoretical & Applied | FM | 2014 |

| Paper 2: Effective facility management and operations via a BIM-based integrated information system |
| Authors: Parsanezhad, P., Dimyadi, J. |
| Published in | Overall focus | Lifecycle focus | Published |
| Proceedings of the CIB Facilities Management Conference | Applied | FM | 2014 |

| Paper 3: Formalized requirements management in the briefing and design phase, a pivotal review of literature |
| Authors: Parsanezhad, P., Tarandi, V., Lund, R. |
| Published in | Overall focus | Lifecycle focus | Published |
| Journal of Information Technology in Construction | Theoretical | Design / Briefing | 2016 |

| Paper 4: Implications of a BIM-based facility management and operation practice for design-intent models |
| Authors: Parsanezhad, P., Tarandi, V., Falk, Ö. |
| Published in | Overall focus | Lifecycle focus | Published |

| Paper 5: A framework for measuring the benefits of BIM in the FM&O sector |
| Authors: Parsanezhad, P., Song, H.S. |
| Submitted to | Overall focus | Lifecycle focus | Submitted |
| Journal of Information Technology in Construction | Theoretical & Applied | FM | 2018 |

The third and fourth papers are more closely focused on the second objective of the research i.e. to investigate implications of a BIM-enabled FM for the upstream briefing and design phases. Such an alternating shift of the focus across research sequences follows the so-called *mode-2 knowledge* articulated by Gibbons (1994): “a constant flow back and forth between the fundamental and applied, between the theoretical and practical” (Gibbons et al., 1994: 19). Fig. 3 depicts how the major focus of the papers shifts from theory to practice, also from FM to design and vice versa. A summary of the papers has been provided in chapter 6.
All research sequences in this dissertation are grounded on a sole research philosophy i.e. the pragmatic research philosophy. Research strategies and methodological approaches vary, nonetheless, from one sequence to another depending on the corresponding focus, objective(s) and practical circumstances pertaining to data collection and analysis. The research philosophy underpinning this study, the research strategies and the methods applied through each sequence have been introduced, justified and discussed in the following sections.

2.2 Research philosophies and research paradigms

Research philosophies provide the researcher with an overall structure and fundamental guidelines for defining the research aims and designing and executing research activities. Each research philosophy embodies its own set of ontological, epistemological and axiological assumptions. The ontological assumptions are about the nature of the studied phenomenon and are therefore highly abstract. The epistemological assumptions explain what is considered as desirable, acceptable, legitimate and valid human knowledge and how knowledge can be communicated to others. The epistemological assumptions are therefore more tangible than the ontological ones. The axiological assumptions explain how values and ethics should influence the research outline and the extent to which the researcher could remain detached from the collected data (Saunders et al., 2009). Different research philosophies are distinguished from one another through two major dimensions: objectivism/subjectivism, and sociologies of regulation/radical change (Burrell and Morgan, 1979).
The first dimension of a research philosophy concerns the notions of objectivism and subjectivism. Objectivism implies that there is a single reality which exists independently from the researcher and surrounding factors (the so-called ontological assumption of objectivism). Research philosophies grounded on objectivity assume that facts are observable and measurable and lead us to universal truths (the so-called epistemological assumption of objectivism). Ultimate objectivity requires that the researcher and her/his personal values and beliefs remain as detached as possible from her/his research practice and findings (the so-called axiological assumption of objectivism) (Saunders et al., 2009).

Quite the contrary, subjectivism dismisses any belief in some universal truth, rather assumes that each conceived truth is socially constructed by social actors (the so-called ontological assumption of subjectivism). According to subjectivists, phenomena should be studied together with their historical, geographical and socio-cultural context and through different narratives (the so-called epistemological assumption of subjectivism). Subjectivists assert that personal values of the researcher should be acknowledged, reflected upon and questioned actively as part of the overall work of research (the so-called axiological assumption of subjectivism or radical reflexivity)(Cunliffe, 2003).

The other major dimension of a research philosophy is its stance on the ideological aspects of sociology of regulation and sociology of radical change. The former sociology acknowledges existing frameworks, adopts, – when required – adjusts, improves and extends them to further application areas; whereas the latter one questions the very fundamentals of the existing frameworks and strives to create a radically different order (Saunders et al., 2009). Table 2 provides a summary of the two major dimensions of research philosophies and their primary assumptions.

The varying dimensions of research philosophies are not the only concepts used for explaining their underlying assumptions. Research paradigm is an alternative notion. According to Burrel and Morgan (1979), the four major research paradigms are, in turn, derived from the two dimensions of research philosophies (as explained above) and their associated assumptions: both functionalist and interpretivist paradigms are built upon the sociology of regulation i.e. assume that research should be grounded on existing frameworks. The functionalist paradigm assumes objectivism in research, while the interpretivist paradigm adopts subjectivism. The two other research paradigms, the radical structuralist and radical humanist paradigms, on the other hand, build upon the sociology of radical change i.e. denying usefulness of previous orders and structures for future research. The former is based on subjectivism, while the latter adopts objectivism. A summary of the aforementioned research paradigms, their defining dimensions and some examples of their associated research philosophies are presented in fig. 4.

The primary ambition in this work is to develop universally-valid insights about the studied phenomenon i.e. BIM-implementation in FM. Ontologically speaking, this study strives for utmost objectivity. Also from an axiological point of view, utmost effort has been made to curb the effects of subjective measures. For minimizing the subjectivity caused by personal judgements and decisions, choices have been justified through reasoning around how they befit the subject and the aim of the research.
TABLE 2: The two major dimensions of research philosophies, their dichotomous extremes and their underlying assumptions

<table>
<thead>
<tr>
<th>Dimensions</th>
<th>Assumptions</th>
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<tr>
<td><strong>Dimension 1: objectivism/subjectivism</strong></td>
<td></td>
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<tr>
<td><strong>Ontological assumption</strong></td>
<td><strong>Epistemological assumption</strong></td>
</tr>
<tr>
<td><strong>Objectivism</strong></td>
<td>There is a single reality which exists independently from the researcher and surrounding factors.</td>
</tr>
<tr>
<td><strong>Subjectivism</strong></td>
<td>Each version of the truth is socially constructed and influenced by social actors.</td>
</tr>
<tr>
<td><strong>Dimension 2: sociologies of regulation/radical change</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Sociology of regulation</strong></td>
<td>Existing frameworks should be adopted, adjusted, improved and extended to further application areas.</td>
</tr>
<tr>
<td><strong>Sociology of radical change</strong></td>
<td>Existing frameworks should be fundamentally scrutinized. Research should be grounded on a radically different order appropriate to the studied subject and surrounding factors.</td>
</tr>
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</table>

FIG. 4: Research paradigms, their defining dimensions and their associated research philosophies
The current research mainly adopts the sociology of regulation in the sense that existing frameworks and constructs have been partially adjusted and deployed. It would be almost impossible to account for all various technological, social and organizational factors that affect BIM-implementation and its outcomes. A purely functionalist paradigm does, therefore, not accord with the subject and aim of this research. The ambition here is seeking universal clarifications by taking an as objective approach as possible. The interpretivist paradigm does thereupon not suit this study either. The need for a mixed and eclectic use of research paradigms entails adopting a flexible research philosophy. The pragmatic research philosophy has thus been adopted.

2.2.1 The pragmatic research philosophy
A research work based on the pragmatic research philosophy "starts with a problem and aims to contribute practical solutions that inform future practice" (Saunders et al., 2009: 143). In other words, the pragmatic research philosophy prioritizes usefulness of the research outcomes for solving real-life problems over other plausible benefits of research. Pragmatism is a balanced mix of objectivism and subjectivism. A work of research underpinned by the pragmatic philosophy is a pluralistic collage of different assumptions, strategies and methodologies from different research philosophies and research paradigms with the eventual purpose of solving a specific problem (Goldkuhl, 2012). For a pragmatic researcher, concepts are only relevant where they support action (Kelemen and Rumens, 2008). Pragmatic researchers strive to create useful knowledge for practice; knowledge that underpins practical improvements (Goldkuhl, 2012).

The current research primarily aims to resolve a real-life problem i.e. how to obtain the perceived potentials of BIM in FM (see sections 1.1 and 1.2). A problem-oriented philosophy such as the pragmatic philosophy serves, therefore, best the overall aim of this study. The major theoretical grounds deployed here i.e. the BIM Framework (see section 3.2) and the BEM2 model (see section 3.3) are derived from and closely linked to real-life practices. A multitude of assumptions from different philosophies have been adopted here: by seeking a universal clarification for the studied subject, this work bears some of the ontological elements of the positivist research philosophy. At some stages, however, the epistemological assumption of the interpretivist research philosophy has been adopted. According to the interpretivist research philosophy, facts are socially constructed across time and cultural contexts. Multiple interpretations of the same concept may thus co-exist (as articulated by Saunders et al., 2009). This has been most apparent through the study on requirements management when different terminological and taxonomic variations in the field have been acknowledged and elaborated on (presented in paper 3). From an axiological point of view, the methodologies that have been adopted in different sequences of this work are generally aimed to minimize subjectivity and rely on observable and measurable facts.

2.3 Research approaches
The researcher may take any of the three major research approaches i.e. deduction, induction and abduction (Saunders et al., 2009). Research approaches are also called modes of theorizing.
Studies taking a deductive approach begin with a theory. A number of propositions are then formulated based on the original theory and rigorously tested. The suggested propositions are thereupon validated or falsified and thus strengthen or question the legitimacy of the original theory in the new field. In a deductive approach, it is the theory that drives data collection and analysis.

Inductive studies begin, on the other hand, with collecting data. Collected data are then analyzed and compiled into a theory or a conceptual framework. The results of a deductive study are assertive and specific; whereas inductive studies result in hypothetical and general outcomes.

An abductive approach could be suitable when the initially collected data presents some surprising facts that could not be explained by existing constructs. An abductive research starts with collecting data and continues with developing and testing a plausible theory or conceptual. Abduction is, in fact, a combination of inductive and deductive approaches (Suddaby, 2006; Lave and March, 1993).

Access to data and availability of prior knowledge in the intended field of study are decisive factors in the choice of research approach (Stadler, 2004). Depending on the aim and scope of the research, it could result in theories, frameworks and/or models. Theories, frameworks and models are sometimes termed as conceptual constructs (Reisman, 1988). As a prelude to justification of the research approach in this study in section 2.3.2, the conceptual constructs mentioned above have been firstly explained in section 2.3.1.

2.3.1 Conceptual constructs: theories, frameworks and models

According to Meredith (1993), "a construct is an abstract form of concept which cannot be observed directly or indirectly but can be inferred by observable events” (Meredith, 1993: 5). The notion of concept could, in turn, be defined as a "bundle of meanings or characteristics associated with certain events, objects, or conditions and used for representation, identification, communication, or understanding” (ibid.). Conceptual constructs are used for simplifying complex phenomena through identifying the key concepts pertaining to those phenomena and their relationships (Dubin, 1969).

Theories are meta-frameworks (Meredith, 1993). Conceptual frameworks could – in other words – be considered as pre-theories (Dubin, 1969). A framework shows "the gestalt, the structure, the anatomy or the morphology of a field of knowledge or the links between seemingly disparate fields or sub-disciplines” (Reisman, 1994: 24:92).

Frameworks may comprise of models (Meredith, 1993). According to Turban and Meredith (1991), a model is a "simplified representation or abstraction of reality" (Turban and Meredith, 1991: 30). Lave and March (1993) also define a model as ”a simplified representation of the real world” (Lave and March, 1993: 19). According to Ritter (2010), models help dealing with the complexity of the real world and revealing insights that would otherwise be difficult to discern. He describes a well-crafted model as one that "provides a more condensed representation of what was originally given” (Ritter, 2010: 249). Meredith (1993) emphasizes the importance of balancing the level of abstraction and realism in models. Ritter (2010) elaborates further on models and suggests two major requirements for a model to be an accurate representation of a phenomenon:
1) It should have been justified how no essential component has been discarded in the process of condensing the observed facts into a model.
2) It should have also been justified that the adopted level of simplicity/complexity of the model is optimal for facilitating understanding of the phenomenon.

The notion of *conceptual model* is often used when referring to models in the context of theorizing: Lin (1976) defines a conceptual model as “a set of concepts, with or without propositions, used to represent or describe (but not explain) an event, object, or process” (Lin, 1976: 43). Meredith (1993) explains the difference between conceptual models and frameworks through their explanatory power. According to him, conceptual models are the intermediate research results that could be evolved to conceptual frameworks and eventually theories. Through his representation of the *normal research cycles*, Meredith (1993) elaborates on the transition from models through frameworks to theories. Across Meredith’s (1993) normal research cycle, models and frameworks are iteratively used for describing, explaining and testing data and propositions (fig. 5).

![FIG. 5: Normal research cycles (drawn after Meredith, 1993: 4)](image)

Conceptual models need to be based on one or several domain-specific taxonomies. Meredith (1993) defines taxonomies as “listings of items along a continuous scale. The items may be classified under different headings and subheadings but they all have a relative position on the continuum which allows them to be ranked in order” (Meredith, 1993: 8).

### 2.3.2 An abductive approach for developing conceptual models and frameworks

This study is based on pragmatic philosophy and aims toward solving a real-life problem. There is no intention of testing a complete theory in some specific field nor is there any wish to develop all-encompassing theories. Neither of the two major modes of theorizing i.e. deduction and induction has
been thus fully adopted here. The major theoretical outcomes of this research are the conceptual models and framework presented in paper 5. Conceptual models help maintaining a better balance between theory-building and theory-testing (Meredith, 1993).

The process of constructing conceptual models here is a mix of induction and deduction. According to Lave and March (1993) also Suddaby (2006), such a mixed approach could be considered an abductive approach. The process of development of two conceptual models and combing them into a conceptual framework as explained through paper 5 could be roughly considered as an abductive cycle. The overall research approach in this study also resembles the abductive approach in the sense that the point of departure is empirical data which is then analyzed and deployed for developing conceptual constructs. This study does, however, not implement the abductive approach in such strictly disciplined fashions as systematic combining as conceptualized by Dubois and Gadde (2002).

## 2.4 Research strategies

A research strategy is "a way of investigating an empirical topic by following a set of pre-specified procedures” (Yin, 2003: 16). Saunders et al. (2009) enumerates research strategies as experiment, surveys, case study, grounded theory, ethnography and action research. Yin (2003) suggests a slightly different set of research strategies comprising case study, survey, experiment, archival documents and history. According to him, grounded theory and ethnography should be considered as research methods rather than research strategies since they offer no theoretical proposition. The research strategy deployed in papers 2, 3 and 4 is case study research. Paper 2 also partially adopts the principles of grounded theory. Papers 1 and 5 don’t deploy any of the research strategies mentioned above. Below, follows a brief justification of the choice of case study as the major research strategy in this work.

Yin (2003) mentions three conditions for adopting case study as the main research strategy:

1) when the research work is exploratory;
2) when the investigator has little control over the studied phenomenon; and
3) when the studied phenomenon is contemporary.

In other words, the case study research is "an empirical inquiry that investigates contemporary phenomena within their real-life context, especially when the boundaries between the phenomenon and the context are not clearly evident” (Yin, 2003: 13). Contrariwise in an experiment, the studied phenomenon and its context are entirely separated from each other. Surveys are, on the other hand, implemented when the researcher’s ability to directly investigate the subject of study is limited. As a thorough research strategy, case study helps determining further aspects of the research work such as methods, data collection techniques and the researcher’s approach to data analysis.

All the three requirements for conducting a case study as specified by Yin (2003) are met through this study:
1) investigating a new technology (BIM) could be best conducted through an exploratory approach as there is often no established approach or methodology that would guarantee producing viable results;
2) due its multidisciplinary nature, the researcher rarely has full control over the BIM-implementation process; and
3) the studied phenomenon is contemporary.

According to Yin (2003), the case study strategy is common for evaluation purposes. Bakis et al. (2006) also assert that case study is a more appropriate strategy for evaluating the business benefits of an information technology compared with experiment or survey. The fact that this research aims to evaluate BIM-implementation further justifies the use of case study as a research strategy. Love et al. (2013) emphasize that a BIM evaluation study should focus on both the content and the context; which again renders case study research an appropriate choice for this research.

As opposed to theory-driven studies, Paper 2 has been based on the principles of grounded theory in that data were collected from a studied case in search of patterns and regularities. Not all detailed steps of the grounded theory methodology e.g. identifying codes, concepts and categories have however been applied in this work.

2.5 Research methods

As common to pragmatic research (Saunders et al., 2009), this study adopts a multi-method approach. The data collection and data analysis methods used for different sequences (the included papers) vary from one sequence to another with regard to the studied aspect. All data were though analyzed qualitatively. No specific text analysis method has been applied in this study. The choices of methods and the types of the data collected for each paper have been briefly presented here:

For all papers, the required background information was secondarily collected from the literature. For Paper 2, primary data was collected from the studied case project through direct observation as well as reviewing project documentations. The co-author also being one of the developers of the BIM-enabled FM system could – in principle – have been a source of bias in the results. It was though the main author who selected the case project based on the criteria for a best practice, developed the research design and analyzed the data.

For Paper 3, the framework developed by vom Brocke et al. (2009) was used as a roadmap for conducting this study. Cooper’s taxonomy (Cooper et al., 1998) was applied for defining the review scope as a pivotal review and analyzing the data. The web-based database, Google Scholar, was used for searching all types of the materials published in the last 20 years in the studied area. A combination of the search terms requirements management and construction were used for database searching. Firstly, the abstracts of the retrieved papers were monitored. Relevant papers were then studied thoroughly. The search was complemented by a backward search through further relevant papers and books that had been cited through the reviewed papers.
For Paper 4, secondary data was collected from the literature as well as project directives. Primary data for the study was collected from the studied case project through analysing the original BIM deliverables, direct participation in project meetings, informal talks with project participants and an in-depth interview session with the project’s BIM strategist. The collected data were qualitatively analyzed using text-editing and model-checking software.

For Paper 5, again the framework developed by vom Brocke et al. (2009) was applied also as a guidance for executing the review. Cooper’s taxonomy (Cooper et al., 1998) was also used for defining the review scope as an exhaustive and selective review. The literature on conceptual models and conceptual frameworks (Cameron and Whetten, 1983; Dubin, 1969; Lave and March, 1993; Meredith, 1993; Ritter, 2010) was consulted and adopted for analysing the collected data, developing two conceptual models and combining them into a conceptual framework for measuring the benefits of BIM in FM. The two major requirements for developing conceptual models according to Ritter (2010) as addressed in section 2.3.1 were also applied here. These have been described in full details in Paper 5. As expressed by Reisman (1994) and addressed earlier in section 2.3.1, the conceptual framework presented in Paper 5 links the two seemingly disparate fields of construction informatics and FM. In line with the principles of pragmatic research, the framework developed here was primarily intended as a means for action (Goldkuhl, 2012; Saunders et al., 2009) rather than a pre-theory (Dubin, 1969). Meredith’s (1993) normal research cycle (as addressed in section 2.3.1; fig. 5) was therefore not fully followed down to theory-building.

FIG. 6: The epistemological choices made through this study depicted upon the research onion (Saunders et al., 2009)
As explained above, the most prominent data collection method in this study is literature review. Meredith (1993) highly recommends “synthesizing previous research” and “building on earlier studies” (Meredith, 1993: 11) which is central to the literature review data collection method. Through Paper 5, in specific, literature review is used as a ground for developing conceptual models and frameworks. Such an approach has often been recommended through the literature on conceptual models and frameworks (e.g. by Dubin, 1969; Lave and March, 1993; Meredith, 1993).

Fig. 6 depicts the epistemological choices made through this study depicted upon the research onion (Saunders et al., 2009). When applicable, the more detailed layers of the research onion (ibid.) i.e. time horizons, techniques and procedures have been explained in sections 6.1 to 6.5 separately for each paper.
3 THEORETICAL GROUNDS

This study originates from and contributes to the relatively new academic field of construction informatics. Construction informatics could be described as "an applied science that studies the construction specific issues related to processing, representation and communication of construction specific information in humans and software" (Turk, 2006: 188). This study covers, therefore, different aspects of BIM implementation that could pertain to humans or software.

As previously mentioned in section 2.3.2, this study is neither an inductive research with the intention of developing a theory, nor is it a deductive research applying a theory to a new field. The overall theoretical instance of this study is rather governed by the underlying pragmatic philosophy i.e. using and contributing to theory as it best serves usefulness of the outcomes in action (Goldkuhl, 2012). The theoretical constructs addressed in this section should thus be regarded merely as analytical lenses used for understanding the studied phenomena rather than to be fully applied.

The two major conceptual frameworks used here are BIM Framework (Succar, 2009) and the built environment management model (BEM2)(Ebinger and Madritsch, 2012). The former is the primary theoretical construct used throughout this study for analyzing BIM-related materials and the latter provides the basic concepts and guidelines for approaching the field of FM. These two frameworks have been briefly introduced in sections 3.2 and 3.3. Prior to this, the definitions of the basic concepts addressed in the aforementioned frameworks have been presented in section 3.1. The concepts introduced here are data, information, knowledge, BIM, interoperability and facility management. Among the wide variety of suggested definitions for these concepts, the ones that best correspond to the phenomenon studied and the conceptual frameworks used here have been chosen and presented.

3.1 Basic concepts

3.1.1 Data, information and knowledge

The three notions of data, information and knowledge are central to the mainstream discourse of information management. A common idea is that the universal objective facts known as data are progressively contextualized, subjectified and fit into the specific goals of societies, organisations and individuals.

There is, however, no consensus among researchers regarding the definitions of the terms data, information and knowledge; nor do they agree on the direction of the suggested evolutionary processes. A number of alternative explanations have been provided by Davis and Olson (1985), Dretske (1999), Tuomi (1999), Smith (2001), Alavi and Liender (2001) and Rezgui et al. (2010). A summary of those explanations is presented in fig. 7 as a cyclic model for transformation of semantic levels (Parsanezhad, 2015).
Within the context of building information management, the terms data, information and knowledge are often used interchangeably. Yet, the medial notion of information is more commonly used for describing the type of the resources that "is meaningful to the recipient and is of real or perceived value in current or prospective actions or decisions" (Davis and Olson, 1985: 200). Information as a resource is the cornerstone of BIM.

3.1.2 Building information modelling (BIM)

Building information modelling (BIM) is one of the most prominent initiatives in the broader context of construction informatics. Central to BIM is the notion of objects implying the "collections of data that are related in some meaningful way" (Björk, 1989: 73). Each object carries a number of attributes also called properties or parameters (ibid). In its early days, BIM was known as building product modelling (Eastman, 1999) or building data modelling (Penttilä, 2006) and was conceptualized as "a methodology to manage the essential building design and project data in digital format throughout the building’s lifecycle” (Penttilä, 2006: 403). A more accurate definition of the term is, however, the one provided more recently in BIM Handbook (Eastman et al., 2011): "a modeling technology and associated set of processes to produce, communicate, and analyze building models” (Eastman et al., 2011: 16). Building models, as intended in BIM Handbook, are digital representations of buildings and building components containing attributes and parametric rules. BIM contents are coordinated and consistent through all views across the BIM environment (ibid.).

3.1.3 Interoperability

Not all definitions of BIM embrace the processes underpinning BIM-implementation, the actors involved in those processes and the importance of a smooth and seamless collaboration and exchange of information among them. The synergic benefits of IT in construction could, however, not be realized unless it is used in collaborative environments. An essential requirement for such environments is interoperability. Shen et al. (2010) define interoperability simply as "the ability that data generated by any one party can be properly interpreted by all other parties” (Shen et al., 2010: 197). Alternative definitions of the term lay higher emphasis on transfer of data/information among systems (Geraci, 1991) or firms (Gallaher et al., 2004: ES-1) instead. Succar (2009) clarifies the concept by using the term exchange as opposed to interchange. The former refers to transfer of data/information where the
received contents are neither structured nor computable; whereas the latter describes a process that results in structured and computable contents at the recipient’s system and conforms therefore to the principles of interoperability.

Shen et al. (2010) add further dimensions to the concept of interoperability: common data models and formats enable system integration, data sharing and collaboration among different parties i.e. data interoperability. Future-proof long-term interoperability, however, deals with communication languages and protocols and is realized through loosely-coupled distributed systems. The latter is called framework interoperability. Promoting interoperable implementation of BIM is sometimes termed as open BIM. Open BIM requires pervasive use of standards (van Berlo et al., 2012; Tarandi, 2011). A number of international and national BIM-related standards are presented in chapter 5.

3.1.4 Facility management

According to Atkin and Brookes (2014), a well-planned and implemented FM practice would enable organizations to deliver effective and responsive services, smoothly adopt their use of spaces to their core business activities, create competitive advantage over rivals and improve their culture and image. FM as a discipline is, however, still in its infancy (Noor and Pitt, 2009; Ventovuori et al., 2007). Coordinated FM services were, for the first time, provided in the U.S. in 1960s and were fully developed by the late 1970s. FM did not emerge in Europe until 1980s (Mangano and De Marco, 2014). The emergence of FM in Europe was initially triggered by the recession in 1980s and early 1990s (K. Alexander, 2003) and aimed to make a more efficient use of organizations’ capital assets including buildings.

Over the last decades, a multitude of national and international FM organizations have emerged aiming for coordination and policy-making. This could be a sign of the transition from FM as a mere practice to a multidisciplinary profession (Irizarry et al., 2014). Some prominent examples of such organizations are the International Facilities Management Organization (IFMA)\(^1\), the Institute of Workplace and Facilities Management (IWFM)\(^2\), the European Facility Management Network (EuroFM)\(^3\) and the Institute of Asset Management (IAM)\(^4\) (Ebinger and Madritsch, 2012). Other major actors in the field of FM are FM contractors, in-house FM teams, FM vendors, FM consultants and research institutions (Nutt, 1999; Tay and Ooi, 2001).

According to Then (1999), "the practice of FM is concerned with the delivery of the enabling workplace environment, the optimum functional space that supports the business processes and human resources” (Then, 1999: 469). He defines the role of the facility manager as “to meet the business challenges that confront the organization it is supporting” for reaching “the optimum balance between people, physical assets and technology” (ibid.). IFMA defines the term facility management as "a

---

profession that encompasses multiple disciplines to ensure functionality of the built environment by integrating people, place, process and technology". According to BIFM, facility management is “the practice of coordinating the physical workplace with the people and work of an organization”.

The OmniClass Construction Classification System (OCCS) differentiates among the terms facility management, facility operation and maintenance, and facility operations. According to OCCS, facility management is mainly about the administrative activities for guaranteeing a safe and functioning building; facility operation and maintenance encompasses both oversight and maintenance of the systems and services within facilities; while facility operations refers to the act of providing services to support operation within facilities (OCCS, 2013 - Table 33 - Disciplines).

FM could also be defined as a discipline that "encompasses all of the broad spectrum of services required to assure that the built environment will perform the functions for which a facility was designed and constructed” (Sapp, 2013). Barrett and Baldry (2009) define FM in more detailed terms as "an integrated approach of maintaining, improving and adapting the buildings of an organization in order to create an environment that strongly supports the primary objectives of that organization" (Barrett and Baldry, 2009: xi). Becker (1990) urges though a broader approach and asserts that “FM is responsible for coordinating all efforts related to planning, designing and managing buildings and their systems, equipment and furniture to enhance the organization’s ability to compete successfully in a rapidly changing world” (Becker, 1990: 7). Ebinger and Madritsch (2012), too, suggest expanding the domain of FM to the entire construction process and propose a conceptual model that has been constructed accordingly. This model is presented in the section 3.3.

3.2 BIM Framework

Over the last decades, a variety of BIM frameworks have been developed by different scholars. Within the BIM framework introduced by Jung and Joo (2011), technology and policy making have been presented on the same axis. The Collaborative BIM Decision Framework introduced by Gu and London (2010) is exclusively configured as a decision-making framework aimed for facilitating BIM adoption rather than better understanding and structuring of concepts. The BIM Framework developed by Succar (2009) better explains the way BIM is being practiced in the construction industry, the corresponding processes and the variety of actors who are involved. A brief explanation of the overall structure and components of Succar’s BIM Framework follows. At its base level, the framework comprises three axes each encompassing further components:

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1) BIM fields of activities encompass different actors and their deliverables and are divided to:
   a. The technology field: comprises such actors as manufacturers and suppliers of BIM software and hardware, network equipment, communication systems, database technologies, model servers, GIS software, etc.
   b. The process field: encompasses various actors in construction industry including architects, engineers, project managers, facility managers, etc. and the information they consume and produce.
c. The policy field: comprises such actors as research centers, educational institutions, regulatory bodies, insurance companies as well as regulations, contracts, standards, educational programs, research projects, etc.

2) BIM stages describe different levels of sophistication of BIM-implementation as follows:
   a. Pre-BIM: traditional CAD tools mainly in 2D-drawing form are used.
   b. Object-based modelling: the minimum requirements of a BIM-environment are in place (see section 3.1.2).
   c. Modell-based collaboration: different disciplinary models could be combined for collaborative BIM-based functionalities e.g. collision control.
   d. Network-based integration: model servers and federated databases are deployed for performing more advanced analyzes.
   e. Integrated Project Delivery (IPD): connotes the ultimate integration of BIM in construction processes enabling concurrent engineering (Prasad, 1996; Haymaker and Fischer, 2008) and optimization of the final product through endless iterations.

3) BIM lenses define the depth and breadth of enquiry to fields and stages as follows:
   a. A macroscopic lens e.g. push-pull dynamics at industry level
   b. A mesoscopic lens e.g. inter-organizational data flows
   c. A microscopic lens e.g. role of individuals in BIM-implementation

### 3.3 The built environment management model (BEM2)

One of the most all-inclusive conceptual models spanning the entire lifecycle of buildings is the built environment management model (BEM2) developed by Ebinger and Madritsch (2012). The model is based on a number of earlier models for facility and real estate management namely the Integrated Resource Management Framework developed by Then (1999) and the Capital Project Portfolio Management (CPPM) model by Dettbarn et al. (2005). BEM2 is assumed to be more conceptually accurate and more taxonomically consistent than its predecessors (Ebinger and Madritsch, 2012).

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<tbody>
<tr>
<td><strong>Strategic Level</strong></td>
<td>Strategic Planning</td>
<td>Optimized Investment Decisions</td>
<td>Optimal Capital Project Results</td>
<td>Optimal Enterprise Performance</td>
</tr>
<tr>
<td><strong>Portfolio Level</strong></td>
<td>Facilities Planning</td>
<td>Project Portfolio Management</td>
<td>Facilities Portfolio Management</td>
<td></td>
</tr>
<tr>
<td><strong>Operational Level</strong></td>
<td>Project Transaction Management</td>
<td>Operations Mgmt, Maintenance Mgmt and Services Mgmt</td>
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TABLE 3: The expanded view of BEM2 (drawn after Ebinger and Madritsch, 2012: 192)
BEM2 splits the production lifecycle of facilities up into the four main key process areas (KPAs) of strategic planning, facilities planning, project and transaction management, and service, operation and maintenance management. Each KPA within BEM2 has been divided into a number of sub-areas specific to strategic, tactical (portfolio) or operational level (see table 3). FM as intended in this work could be most closely associated with – but not limited to – the KPA-4 of BEM2 i.e. operation and maintenance management. This KPA comprises services management, maintenance management and operations management. A brief definition of these sub-areas follows.

**Operations management**

This sub-area comprises activities that provide an optimal environment for running the core business of organizations. Heating, ventilation and air-conditioning (HVAC), electrical and plumbing systems are central to operations management.

**Maintenance management**

One of the most holistic taxonomies of maintenance activities have been suggested by Mangano and De Marco (2014). They suggest the following categories of maintenance activities:

1) Preventive maintenance activities also called proactive maintenance activities are performed before any defect or breakdown occurs. Preventive maintenance activities are, in turn, divided to two subcategories:
   a. Time-based preventive maintenance activities also called planned maintenance activities comprise a set of specified maintenance tasks to be performed at specific intervals as instructed by the manufacturers of building components.
   b. Condition-based preventive maintenance activities or predictive maintenance involve constant monitoring of the overall condition of building components and systems and taking actions only when indications of some problem have been observed.
2) Corrective maintenance activities also called unplanned, reactive, failure-based, repair or breakdown maintenance activities imply taking no action until a tangible failure or breakdown occurs. Lucas et al (2013a) mentions the two major categories of repair activities as contractor repair and in-house repair activities.

The downtime caused by corrective maintenance is often more costly than other types of maintenance (Mangano and De Marco, 2014). Examples of the costs incurred by corrective maintenance are damages to other components, lost supplies and displaced revenue (J. Lucas et al., 2013b). Minimizing corrective maintenance activities is, therefore, a common maintenance policy of organizations. Time-based preventive maintenance reduces the costs substantially compared with corrective maintenance. Yet, it relies on a rather conservative approach and could be both inefficient (since some occasions of corrective maintenance will occur nevertheless) and costly (some interventions could be totally unnecessary). Condition-based preventive maintenance is the most resource-efficient type of maintenance. A shift to more predictive maintenance activities is thus often encouraged by strategic FM plans. The ubiquity of cost-efficient sensors during the recent decades has triggered a surge in developing and implementing various condition-based preventive maintenance methods.
Services management
This sub-area addresses a variety of facility management services ranging from lease administration and space management to food, security, office support and janitorial services.
4 REQUIREMENTS MANAGEMENT

The ultimate goal of systematic management of building information across the entire lifecycle of a building is improving its performance during the operation phase. The client’s expected performance is, in turn, formulated and documented during the earliest phases of the construction process. In the absence of well-organized and accurate requirements management routines, the actual performance of the final product would not comply with the client’s expectations (Kiviniemi, 2005). Requirements management, in this sense, could be defined as “the process of creating, maintaining, and testing requirements” (Fiksel and Dunkle, 1992: 231); where a requirement is “a description of a set of testable conditions applicable to products or processes” that should be “satisfied by a product (or process)” (ibid.).

Requirements on any procured product including buildings are often formulated collaboratively by a multitude of stakeholders; are largely diverse and sometimes even contradicting; are applicable to both the final product and the production process (Christiansson et al., 2009); and are formulated, complemented and revised incrementally and iteratively (Fu et al., 2007). The fuzziness inherent in the building design process (Lawson, 2006) and the silo mentalities prevalent in construction industry in general impede a structured whole-life requirements management practice. An alternative solution to this is formalized requirements management across the entire lifecycle of the building enabled through construction informatics (Kiviniemi, 2005). Documenting, revising, retrieving and validating the initial requirements would otherwise be a cumbersome and time-consuming endeavor.

In the following sections, a number of theories pertinent to formalized requirements management have been shortly introduced.

4.1 Schema Theory

Rumelhart and Ortony (1976) used the principles of the earlier Semantic Network Theory (Collins and Quillian, 1969) for devising the Schema Theory. Schema Theory envisions small inter-linked bundles of information called schemata as a means for facilitating understanding of the real-world phenomena for human brain. As the experimental psychologists Bartlett and Bartlett (1995) point out, representing external phenomena using schema would inevitably be based on a specific internal image of those phenomena. Such internal images could be different for different individuals. Yet, the notion of schema helps organizing past experiences with the aim of planning future measures (Bartlett and Bartlett, 1995).

Using Schema Theory for structuring building information was first proposed by Chan (1990) with a specific focus on building requirements management. He devised a number of the so called perceptual tests for validating design alternatives against project goals. The notion of object as used in the BIM discourse could be considered as the modern equivalent of the earlier notion of schemata in Schema Theory.
4.2 Pattern Language

Known as one of the most robust theories, Pattern Language was introduced by the design theorist and architect, Christopher Alexander (Galle and Kovács, 1992). The theory promotes a rational approach to building design and use of explicit pre-defined rules in practice. The central idea in Pattern Language is compiling and structuring a number of design solutions that could be easily customized and applied to design problems (C. Alexander et al., 1977). Here, different building design alternatives are considered as customized responses to specific structures or patterns of design problems (Chermayeff and Alexander, 1963). In order to facilitate the cognitive process of understanding design problems, graphical representations of problems are developed as part of the Pattern Language syntax (Lawson, 2006). The initial justification of such rational approaches as Pattern Language was the need for a scientific and subjective tool for formation and evaluation of design alternatives and thereby optimizing the use of resources in construction (Jones, 1992). Inspired by Pattern Language, a handful of methods were developed for automating and optimizing the building design process. Galle & Kovács (1992), for instance, envisioned design systems that were capable of automatically identifying whether an evolving design solution satisfied some specific pattern or not. This could be considered as a precursor of the present-day model-checker software.

The theory has also faced some criticism: Broadent (1973) described Pattern Language as a too mechanistic view of design. Moreover, due to correlated or missing values, no distinctive or exhaustive list of requirements could be set in the beginning. Some clear and explicit methods or metrics for evaluation and validation of the requirements are also not always available (Lawson, 2006).

4.3 The theory of axiomatic design

Similarly to Pattern Language, the theory of axiomatic design deals primarily with systematic processing of design information. The ambition is developing design solutions that fulfill different types of requirements associated with different abstraction and compositional levels. The theory has been developed by Suh (2001).

The three major principles of the theory of axiomatic design are as follows:

- Functional requirements should be defined independently from one another (the independence axiom).
- Information content of the design should be minimized (the information axiom).
- Design is a progressive and iterative process comprising of back-and-forth shifts between different compositional levels of functional requirements and design parameters (the concept of zigzagging). In other words, design parameters are incrementally defined as partial solutions that fulfill partial functional requirements.

Jansson et al. (2013) extended the two categories of functional requirements and design parameters in the theory of axiomatic design to four consecutive domains of customer, functional, physical and production. Each domain comprises respectively customer attributes, functional requirements, design parameters and production variables. Building information is transmitted between different domains
through *views* and *constraints*. Time-efficient iterations and back-and-forth shifts between the above domains demand IT tools with high analytic capacities, appropriate design methods such as concurrent engineering (Haymaker and Fischer, 2008) and the related standards such as PLCS (ISO, 2005).
5 BIM STANDARDS

Development of an agreed set of industry standards is the cornerstone of through-life interoperability from the initial planning to the operation phase (Sabol, 2018; Kiviniemi and Codinhoto, 2014; Hallberg and Tarandi, 2011). The most widely-used standards in this area have been developed and maintained by the non-profit international organization buildingSMART\(^7\). A number of such standards developed by buildingSMART i.e. IFC, IDM, bSDD, BCF as well as some other international and Swedish standards have been briefly introduced in this chapter as contextual information for the included papers.

5.1.1 Industry Foundation Classes (IFC)

The first version of the IFC standard (ISO 16739) was released in 1998 by buildingSMART (then the International Alliance for Interoperability, IAI) (buildingSMART, 2016). The constituent components of IFC namely data types, entities, attributes, supertypes, subtypes, and algorithmic constraints have been derived from the EXPRESS data modelling language (ISO, 2004). IFC standard is based on the STEP standard and its exchange formats *STEP physical file format* (ISO, 2008). The more recent versions of IFC included further content and syntax features such as the IFCXML specification. The latest version of IFC, IFC4\(^8\), also embraces infrastructural entities and other components of the built environment.

IFC serves as the vendor-neutral data model for exchange of building information among software and firms. It is now widely implemented as an essential component of building information hand-over specifications around the globe and is incorporated in many national and firm-specific BIM guidelines.

5.1.2 Information Delivery Manual (IDM)

IDM is an international standard (ISO 29481-1:2010 - Part 1) that defines a methodology for documenting processes for exchange of facility and construction information. IDMs also specify the types of information that each actor should provide so that software-based information exchange scenarios could be executed successfully and the loss of data upon the transferring and interpretation processes is minimized. IDMs need to be developed together with the required provisions for software development and are crucial to interoperability (buildingSMART, 2014a).

5.1.3 Model View Definition (MVD)

MVD specifications define application- or actor-specific subsets of the IFC schema (buildingSMART, 2014a). Examples of the different use-cases that require allocated IDMs are different types of analyses namely environmental, energy, evacuation, safety, fire, acoustic, accessibility, constructability and indoors climate analyses as well as quantity take-off, cost calculation and scheduling. The


Coordination View\(^9\) was the first MVD developed by buildingSMART for common exchange purposes.

5.1.4 BuildingSMART Data Dictionary (bSDD)  
bSDD, initially called the International Framework for Dictionaries (IFD) is intended for interlinking the broad variety of ontologies and vocabularies used for describing components of the built environment and their properties across different countries, sectors, lifecycle phases and corporations (buildingSMART, 2014b). bSDD and IFC rely on the Global Unique Identifiers (GUID) that are randomly created by BIM software and unanimously maintained and used by all actors during the entire lifecycle of the building components. In the recent years the need for an integrated approach to building and product information management has urged linking GUIDs to such product-specific indexing systems as Global Trade Item Number (GTIN)\(^10\).

5.1.5 BIM Collaboration Format (BCF)  
BCF is an alternative information transfer format for minor information transactions among actors often during the design phase. By dismissing the need for tedious importing and exporting of bulky BIM models, BCF enhances cross-disciplinary model coordination. BCF is an open XML file format. The BCF file format facilitates visual tracing of issues and change requests through object-oriented building models during the design phase and also verification and validation processes. BCF import and export functionalities have now been incorporated in the majority of the common BIM software applications (buildingSMART, 2014c).

5.1.6 Construction Operation Building information exchange (COBie)  
COBie is a widely-used MVD for facility management information handover. COBie was developed in 2007 by the U.S. Army Corps of Engineers. A COBie deliverable consists of the building information that is crucial to facility management. COBie documentation is initially compiled during the briefing phase through capturing the information sourced from the project program, spatial and functional requirements, room data sheets and other specification documents. During the architectural design phase, tabulated information about rooms, doors, windows, lighting fixtures and HVAC equipment are added to COBie documentation. Later on, the COBie documentation is complemented with information about the installed components such as manufacturer, maintenance instructions and guarantee information (East and Carrasquillo-Mangual, 2012).

A COBie handover could be delivered in different formats e.g. IFC, IFCXML or Excel spreadsheets. The latter is often considered to be the most convenient alternative for FM actors who are often not familiar with complicated BIM file formats. A COBie spreadsheet is composed of a number of predefined tabs namely Space, Zone, Type, Spare, Resource, Document and Attribute. COBie is based on the U.S. classification system OmniClass (Teicholz, 2013b).

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In 2011, COBie was adopted as part of the U.S. National BIM Standard (NBIMS-US). In 2014, it was also included in the British standards (BS 1192-4:2014). During the last decades, buildingSMART alliance\textsuperscript{11} has undertaken a series of experiments for testing the COBie exchange functions devised in a number of BIM software programs and developed a set of guidelines and tools for implementing COBie.

COBie serves well as an index encompassing the most common types of the building information required in FM (Aldaham et al., 2013). The specific requirements and needs of real-world projects and FM organizations compels, however, developing customized setups for transferring building information from construction to FM (Lewis, 2013). Another issue with implementing COBie is the differences among national construction classification systems. Such differences are often also mirrored in the regulatory requirements of different countries. Implementing COBie in a construction project in Sweden where the national BSAB classification system was used, for instance, failed to retrieve the required information from the project’s BIM handover documentations (Parsanezhad, Tarandi, and Falk, 2016).

The contents of a COBie documentation are sourced from a large number of different actors involved in a construction project sometimes working in parallel. In case spreadsheets are used as the main information transfer format, meticulous routines need to be developed for checking out, checking in and version management of the COBie files themselves. Moreover, much of the information required according to COBie specifications are often provided in formats that could not be easily translated into the COBie structure and require huge amounts of manual work. Examples are product datasheets, Environmental Product Declarations (EPDs), guarantee documents and maintenance manuals. Artificial Intelligence (AI) technologies could help solving this issue.

5.1.7 Uniformat, MasterFormat, OmniClass and Uniclass

There is no globally accepted classification system for building components and processes. In the U.S., OmniClass Construction Specifications (OCCS) is the most widely-used classification schema. OmniClass is developed by the OCCS Development Committee and consists of 15 interrelated tables. It draws from a number of minor domain-specific systems i.e. UniFormat (for building components), MasterFormat (for work results) and Electronic Product Information Cooperation (EPIC) (OCCS, 2013). In the U.K., Uniclass\textsuperscript{12} is used instead.

5.1.8 CoClass

CoClass\textsuperscript{13} is the latest Swedish construction classification system which is developed by Svensk Byggjtjänst\textsuperscript{14} – a company owned by 32 Swedish construction and FM organizations. CoClass is

\textsuperscript{14} https://byggtjanst.se/ – accessed 2019 April 18.
intended as a modern replacement for such earlier systems as BSAB\textsuperscript{15} for design and construction and Aff codes\textsuperscript{16} for FM. The expected advantage of CoClass over earlier systems is its focus on digital communication of information, embracing all disciplinary actors, the entire built environment and all lifecycle phases, relying on international standards and focus on functionality.


6 SUMMARY OF PAPERS

In table 1, the constituent papers in this dissertation were shortlisted and it was clarified how they – through alternating focus from applied to theoretical and from the earlier to the latter lifecycle phases – contribute to the overall research aim. In the following sections, a summary of each paper including its purpose, theoretical grounds and the methods applied will be clarified. The findings of the papers have been presented in more details in chapter 7. As a preface to the summaries of the papers, Table 4 presents the temporal and thematic focus of the papers in a concise tabular format as an alternative representation of fig. 3.

TABLE 4: The temporal and thematic scope of the papers

<table>
<thead>
<tr>
<th>Papers</th>
<th>Lifecycle focus</th>
<th>Approach</th>
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<tr>
<td>Paper 2: &quot;Effective facility management and operations via a BIM-based integrated information system”</td>
<td>Construction</td>
<td>Applied</td>
</tr>
<tr>
<td>Paper 3: &quot;Formalized requirements management in the briefing and design phase, a pivotal review of literature”</td>
<td>Briefing/Design</td>
<td>Theoretical</td>
</tr>
<tr>
<td>Paper 4: &quot;Implications of a BIM-based facility management and operation practice for design-intent models”</td>
<td>Construction</td>
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</tr>
<tr>
<td>Paper 5: &quot;A framework for measuring the benefits of BIM in the FM&amp;O sector”</td>
<td>Construction</td>
<td>Theoretical</td>
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6.1 Paper 1: An overview of information logistics for FM&O business processes

Departing from definitions of data and information, the focus of this paper is on the significance of developing enhanced FM processes that enable a seamless flow of information. A prerequisite to this is an overall analysis of current practices and identification of the procedural bottlenecks where lack of information, timely processes for retrieval of information and/or inappropriate information formats disturb the core activities of the firms and results in loss of resources. This paper aims to provide the theoretic basis for more focused studies on existing and desired processes in FM and their associated information transactions. In order to achieve this, academic literature as well as empirical studies in the subject area of building information management and FM workflow processes have been consulted and analyzed. All data for this study is collected from the literature. This study has thus adopted a qualitative secondary data analysis approach.
Through this study, an overview of the types and taxonomies of generic FM activities and processes, major roles and actors in FM and their information needs have been presented. Firstly, different definitions of the key concepts in the studied subject area e.g. data, information, knowledge, BIM, facility management and business processes have been revisited. Then, generic processes, activities and organizational roles common to FM, the types of information required by each actor and how those pieces of information are acquired have been briefly presented.

Based on the literary findings, strategic and operational facility/property management are the two main categories of FM activities. When documenting generic FM activities through case studies with the aim of formulating generic taxonomies of FM activities, the core activities of the studied organization should be excluded, since such activities differ largely from one organization to another. The core activities associated with educational, healthcare and industrial facilities, for instance, are largely distinctive and entail specific requirements that could not be generalized across the entire FM sector as a whole contrary to such generic activities as inspection, maintenance and cleaning.

6.2 Paper 2: Effective facility management and operations via a BIM-based integrated information system

Through a mainly descriptive approach, a prominent example of implementing BIM in FM is presented in this paper. Moreover, a summarized account of similar efforts around the world for implementing BIM in FM is provided alongside the methods and techniques that have been applied. The purpose of this paper is firstly, to summarize the current status of the building information management technologies applied in FM and identify the prevailing issues; and secondly, to devise technical solutions for those issues based on an exemplar case.

The underlying concepts and constructs addressed in this work have been taken from BIM Framework (see section 3.2). As opposed to theory-driven studies, this work has been based on the principles of grounded theory in that data were collected from a studied case in search of patterns and regularities. Not all detailed steps of the grounded theory methodology e.g. identifying codes, concepts and categories have however been applied here.

Through the first part of this study, a summarized description of the information management configurations implemented in eleven projects was extracted from academic papers, books and technical reports. The issues identified in the studied cases have been presented alongside five major categories of contemporary technical solutions for enhancing the practice of transferring building information from construction to FM. Through the second part of this study, a narrative and illustrative representation and reconstruction of a BIM-implementation project at the campus buildings of Unitec Institute of Technology in Auckland (New Zealand) has been carried out. The choice of the case project was a purposive sampling based on the positive impacts of the project such as energy savings and improved workflows. Through this retrospective study, a mesoscopic BIM lens was applied (see
section 3.2). The data for the second part of this study were collected by the co-author through direct observation of the implementation process as well as reviewing project documentations.

Through the studied project, three campuses comprising 191 buildings had been modeled during a 4-year period and in three different stages. The BIM repository implemented in the project was based on the industry standard, SQL Server-ISO/IEC 9075. BIM models were created in a proprietary BIM format and then exported and archived in IFC format. This was intended as a provision for further implementation of open standards. The FM department of Unitec being in charge of development of the integrated solution proved to be a success factor as the resulting system directly addressed the requirements of their FM team on information types and levels of detail (LODs).

6.3 Paper 3: Formalized requirements management in the briefing and design phase, a pivotal review of literature

Increased efficiency in FM through BIM-implementation has far-reaching implications for the initial phases of the construction process. This paper takes, thereupon, a deeper look into the principles of requirements management in the early briefing and design phases as a key factor for efficient use of building information hand-over in the following phases. The aim of this paper is to provide a knowledge base for developing further theoretical frameworks and conceptual models that support IT-implementation for formalized requirements management. The framework developed by vom Brocke et al. (2009) has been used as a roadmap for conducting this study. Cooper’s taxonomy (Cooper et al., 1998) was applied for defining the review scope and analyzing the retrieved literature. A number of prominent earlier and recent theories e.g. Schema Theory, Pattern Language and the theory of axiomatic design were consulted in search of further insights into the field of formalized requirements management.

6.4 Paper 4: Implications of a BIM-based facility management and operation practice for design-intent models

It is often during the design phase when the very first object-based geometric models are developed. The information handover produced by the design team needs to be complete and well-structured so as to be beneficial to FM. This paper studies therefore the design-intent models from an FM point of view. The aim of this paper is to investigate how beneficial contemporary design-intent BIM deliverables could be to FM and what should be improved with regard to their structure and content so that they could form the basis for FM-intent BIM documentation.

The ontological approach of the paper and conceptualization of the studied domain build upon BIM Framework (see section 3.2) and the built environment management model (BEM2; see section 3.3). The basic concepts and definitions used for data analysis and presentation of the results have been derived from the specifications of IFC2×3 and COBie.
The studied project, Undervisningshuset, is an educational facility located in the main campus area of the Royal Institute of Technology (KTH) in Stockholm. The building has 7 floors and a total gross floor area (GFA) of 937 m². Data for this study has been collected from national and international standard specification documents and classification initiatives, earlier research, directives of the client organization, BIM guideline documents of the studied project, original BIM deliverables, personal notes of the author from BIM collaboration meetings, informal talks with the BIM representatives of the participating firms and an in-depth interview session with the BIM-strategist of the project. The BIM deliverables have been examined and analyzed using model-checking, text-editing and IFC-explorer software applications. Of totally 32 requirements considered here, 17 were fully met by the BIM deliverables of the studied case, 10 were partially met, 3 were not fulfilled at all and 2 were deemed non-relevant for this study.

6.5 Paper 5: A framework for measuring the benefits of BIM in the FM&O sector

Concrete empirical evidences are needed so that FM decision-makers are convinced about the benefits of BIM. Any effort for realizing the benefits of BIM in FM would be otherwise in absolute vain. The very first step in this direction is clarifying how such potential benefits could be measured.

The aim of this paper is, therefore, to develop a framework consisting of a list of cost and benefit indicators for measuring the benefits of BIM-implementation in FM at an operational level through an ex-post (prescriptive) approach (Love et al., 2013). The built environment management model (BEM2) has been used for defining the central concepts and delimiting the subject area of the research. The scope of the study has, thereupon, been confined to the operational activities within the forth key process area (KPA) of BEM2 i.e. service, operation and maintenance management. The delimitation of the scope of the study has been motivated by the principle of the vertical strategic chain of value realization.

An exhaustive and selective literature review has been performed based on the framework developed by vom Brocke et al. (2009). In-depth analysis of the reviewed literature and development of conceptual models and the resulting framework has been guided by the respective literary guidelines and recommendations (Cameron and Whetten, 1983; Dubin, 1969; Lave and March, 1993; Meredith, 1993; Ritter, 2010). The trinity of the strategic/tactical/operational decision-making levels, the polar concepts of core/non-core businesses as well as the insourcing/outsourcing approaches have been identified as the central concepts in FM. Those concepts were used as the epistemological basis for developing the suggested framework.

Overall, this paper suggests a methodology for measuring the benefits of BIM in FM using a proposed benefits realization assessment framework. The benefit indicators comprising the proposed framework are work order accomplishment time, energy consumption, material consumption, the generated revenue and the number of reactive maintenance work orders. The cost indicators include the costs of
hardware and software applications, training and services. An alternative case study design has also been presented as the basis for future empirical research implementing the suggested framework.
7 FINDINGS

In this chapter, the findings have been presented in the form of comprehensive answers to the research questions introduced in section 1.2:

What is the current status of the building information management technologies and processes deployed in FM?

The main FM roles could be articulated as facility manager, facility administrator, facility operator, operation engineer, facility assistant, facility service roles and custodian roles (Paper 1). Based on the specific tasks assigned, each of these actors could be an administrator, contributor or consumer of information (ibid.).

When the construction project is over and the building is in use, the building as a whole and the constituent building components are often called assets. Some of the most common types of asset information required in FM are asset provider, purchase price, installation date, commissioning data, asset location, serial number, barcode number, expected useful life (EUL), warranty terms, equipment preventive maintenance plans, startup and shutdown procedures, guaranty information, and spare and consumable parts information (Paper 1). Obviously, not all types of the information mentioned above are required for all asset types. Since the majority of maintenance tasks are performed on HVAC systems, plumbing systems and elevators, there is a greater need for information about those assets (ibid.).

The common practice for collecting the required asset information in the majority of organizations that own, acquire, lease or rent facilities is still searching through a mix of digital and paper documents and databases including 3D-models, 2D-drawings, product datasheets, warranty manuals, part diagrams, installation instructions and other submittals (Paper 1). This leads to delayed, sluggish, iterative, and error-prone data entry procedures, and lack of current and complete equipment data in FM systems e.g. computerized maintenance management systems (CMMS’s), computer-aided facility management (CAFM) systems, document management systems (DMS’s), building management systems (BMS’s) and building automation systems (BAS’s). Consequently, maintenance planning is postponed, warranties are voided and the intended service life of the equipment cannot be achieved (ibid.).

To eradicate this problem, enhance interoperability among construction and FM systems and provide FM actors with their desired asset information, a variety of technical solutions have been implemented by different actors around the world (Paper 2). One of the most common practices is using spreadsheets simply as document indexing tools containing hyperlinks to different sources of building information. Within more advanced setups, spreadsheets could be synchronized with databases at certain intervals. The COBie guidelines suggest a specific way of structuring such spreadsheets. Based on the findings from the studied cases, the data structure suggested by COBie does not always correspond to the needs
and requirements of the recipient organizations. In such occasions, a customized and firm-specific translational spreadsheet was developed and used instead of COBie.

Building information could also be transferred through the ISO-standard file format, IFC (Paper 2). Through this approach, a subset of the contents of the construction- and design-intent BIM deliverables is exported from proprietary software in the open IFC format using the required delivery specifications as defined by MVDs. MVDs are subsets of the IFC schema satisfying certain exchange requirements, here extraction of FM-related information. The resulting IFC models are then imported, embedded and integrated into FM systems. The MVDs used upon exporting sorts out the information that is relevant for FM. A possible issue with this approach is that not all types of information required in FM are included in the BIM handover. The information submitted during the procurement and construction phases, for instance, are often not reflected in the BIM handover (Paper 4). The information sourced from IFC documentation should thus be complemented with other sources (ibid.).

Another approach is using portal solutions as a translational interface between BIM applications and FM systems (Paper 2). Such portals could be customized application programming interfaces (APIs) or commercial off-the-shelf packages.

A summarized account of the current status of the building information management technologies and processes deployed in FM follows:

- The most common types of asset information required in FM are asset provider, purchase price, installation date, commissioning data, asset location, serial number, barcode number, expected useful life (EUL), warranty terms, maintenance instructions, startup and shutdown procedures, guaranty information, and spare and consumable parts information.
- HVAC systems, plumbing systems and elevators require the highest amounts of asset information.
- The major sources of asset information are paper documents, databases including 2D-drawings, BIM deliverables, product datasheets, warranty manuals, part diagrams and installation instructions.
- The major categories of the digital systems deployed in FM using or administrating asset information are CMMS's, CAFMs, DMS's, BMS's and BAS's. Information exchange processes to and across those systems are often error-prone and inefficient.
- The major methods for transferring asset information from BIM deliverables to FM systems are as follows:
  - Simple spreadsheets as document indexing tools
  - Spreadsheets containing hyperlinks to other sources
  - Spreadsheets that are regularly synchronized with databases
  - COBie translational spreadsheets
  - MVDs as subsets of the IFC schema
  - Commercial off-the-shelf portal solutions
  - Portal solutions including customized APIs
What are the implications of a BIM-enabled FM for the upstream planning and design phases?

Some of the greatest concerns upon construction projects are energy reduction, sustainability, lifecycle economy, performance, end-user productivity, flexibility, constructability and safety (Ye et al., 2009). In order to facilitate verification and validation of both the construction process and the final product (the building) against the above requirements, they should be defined early in the planning and design phase and in an as clear and comprehensible way as possible. Building design is, however, a fuzzy, incremental and iterative process. A multitude of stakeholders often with conflicting needs and objectives should be involved in formulating the goals and requirements of the project (Paper 3). The final set of requirements is thus often scattered in a wide variety of documents and sources in different formats (ibid).

IT-enabled formalized management of requirements would facilitate a more structured requirement management practice (Paper 3). A prerequisite for this is, however, stipulating standardized terminology and taxonomies for this domain. The terms objective, goal, constraint, criteria, variable, parameter and attribute, for instance, are intended for referring to requirements at different levels of abstraction; but are not used consistently throughout the literature (ibid).

A BIM-enabled FM has implications also for the upstream design phase (Paper 4). Such requirements could be controlled at two levels:

1) requirements on the models’ overall structure
2) requirements on the contents of the models i.e. objects, attributes and relations.

Regarding the overall structure of the BIM deliverables, they should – first and foremost – be complete and include all major building elements (Paper 4). Quite often, the zone objects that are central to FM processes are not modelled. Examples are fire compartments and reserved spaces for maintenance, transportation of equipment and logistics. The number, naming and geometric definition of floors should be consistent across different disciplines e.g. architecture, structural engineering and MEP. It should be possible to retrieve the north direction and geo-location of the building from the content of the models. A common issue is that landscape handover is quite often delivered in 2D formats. This is partly due to the lack of BIM-compatible software for landscape design.

When it comes to the requirements on objects, it is crucial that all objects contain the information required for FM e.g. tag number codes and descriptions (Paper 4). Some common missing attributes that are crucial to FM are the values for fire rating, security rating and sound rating. Building components should have correct semantic definitions and spatial associations. Objects should not extend across several floors, so that each object is fully contained in and also semantically belongs to one and only one floor plan. Software applications used in different disciplines should be enhanced so that such attributes as classification codes are named consistently upon IFC export.
It should be remarked that the pertinence and usability of BIM models in design, construction and FM sometimes implies different and even contradictory requirements (Paper 4). Design-, construction- and FM-intent models could – in other words – require totally different structures. This could be a major challenge for client organizations when formulating their requirements on the BIM handover documentation.

The implications of a BIM-enabled FM for the upstream planning phase could be summarized as:

- The project requirements should be defined early in the planning and design phase and in an as formalized, clear and comprehensible way as possible.
- The terminology and taxonomies used in the field of requirements management should be standardized.

The implications of a BIM-enabled FM for the design phase could be controlled at two levels:

- The requirements on the models’ overall structure e.g. consistent floor definitions across disciplinary models
- The requirements on the contents of the models i.e. objects, attributes and relations:
  - Below follows some major requirements on the contents of the models:
    - All major building elements should be included in models.
    - Building components should have correct semantic definitions and spatial associations.
    - The naming conventions for floors, elements and attributes should be consistent across different disciplinary models.

How could the benefits of BIM-implementation in FM be measured?

FM is often considered as a strategic tool for companies for reducing overheads, increasing operational efficiency and gaining business advantage over competitors. Any intervention such as BIM-implementation should thus reinforce the objectives mentioned above. Identifying relevant performance assessment metrics would help evaluating the impacts of BIM-implementation in FM (Paper 5). Productivity, efficiency, effectiveness and key performance indicators (KPIs) are some examples of the performance assessment metrics that could be used for this purpose. Quantitative and tangible metrics are, however, more appropriate for objective evaluation of the benefits of BIM in FM. The benefit indicators of a suggested framework for assessing BIM-implementation in FM would thereby comprise: work order accomplishment time per cost, energy consumption, material consumption, the revenue generated, and the number of reactive maintenance work orders. The cost indicators of the framework would, on the other hand, comprise of: the costs of hardware and software applications, the costs of training and the costs of services.

Case study is one of the most appropriate setups for applying the framework described above to real-world cases. A multiple-case embedded design is suggested for this purpose. The main unit of analysis in such a case study would be a BIM-implementation project and the embedded units of analysis would be the benefit and cost indicators. Some alternative sources of information for the case studies in question would be contracts, utility invoices, balance sheets, product data sheets, reports,
documentation on start-up and shut-down procedures of equipment, warranty manuals, installation instructions, part diagrams, maintenance records, BIM deliverables and on-sight observation (Paper 5). Eventually, common financial methods could be used for calculating the monetary equivalent of the outcome of the BIM-implementation project in either of an *ex-ante* (predictive) or *ex-post* (prescriptive) fashion (ibid.). Some examples of such methods are *payback period* (PP), *accounting rate of return* or *return on investment* (ROI), *internal rate of return* (IRR) and *net present value* (NPV).

In summary, the suggested framework for measuring the benefits of BIM-implementation in FM consists of

- The benefit indicators: work order accomplishment time per cost, energy consumption, material consumption, the revenue generated, and the number of reactive maintenance work orders
- The cost indicators: the costs of hardware and software applications, the costs of training and the costs of services.
8 DISCUSSION

In addition to developing a set of guidelines as a means for action, this study also contributes to the body of academic knowledge in the field of construction informatics and aims to fill in the literary gaps addressed in section 1.1:

The papers 2 and 4 present empirical insights on implementing BIM in FM. Paper 3 suggests a number of theoretical constructs for studying formalized requirements management. The terminological and taxonomic ambiguities throughout the literature on requirements management have been disclosed in paper 3. This could be considered as a prerequisite for developing further theoretical grounds for BIM-enabled formalized requirements management. The contributions of Paper 5 correspond to yet another gap in the literature i.e. studies on the benefits realized by BIM implementation in FM. The suggested framework for measuring the benefits of BIM in the FM together with the suggested multiple-case embedded case study design could be used both for expanding the body of literature in this subject area and further researching the under-researched field of FM.

The choices made by the researcher(s) through this study were presented, justified and discussed in chapter 2, Research outline. All the choices made and the philosophy, approaches, strategies and methods applied here have, nevertheless, some limitations. A common problem with case study research, for instance, is that generalization based on one or a limited number of case studies could jeopardize the external validity of the research (Trochim and Donnelly, 2008; Yin, 2003; Patton, 2002). For mitigating this, it is suggested to adopt a pragmatic approach to case study i.e. to consider case study merely as a means for learning from the specific observed case rather than a means for generalization and theory building (Stake, 1995).

Another possible limitation of this study as a whole is the fact that not all different aspects of implementing BIM in FM have been covered here. The choices of the aspects addressed through the three objectives have been justified in section 1.2. Yet, studying further aspects could have strengthened fulfillment of the aim of the study i.e. to investigate the challenges against successful implementation and realizing the benefits of BIM in FM.
9 FINAL REMARKS

Enabled by the widespread digitalization of data, increased mobility, user-friendly data devices and big-data analytics, information management practices in FM are undergoing dramatic changes. The BIM handover from the construction project is no longer the single source of building information: the enormous amounts of real-time data sourcing from sensors and users’ smartphones could be integrated with the information derived from the BIM handover. Such integration would enable owners to run totally new forms of business models and offer new services. Service development, in turn, requires acquisition of new procurement strategies by FM organizations and owners. This requires a more active presence of facility managers in design and construction and a more holistic approach to building information management (SISAB, 2018).

The fundamental principle for a holistic approach to information management in FM is developing systems and processes that rely on objects and assets. The information management strategies of the FM and owner organizations should be designed at a fairly rough level of detail and be closely linked to their business models. They would otherwise lose their relevance over time as new technologies emerge and current technologies expire. A system-oriented mindset is the key to success: everything is connected to everything; so should it also be with the corresponding information models and digital representations (SISAB, 2018). Such interconnected digital representations as described above requires development of further open international standards that pertains to both project documentation and sensor data.
10 FUTURE RESEARCH

Obtaining the full range of the benefits of BIM in FM requires radical organizational changes and introducing new roles. Further research is needed for defining new business models that underpin and motivate such extensive organizational and procedural changes that are – in turn – required for full-scale BIM implementation. More research should also be undertaken for enhancing data interoperability among different actors as well as among IT platforms used at different spatial scales namely BIM and GIS applications.
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A BALKEMA BOOK
An overview of information logistics for FM&O business processes

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ABSTRACT: Systems that warrant a sustained collection, analysis and retrieval of building information are essential to maintain a smooth and steady flow of information across the diversity of actors throughout building lifecycle phases. Benefits of using Building Information Management (BIM) tools for this purpose will not be fully realized unless the facility management and operation (FM&O) activities and processes are adjusted accordingly. This paper aims to provide the theoretic basis for more focused studies on existing and desired processes in the FM&O sector and their associated information transactions. Academic literature as well as empirical studies in the subject area of building information management and workflow processes of the FM&O sector are consulted and analyzed. An overview of the types and taxonomies of generic FM&O activities and processes, disciplinary actors within the sector and their information needs are provided.

1 INTRODUCTION

Transition from a project-centric construction industry to a final-product-oriented and integrated discipline is substantial to producing more efficient buildings for the eventual users i.e. society and private owners (Rezgui, Hopfe & Vorakulpipat 2010). Since the very ultimate goal of the entire process – from the society’s point of view - is to supply firms and organizations with facility assets that underpin their business processes, improved performance of the buildings during their operation time should be envisioned as the primary objective of the project from the beginning. This entails a shift from project-centric to product-centric construction settings (Karrbom Gustavsson, Samuelson & Wikforss 2012). Such a holistic approach demands, first and foremost, information management systems that warrant a sustained collection, analysis, and flow of information across the diversity of organizations and disciplinary roles throughout a building’s lifecycle (Tarandi 2011).

According to a study by the US National Institute of Standards and Technology (NIST), 12.4 percent of the total annual mean expenditures in the facility management and operation (FM&O) phase are caused by insufficient interoperability among different information systems (Gallaher et al. 2004). Interoperability can be defined as “the ability that data generated by any one party can be properly interpreted by all other parties.” (Shen et al. 2010). Building information modeling/management (BIM) technologies demonstrate promising potential for reducing the costs in the FM&O sector incurred by insufficient interoperability (Eastman et al. 2011; Khemlani 2011; Jordani 2010; Ding et al. 2009). Challenges to this vision can be divided into the three major categories of IT provisions, business processes, and contracts (Parsanezhad & Tarandi 2013; East, Nisbet & Libich 2013). According to a recent report by McGrawhill Construction, over 50% of the owners in North America are still beginners in using BIM technologies (Bernstein 2012). The majority of the research on implementing BIM for facility management and operation has so far been focused on the technical requirements (Cahil, Menzel & Flynn 2012; Parsanezhad & Dimyadi 2014; Schevers et al. 2007; Shen et al. 2010; Shen, Hao & Xue 2012; Tarandi 2011; Tarandi 2012); whereas the importance of efficient BIM procurement methods and optimized working procedures have been frequently uttered by scholars and practitioners (Foster 2012; Howard & Björk 2008; Teicholz 2013).
This paper aims to provide the theoretic basis for more focused studies on existing and desired processes in the FM&O sector and their associated information transactions. This study is basically the initial phase of a broader research project investigating information transactions within two specific activities common to FM&O firms: area management and maintenance work order management.

General types and taxonomies of activities and processes carried out within the FM&O phase as well as the information needs of the diversified disciplinary actors involved in those activities are presented. Academic literature as well as empirical studies in the subject area of building information management and workflow processes of the FM&O sector are consulted and analyzed for this purpose.

In Section 2 and 3, it is clarified how the terms building information management and facility management and operation are approached in this paper. Section 4 is an overview of the types of activities carried out within the FM&O phase. Section 5 looks more closely into the FM&O sector and identifies disciplinary actor groups and common processes. Section 6 is a review of the information needs of the FM&O sector, and in Section 7, the plan for a forthcoming empirical research to complement the outcomes of this paper is briefly explained.

2 BUILDING INFORMATION MANAGEMENT (BIM)

The terms data, information and knowledge are often used interchangeably. It is thus important to clarify what the “I” (information) component of the BIM concept stands for. For the sake of this study, “data” are regarded as numeric basic information or quantifiable outcomes of observation; “information” is data that have relevance and context (such as unit of measurement) i.e. processed data; while “knowledge” refers to a subset of information which is useful and meaningful for a specific purpose i.e. authenticated information (Rezgui, Hopfe & Vorakulpipat 2010; Smith 2001). From these assumptions, it is inferred that data may undergo a sequence of evolutionary stages and be consecutively transformed into information and knowledge (Fig. 1).

This clarification is designated by the term “information” as intended in this study as the content that is captured, analyzed, stored and supplied by building information systems. Moreover, the “M” component of the acronym BIM implies “management” rather than “modelling” here. With regard to the scope of this study, BIM is defined as “a business process for generating and leveraging building data to design, construct and operate the building during its lifecycle” (buildingSMART 2012).

3 FACILITY MANAGEMENT AND OPERATION

The OmniClass Construction Classification System (OCCS - ISO 12006-2) provides distinct definitions for the terms Facility Management, Facility Operation and Maintenance, and Facility Operations. Facility Management mainly implies the administrative activities for guaranteeing a safe and functioning building; Facility Operation and Maintenance is defined as both oversight and maintenance of the systems and services within facilities; while the term Facility Operations is designated to refer to the act of providing services to support operation within facilities (OCCS 2013 - Table 33 - Disciplines). We have nevertheless preferred to use the term Facility Management and Operations (FM&O) which encompasses all the aforementioned concepts so as to facilitate addressing the information management tools and processes in this context.

FM&O is also defined as a discipline that “encompasses all of the broad spectrum of services required to assure that the built environment will perform the functions for which a facility was designed and constructed” (Sapp 2013). The following definition by the International Facility Management Association (IFMA) puts more emphasis on the actors who contribute to this sector: FM&O is “the practice of coordinating the physical workplace with the people and work of the organization” (IFMA). The next step is a taking a closer look at the activities within the FM&O sector.
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4 GENERIC ACTIVITIES WITHIN THE FACILITY MANAGEMENT AND OPERATIONS SECTOR

The OmniClass system defines the operation phase of the building as a phase “in which owner or a designated agent occupies, uses, and manages and maintains a facility, which may also include partial or whole facility renovation, repair, reconditioning or remodeling activities as part of the project use lifecycle” (OCCS 2013 - Table 31 - Phases) and offers a detailed hierarchical list of FM&O activities. Figure 2 demonstrates another exemplar classification of FM&O activities developed within the Finish development project, COBIM (Jokela, Laine, & Hänninen, 2012). The two major categories of activities in this breakdown structure are “operative property management” activities and “end-user services”. Activities in the former category are basically aimed to sustain the quality of the main asset (facility) which constantly underpins execution of the activities in the latter category.

Sandesten (2003) articulates the three major categories of FM&O activities as “organization’s core business processes”, “organization’s leadership processes” and “organization’s support processes” (Fig. 3). Figure 4 demonstrates an alternative classification of the FM&O activities based on several classification systems including the preceding ones. The two major categories here are “facility/property strategic management” and “facility/property operational management”. The core activities of the organization are excluded in this taxonomic structure so as to keep the focus on the generic types of activities common to all asset owners. The strategic management activities are planning-like tasks of a long-term and nature; while the operational management activities are in principle more detailed and project-specific tasks of a short-term character. Financial administration, maintenance activities and performance and condition evaluation of properties are common to almost all FM&O firms.

5 ACTORS AND PROCESSES WITHIN THE FACILITY MANAGEMENT AND OPERATIONS SECTOR

Any general activity within a firm is carried out through a number of processes. A process is described as “a specific ordering of work activities across time and place, with a beginning, an end, and clearly identified inputs and outputs: a structure for action” (Davenport 1993). Business processes are assigned to and executed by actors within the firm. The purpose of all information technologies deployed in the FM&O sector including BIM tools is to supply the right information as a critical input to business processes, on the right time and spot, in the
right format and to the right actor (Schevers et al. 2007). For realizing this and thus truly embracing the advantages offered by information management tools, traditional business processes and work flows should also be enhanced accordingly. Practitioners often emphasize the urge for developing and implementing new FM&O processes that enable organizations to leverage the full potential of BIM technologies (Aspurez & Lewis 2013).

Re-engineering processes should be necessarily preceded by accurately describing current processes (Lundgren & Björk 2004). Since the FM&O tasks are executed by different disciplinary actors within firms, they are the most eligible sources of knowledge about how those tasks are carried out. The main actors within the FM&O sector according to the Swedish Association of Local Authorities and Regions are facility manager, facility administrator, facility operator, operation engineers and facility assistant (SKL). The FM&O organizational roles introduced by OmniClass are not much different: facility use roles, facility manager, facility maintenance, facility engineer, facility service roles, and custodian roles (janitor or housekeeper) (OCCS 2013 - Table 34 - Organizational Roles).

The number of FM&O staff dramatically varies from one organization to another. Here are some examples: a sole FM&O agent who supervises the tasks that are performed by external consultants (Lewis 2013a); a team composed of a project manager, a heating-ventilation-and-air-conditioning (HVAC) technician and an electrical technician (Al-daham et al. 2013); a work order administrator together with a shop manager and a work order technician (Beatty, Eastman & Kim 2013); and numerous examples of professional FM&O firms with hundreds of staff. Each of these actors can be an administrator, contributor, or consumer of information at each workflow sequence (Aspurez & Lewis 2013). Workflow processes within the FM&O sector likewise vary a lot from one organization to another. Figures 5-7 demonstrate the workflow process of three common examples of FM&O tasks. Activities that involve some type of information transaction are marked by red circles. Those are in fact the procedural bottlenecks where lack of information in the right time, right spot or right format causes delay, disturbs the organization’s core activities, and leads to loss of resources.

6 BUILDING INFORMATION REQUIRED FOR FACILITY MANAGEMENT AND OPERATIONS PROCESSES

As evident in Figures 5-7, so many activities within an exemplar FM&O workflow process involve either querying or publishing information. Intrinsic needs of every single activity for the tacit and implicit knowledge required for executing that specific activity (Smith 2001) are yet not considered here since they do not lie within the scope of this study.

The types of the information needed by practitioners vary a lot throughout the lifecycle of the building. The extensive need of designers for graphical formats to represent the building diminishes over time and is gradually replaced by a greater interest in attribute data in the operation phase (Teicholz 2013; Aspurez & Lewis 2013). The FM&O sector needs the construction-intent or as-installed models rather than the design-intent or as-designed ones. Yet even not all contents of the construction model are relevant for facility managers. Specifications of concrete forms, the size of rebar within concrete components and pipe and duct hang- ers for instance, should be excluded from the models. This necessitates data cleaning procedures prior to information hand-over to the FM&O team (Aspurez & Lewis 2013; Lewis 2013a).

Asset information may be sourced from the manufacturer, the vendor, or the installation contractor of the asset. The most common asset information fields in the FM&O relational databases are asset name, provider, purchase price, installation date, commissioning data, asset location, serial number, bar-code number, expected useful life (EUL), warranty terms, equipment preventive maintenance plans, startup and shut-down procedures, guaranty information, and spare and consumable parts information, and performance units (Lewis 2013b; East 2013). The majority of preventive maintenance tasks are performed on HVAC system, plumbing systems, and elevators which demonstrates the greater need of information on those assets (Lewis 2013a). From a strategic perspective, FM information about assets and equipment such as warranty data and asset cost data are needed for estimating the life time of the asset, optimized timing of recapitalization, security, etc. (Jordani 2010). Prospects of integrating real-time sensor information with FM systems (Cahil, Menzel & Flynn 2012; East, Bogen & Rashid 2012) envisions even more advanced capabilities for FM information management systems. There is however still a wide gap among visions and reality. Figure 8 depicts the range of forms and formats of the FM&O information deployed across the sector. In this diagram, the more recent BIM formats are aligned with their corresponding BIM maturity level as defined by the UK Government Construction Client Group (CCG 2011).

Common practice for collecting relevant and required information on facilities in the majority of FM&O firms is still gliding through a mix of digital and paper documents including submittals, product datasheets, warranty manuals, part diagrams, and installation instructions (Teicholz 2013). This leads to delayed, sluggish, iterative, and error-prone data entry procedures, and lack of current and complete
An overview of information logistics for FM&O business processes

Figure 5. Work flow diagram of an exemplary FM&O work order process (after Forns-Samso, 2010).

Figure 6. Work flow diagram of a traditional FM&O routine (after Aspurez & Lewis, 2013).

Figure 7. Swim-lane flow diagram of FM&O tasks in a health center (after Beatty et al., 2013).

Figure 8. Spectrum of forms and formats of FM&O information.
equipment data in Computerized Maintenance and Management Systems (CMMSs). Consequently, preventive maintenance (PM) planning is postponed, warranties are voided and the intended service life of the equipment cannot be achieved (Aldaham et al. 2013; Foster 2012).

Development and deployment of standardized information formats such as IFC (buildingSMART) and COBie (East, Nisbet & Liebich 2013) together with their complementing initiatives such as ifcXML, aecXML, BLIS-XML, bcXML (J. Beetz, J.P. van Leeuwen & B. de Vries 2005) will pave the way for more interoperability. Nevertheless, the FM&O sector will not fully benefit from such processes unless business processes within the FM&O sector and their information needs are fully acknowledged and enhanced.

7 FUTURE WORK

This study provides the theoretic basis for a more focused study on the FM&O workflow procedures so as to more closely investigate existing and desired information transactions within the sector. For the sake of clarity and concision, the study will be delimited to two specific activities common to FM&O firms: area management and maintenance work order management. The former is often considered as a means for strategic decision-making processes and executed within computer-aided facility management (CAFM) systems; while the latter deals with day-to-day operative activities of the FM&O team and is often managed by CMMS’s. The information elicited from actors within an organization which operates research and education facilities will be used to reconstruct both generic and detailed business processes and identify their information needs. The bottlenecks triggered by inefficient or tedious information acquisition routines will be then identified and - when applicable - associated with deficiencies and limitations of the prevailing workflow processes. Finally, suggestions will be provided on how workflow processes can be optimized for embracing BIM-based FM&O technologies.

8 CONCLUSIONS

Efficient and reliable information management tools and routines could substantially reduce the losses in the FM&O sector. Timely and effective implementation of such systems, however, entails adjustments in actual FM&O practices. This, in turn, calls for better acknowledgement of FM&O activity types, business processes, disciplinary actors and their information needs. Both major categories of activities in the FM&O sector i.e. strategic and operational management rely on information about buildings and their performance. Although development of new information technologies and corresponding standards is a strong drive towards a more efficient and profitable FM&O sector, it is similarly important to meticulously identify what types of information, in which manner, and to what extents need to be supplied to different business processes and involved disciplinary actors.

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EFFECTIVE FACILITY MANAGEMENT AND OPERATIONS VIA A BIM-BASED INTEGRATED INFORMATION SYSTEM

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ABSTRACT

Purpose: The purpose of this paper is firstly to summarize the status quo of the building information management technologies applied in the facility management and operations (FM&O) sector and identifying prevailing issues; and secondly, to devise technical solutions for those issues based on an exemplar case.

Background: Considerable financial losses could occur as the result of insufficient interoperability issues among information systems. In order to minimize losses, Building Information Management (BIM) tools must be able to interoperate with a variety of digital FM&O systems.

Approach: This research applies the principles of grounded theory as well as conceptual constructs of a proposed BIM framework. Firstly, descriptions of information management systems of eleven projects in technical reports are analyzed and the prevailing technical issues extracted. Then, a narrative representation of an IT-implementation project together with its organizational context has been provided. Finally, the most important issues from recent projects have been presented together with their respective solutions provided by the case project.

Results: The results demonstrate that the most important issues in implementing BIM for streamlining FM&O activities are lack of guidelines and efficient technologies for capturing BIM models of existing facilities, coping with non-consistent terminologies and taxonomies, requirements specification in BIM applications, and identifying which information and what levels of detail are desired by the FM&O teams.

Practical implications: In addition to scholars, the results are useful to database implementers and database designers, as well as decision-making buddies in the FM&O sector.

Research limitations: More research in this area is needed with a focus on business processes and regulatory requirements.

Originality/value: No earlier research has so thoroughly described the overall architecture and functionalities of different components of an integrated BIM FM portal solution with regard to the latest findings in both theory and practice.
Keywords: BIM FM, Facility Management, FM&O, Building Information Modelling, Interoperability

1 INTRODUCTION

Facility managers of corporations are responsible for the operation and maintenance of assets. This constitutes a considerable share of their annual expenditures. In the building industry, 85 percent of life-cycle costs of a facility occur post construction (Jordani, 2010). Accessibility of the required information is essential to any efficient facility management and operations (FM&O) practice (Teicholz, 2013) i.e. lack of information dramatically lowers the efficiency of maintenance activities (Motawa & Almarshad, 2013).

In recent years, Building Information Management (BIM) technologies have substantially influenced information management practices throughout the entire building industry. BIM has demonstrated potential for tackling problems induced by insufficient access to information in all phases including FM&O (Sabol, 2008). Facility owners are now pursuing a variety of business objectives by using BIM including but not limited to reducing operating and maintenance costs, improving service delivery, streamlining business processes, underpinning and optimizing future building modifications, and consequently achieving higher return-on-investments (ROIs) (Aspurez & Lewis, 2013; Teicholz, 2013; Eastman, Teicholz, Sacks, & Liston, 2011; Khemlani, 2011; Jordani, 2010; Ding et al., 2009).

Nonetheless, there are three major obstacles against leveraging BIM for FM&O in its full capacity, namely IT provisions, business processes, and contracts (Parsanezhad & Tarandi, 2013; E. W. East, Nisbet, & Liebich, 2013). The three categories correspond to the three industry foundations constituting the IFC (Industry Foundation Classes) standard which are articulated by Owen (2009) as technologies, processes, and people, as well as the three fields of activity formulated in the BIM framework developed by Succar (2009), i.e. technology, process, and policy.

This paper is a qualitative work that is based on the principles of grounded theory. It mainly addresses how the first obstacle (IT provision) can be overcome. A summary of the literature on implementation of BIM for FM&O is provided, an example of such systems is described, and its components and functionalities are analyzed in relation with the findings of the literature review. The purpose of this paper is twofold: firstly, to summarize the status quo of the building information management technologies applied in the facility operation activities and identifying prevailing issues and impediments; secondly, to devise technical solutions for those issues based on an exemplar cutting-edge case.

2 STATE OF THE ART

2.1 Technological BIM FM integration solutions

Considerable financial losses occur as the result of insufficient interoperability issues among information systems in the building industry. A substantial proportion of these losses is attributable to the FM&O sector (NIST, 2004). Owners are willing to use BIM to enhance their operation and maintenance activities and to minimize or eliminate losses (Jordani, 2010). BIM-enabled information systems are aimed to seamlessly convey the information from design and construction models and databases to actors within the FM&O sector. Such systems
must be capable of interacting with other digital tools that are already used in the sector. FM&O staff work with a variety of tools ranging from paper and pencil to spreadsheets, Computerized Maintenance Management Systems (CMMS’s), Computer-Aided Facility Management (CAFM) tools, Document Management Systems (DMS’s), Building Management Systems (BMS’s), Building Automation Systems (BAS’s), etc. (Lewis, 2013a; Jordani, 2010).

CMMS’s are deployed for asset management, generation of service requests, managing work orders of different types, calculating/tracking required/used resources for planned/executed jobs, keeping employees records, and inventory of managed assets (Sapp, 2013; Lewis, 2013a). FAMIS (by Accruent), IBM Maximo, Corrigo, WebTMA (by TMA Systems), and AiM Maintenance Management (by AssetWorks) are some commercial example of CMMS’s. FAMIS uses an ORACLE database which is integrated with financial databases (Aspurez & Lewis, 2013).

CAFM systems are a combination of Computer-Aided Design (CAD) and relational database software aimed for space management i.e. administering room numbers, departments, usable heights, room areas etc. (Sapp, 2013; Lewis, 2013b; B. East, 2013). Most contemporary CAFM systems still acquire manual querying and updating routines such as overlaying polygons on drawings (Aspurez & Lewis, 2013). FM:Interact (by FM:Systems), Archibus, and AiM Space and Facilities Management (by AssetWorks) are some commercial examples. Despite the widespread acknowledgement of advantages of implementing BIM technologies for operating facilities, the adoption of as-built BIMs within FM&O is still more a vision rather than a reality (Teicholz, 2013). This is partly attributed to the large variety of CMMS’s, CAFM systems, and DMS’s. Sporadic examples of such adoption have nevertheless emerged in recent years namely the Revit-compatible version of Archibus (Jordani, 2010).

The cutting edge technical solutions in the field can be categorized as seen in Table 1 (after Teicholz, 2013; Lewis, 2013a). Construction Operations Building information exchange (COBie) is an open data transfer specification developed by the U.S. Army Corps of Engineers which facilitates delivery of managed asset information by using low-level formats such as the Excel spreadsheet (E. W. East & Carrasquillo-Mangual, 2012; Sabol, 2008). In Table 2, a number of real-world applications of the above initiatives are briefly introduced.

<table>
<thead>
<tr>
<th>Solution</th>
<th>Technical approaches for linking information</th>
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<tbody>
<tr>
<td>Using spreadsheets as simple document indexing tools</td>
<td>Hyperlinking</td>
</tr>
<tr>
<td>Using spreadsheets according to COBie guidelines</td>
<td>Hyperlinking, exchanging and synchronizing data</td>
</tr>
<tr>
<td>Using the IFC format for exchanging building information among BIM and FM&amp;O systems</td>
<td>Exchanging and synchronizing data (embedding and integrating data to the recipient system)</td>
</tr>
<tr>
<td>Coupling CMMS’s with BIMs via Application Programming Interfaces (APIs)</td>
<td>“Portal solution”</td>
</tr>
<tr>
<td>Using proprietary middleware such as EcoDomus, Onuma Systems, and FM:Interact</td>
<td>“Portal solution”</td>
</tr>
</tbody>
</table>
Table 2: A number of recent real-world applications of BIM for FM&O

<table>
<thead>
<tr>
<th>Project</th>
<th>Approach and achievements</th>
<th>Issues</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sydney Opera House</td>
<td>A unified central data repository was devised by integrating information from different resources.</td>
<td>There was no detailed methodology for capturing existing facilities as an accurate object-based building</td>
<td>(Ding et al., 2009; Moffat, 2013; Sabol, 2008; Schevers et al., 2007)</td>
</tr>
<tr>
<td>A pilot project by the US General Services Administration (GSA)</td>
<td>The objective was to transfer the records from the modelling tool (Revit) to the CMMS (Maximo).</td>
<td>Only 17 percent of the records in Maximo could be matched into Revit fields.</td>
<td>(Teicholz, 2013)</td>
</tr>
<tr>
<td>A federal project in New Jersey</td>
<td>It was planned to use COBie for transfer of data from BIM to the CMMS or CAFM systems. Onuma Systems was used for validating COBie deliverables.</td>
<td>The biggest problem was to identify which information was important for FM&amp;O. Another challenge was to select a suitable CMMS in advance. The implementation of COBie has not been fully realized yet.</td>
<td>(Teicholz, 2013)</td>
</tr>
<tr>
<td>A federal project in Minneapolis</td>
<td>Their strategy was to engage the FM team in early modeling efforts.</td>
<td>Early identification of FM-specific systems and zones in the design model proved to be difficult, since the FM team was merely interested in as-built models and closeout documentation. The modeling team believed that there was no clear way to specify detailed data requirement in BIM compared with earlier drafting tools.</td>
<td>(Teicholz, 2013)</td>
</tr>
<tr>
<td>A project for integrating disparate BIM, CMMS, and BAS systems of a court house</td>
<td>Omniclass Table 13 and Uniformat standards were used to specify space types as well as the facility data classification levels i.e. spaces, zones, components, and systems. CMMS’s and inventory spreadsheets were the sources for collecting data for the project.</td>
<td>Naming conventions and data structures developed by local key personnel hindered interoperability among systems.</td>
<td>(Teicholz, 2013)</td>
</tr>
<tr>
<td>Mathworks project</td>
<td>Information synchronization through FM:Interact-Revit integration and early presence of the FM&amp;O manager in the conceptual design phase were the main strategies. COBie was used as a reference source and as a standard rather than a transfer format. The time spent for space planning was reduced to one-tenth.</td>
<td>No direct integration of the CMMS data with the BIM model or linking among them was realized.</td>
<td>(Beatty, Eastman, &amp; Kim, 2013)</td>
</tr>
<tr>
<td>Information administration of an existing health science center</td>
<td>Importing submittals of an existing health science center to TORKO (now EcoDomus) via COBie format helped reducing the average work order duration by 8.7%. Omniclass was used for classifying the assets.</td>
<td>Ambiguities with specifying the level of detail (LOD) of the FM model and use of non-standard internal naming, numbering, and classification conventions for spaces and assets by the client significantly hampered the project.</td>
<td>(Aldaham et al., 2013)</td>
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<td>A construction project at the University of South California</td>
<td>Information from BAS, CMMS (e.g. assets records), and DMS (e.g. warranty documents) were decided not to be imported to Navisworks rather be linked to within the FM system. Equipment and component schedules were composed using parametric attributes rather than hard-coded Excel entries. They had to use a wide assortment of both industry-wide and internal standards i.e. Omniclass for equipment names, and National CAD standards for equipment abbreviations, types, and instances.</td>
<td>Varying information requirements according to the organizational role of the FM&amp;O actors alongside with varying naming conventions, LODs, and the varied types of data available for different assets were major challenges in the data collection phase.</td>
<td>(Teicholz, 2013)</td>
</tr>
<tr>
<td>The construction project of Xavier University in Cincinnati, Ohio</td>
<td>FM:Interact Space Management module was deployed for synchronizing room and element data with Revit. A person-year of data entry was avoided.</td>
<td>The main challenge was integrating the CAFM system (FM:Interact) with the CMMS (WebTMA).</td>
<td>(Afedzie et al., 2013)</td>
</tr>
<tr>
<td>A residential hall at University of Wisconsin</td>
<td>Revit models were exported to IFC format and imported to the CMMS (TMASystems). A SQL database was then implemented for processing the information residing in the CMMS.</td>
<td>The equipment and room types were not defined prior to importing information to the CMMS. This slowed down the process. Another problem was that default values for the MEP equipment, e.g. airflow for the air handling units (AHUs) were inserted instead of real values. It was also difficult to specify whether the information was as-designed or as-built.</td>
<td>(Lewis, 2013a)</td>
</tr>
<tr>
<td>A renovation project in the University of Chicago</td>
<td>The participants firstly specified the types of information to be collected, how to organize the information, and how to map the information onto the CMMS (Maximo). A set of drop-down menus and pick-lists were maintained in the translational tool to handle inconsistencies among naming conventions used by design, construction, and FM&amp;O practitioners. Since the fields mandated by COBie did not fully align with the needs of the project, COBie was replaced by a translation spreadsheet produced by a third-party database consultant.</td>
<td></td>
<td>(Lewis, 2013b)</td>
</tr>
</tbody>
</table>

2.2 Towards an integrated solution for a more effective FM&O practice

As evident in some of the examples introduced in previous section, the COBie initiative is helpful as a set of guidelines for identifying which data should be collected and by whom. Nonetheless, there are some downsides to implementing COBie as a standard format for conveying information to the FM&O team, e.g. mismatch of mandatory information fields in COBie with those necessitated by the business goals of each specific organization, and lack...
of incentives for manufacturers to provide their product information in a COBie-compatible format.

IFC format and its associated Coordination Model View, on the other hand, have not been successful in providing consistent semantics for all stakeholders. The IFC schema is often deemed to be too rigid to be implemented during all life cycle stages of the facility (E. W. East et al., 2013; Tarandi, 2011). Another problem with IFC export as a means for information transfer to FM&O is the large file sizes and populated information that is not totally relevant or useful for FM&O (Lewis, 2013a). Such problems can be overcome in the future by development and implementation of Model View Definitions (MVDs) specific to FM&O.

Middleware solutions are relatively expensive, but are commonly used successfully by sizable organizations such as NASA and GSA. “BIM for FM Portals”, emerging some years ago (Jordani, 2010) are the most appraised FM&O information handling systems. Portals are simple and flexible from user’s perspective. They provide windows to different FM&O systems and directly interact with CMMS’s, DMS’s, and BAS’s. Technicians prefer to be able to use their own downstream systems for troubleshooting. Portals fulfill this requirement and perform queries on the model in the background (Aspurez & Lewis, 2013). Portals are flexible enough to comply with a wide variety of FM&O software, and are relatively inexpensive to develop and run (Sabol, 2013).

3 APPROACH

3.1 Theoretical framework

Among the variety of definitions of the acronym BIM (Eastman et al., 2011; GSA, 2011; Howard & Björk, 2008) and a number of proposed frameworks for research around BIM (Gu & London, 2010; Jung & Joo, 2011), the definition and research framework provided by Succar was deemed the most appropriate and clarifying one for the purpose of this study. He defines BIM as “a set of interacting policies, processes and technologies producing a methodology to manage the essential building design and project data in digital format throughout the building’s life-cycle” (Succar, 2009, p. 357). The definition is, in turn, based on an earlier definition articulated by Penttilä (2006, p. 403).

Succar regards BIM as a modern framework for organizing domain knowledge which is in turn based on the definition of “Frame” by Minsky. According to Minsky, new frameworks (in this case, Succar’s BIM framework) may be invented for new conditions or substantial changes (in this case, development of BIM technology and tools) and applied by the researcher for representing stereotyped situations (Minsky, 1974). Among the three fields of activity within BIM, our research lies in the “Technology field” and is focused on the sub-fields of software and network solutions (Succar, 2009).

3.2 Methodology

The research field of building information management in general and information management tools for FM&O in particular, is rather new and overwhelmed by empirical findings and influences of new information technologies. Hence, theory-driven and linear models have been deemed inappropriate for the purpose of this study. Instead, the principles of grounded

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13 http://www.buildingsmart.org/standards/mvd (accessed 20 February 2014)
theory (Flick, 2009) have been followed and the knowledge derived from an exemplar case project has been used to complement existing literature in the field. Grounded theory is a method for qualitative studies which was introduced by Glaser & Strauss (1967) and is based on initiating the research with data collection and subsequently seeking codes, concepts, and categories that help further formulation of theories.

Firstly, the literature about some ad-hoc solutions has been consulted for presenting the status quo. Descriptions of information management configurations in eleven projects have been derived from technical reports and analyzed to extract technical issues prevailing in existing solutions.

Then, a narrative and illustrative representation and reconstruction (Flick, 2009) of a progressive IT-implementation project in the field together with its organizational context has been provided. One of the advantages of an original analysis of case studies over other methods for collecting data about information systems, e.g. interviews and surveys, is less subjectivity (Bakis, Kagioglou, & Aouad, 2006) and less distortions (Harris, 2001). The choice of the case study is a purposive sampling. This approach improves the efficiency through collecting the data that is relevant to the objectives of the research (Morse, 1998).

The observed case fulfills the requirements of a “primary selection” in that the required information is readily available to the authors. One of the authors is the designer of the system and thus has the double roles of researcher as well as the participant in the case project. This is also a retrospective study since it uses secondary data collection in an after-the-fact manner. As a criterion for studying the case project and based on the descriptions of the third dimension of the BIM framework suggested by Succar (2009), i.e. BIM Lenses, a mesoscopic lens within the FM&O domain has been applied as a mental construct for research in this field. BIM lenses are applied to Fields and Stages and are defined layers of analysis that “allow the domain researcher to selectively focus on any aspect of the AECO industry and generate knowledge views that either (a) highlight observables which meet the research criteria or (b) filter out those that do not” (Succar, 2009, p. 367). A Mesoscopic Lens implies medium coverage, focus and detail (Succar, 2009).

Finally, the most important issues from recent projects have been presented in three categories together with their respective solutions provided by the case project.

4. CASE STUDY: FM&O AT UNITEC INSTITUTE OF TECHNOLOGY (UNITEC)

In this section, the technical specifications of a BIM-driven solution developed at Unitec are studied and illustrated in their organizational context. This project has been selected for the study as it exhibits excellence in several aspects. The Unitec’s FM System integrates BIM with FM&O processes; it facilitates FM&O actors’ access to information sourced from the BIM models by sharing it with downstream applications; the implementation of the system and its applications have led to improved workflow, more effective communication of the facility information to the end users, as well as considerable costs savings in several areas.

Unitec is a tertiary education facility with three campuses in Auckland, New Zealand, serving more than 23,000 students each year, and with about 800 staff members. Its Facilities Man-
The management (FM) department is located in the main campus and is managed under the directorate of Finance & Infrastructure, which is responsible for assets with a current total replacement value of approximately US$300 million.

4.1 BIM and FM Information Integration at Unitec
The BIM project started in 2008 following a decision to undertake an in-house development of an integrated suite of FM software applications to assist with the day to day operations and to support more efficient information management. One reason behind the decision was the unavailability of a suitable off-the-shelf product for this purpose. “FM Desktop” was a promising tool, but it was discontinued soon after being acquired by Autodesk. Archibus only dealt with 2D plans and was not BIM-compatible at the time. Also, the available commercial software applications all used proprietary database systems and did not allow for user customization. Furthermore, none of them provided any BIM integration with the FM&O workflow, which was one of the main criteria behind the project. Within the project, two mainstream activities were carried out consecutively: constructing information-rich object-based models of the campus, and leveraging IT solutions for connecting those BIMs to the FM systems and databases.

Using an earlier repository of CAD files called "base drawings" and complementary site surveys, a total of 191 buildings were modeled in Revit over 4 years and in three different stages, i.e. building shells; internal walls, fixtures & fittings, and roofs; space objects and other properties. The next phase is to add building services, and to incorporate underground infrastructure and above-the-ground assets such as trees, roads, and lamp posts into the campus model that is being developed.

A software tool was written using Revit’s API to automatically update or synchronize the model data at the end of each modeling session with a centralized database in a SQL Server DBMS (database management system). This is the core component of the in-house developed client/server FM Applications Suite, some of which are described in the following sections. The tool also generates Portable Document Format (PDF) floor plans, images of each space, and a normalized representation of the building geometry in Extensible Markup Language (XML) format for post-processing, e.g. energy analysis. An IFC file of each model is saved together with the Revit model in the repository and used for general post-processing and visualization.

A number of downstream applications can access the centralized database linked to the BIM models and update various information as required, which would then automatically update the models when they are subsequently opened for editing. A brief description of the Unitec’s FM System is given in Figure 1. A number of key components of the system are described below.
4.2 FM Help and Workflow Management Downstream Applications
FM Help is a help desk system developed for managing the unique work flow requirements within FM&O. The system provides a simple online form accessible on the intranet across all campuses, which is prepopulated with the essential information sourced from the BIM models, e.g. building and space numbers, departmental charge codes, and contact details of the person logging the job. Anyone on campus can log a job to request general repairs and maintenance, to notify health & safety issues, and to keep track of each job’s status. Upon submission, the information is immediately available on the FM Help Admin system for moderation purposes. Once checked and verified, the job request is then assigned to the appropriate sections within FM&O and becomes available on their respective workflow management applications, e.g. FM Actions, FM Security, FM Cleaning, FM Vehicles, and FM Signage which are all web-based and accessible on desktop or portable devices anywhere on the campus.

4.3 FM Space and FM Space View for communicating building information
FM Space and FM Space View are web applications that provide access to spatial information and a set of BIM-generated floor plans in various scales. For teaching spaces such as classrooms or lecture theatres, the available equipment in each space is also listed so that the user can look up what teaching facility is available, e.g. data-show, PC, etc. At the moment, the list of equipment is derived from a database that is managed manually via an application called FM Equipment. Eventually, the equipment data will be incorporated into the BIM models, which will provide another means of updating the information automatically. Space utilization data derived from the BIM models are used for the institutional finance and accounting purposes, but also for automatically generating various regional FM statistical reports, e.g. Tribal, TEFMA, etc.

4.4 FM BMS
FM BMS application interfaces with the BMS to control the HVAC in bookable spaces. The application continuously checks the room-booking timetable database for any scheduled or one-off booking information. It sends an instruction to the BMS to turn on the ventilation or air-conditioning system half an hour before a room is scheduled to be occupied, and an instruction to turn it off 5 minutes before the end of the booking period. This has provided a huge energy saving in comparison with the previous preset daily on/off mode of operation.

4.5 FM Projects
FM Projects application provides the Projects office with an online tool to manage capital projects, e.g. new and major building works, and relocation projects. As part of the new project setup, a new record is created in the BIM models maintenance schedule, which will remain active until it is ticked off after the model is updated with the as-built information handed over to the FM office. FM Projects also provides workflow management as well as costs management functionalities. Currently, information handed over to the FM office is still in the form of printed drawings or CAD files. However, work is in progress to implement a method of assimilating as-built information directly into existing models.

4.6 FM Maintenance Costs
FM Maintenance Costs application extracts interior and exterior surface areas, and condition ratings from the BIM models, and allows managers to specify various parameters such as repair or replacement costs, and then generates maintenance cost schedules. Space condition audit is carried out visually by observation as required, but at least once every couple of
years. Space condition rating is then determined by using the weighted average of all interior surface condition ratings of that space as per NAMS (NAMS, 2006) in the scale of 1 to 5.

### 5 RESULTS

The Unitec’s FM System is a web-based portal solution which serves all functions of CMMS’s, CAFM systems, and DMS’s, and at the same time integrates and seamlessly and reliably synchronizes the underlying FM&O building information databases with the BIM models. In Table 3, most significant problems in the field (derived from literature and presented in Table 2) are presented together with their respective solutions provided by the Unitec’s FM System.

<table>
<thead>
<tr>
<th>Issues with current FM&amp;O information systems</th>
<th>Provisions in Unitec’s FM System</th>
</tr>
</thead>
<tbody>
<tr>
<td>Issues with as-designed and as-built information</td>
<td></td>
</tr>
<tr>
<td>- Issues with identifying which data are important for FM&amp;O</td>
<td>The solution has been developed by the FM department of Unitec and thus directly addresses the requirements of their FM team on information types and LODs.</td>
</tr>
<tr>
<td>- Issues with specifying LODs required for the FM model</td>
<td>See above.</td>
</tr>
<tr>
<td>- Varying information requirements according to the organizational role of the FM&amp;O actors</td>
<td>See above.</td>
</tr>
<tr>
<td>- Non-useful information coming from design- and construction-intent models</td>
<td>BIM models were constructed and populated in conformity with the needs of the FM&amp;O staff.</td>
</tr>
<tr>
<td>- The variety of industry-wide standards, local naming conventions, and data classification structures, and established colloquial names deployed in various FM&amp;O information sources of the facility</td>
<td>An in-house developed BIM Standard and Conventions handbook is used, which is based loosely on commonly used industry standards.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Issues with FM&amp;O systems</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>- Lack of knowledge for specifying a CMMS early in the design phase</td>
<td>Not applicable to this project since the system was developed for existing facilities.</td>
</tr>
<tr>
<td>- Proprietary database systems not allowing for customization</td>
<td>An industry standard, DBMS (SQL Server-ISO/IEC 9075), has been utilized to maximize data interoperability and to facilitate system maintenance. Further efforts for using IFC more centrally in the system are in progress.</td>
</tr>
<tr>
<td>- Information fields in the CMMS’s not matching those in the BIM authoring tool</td>
<td>The same SQL DBMS that is derived from the BIM model also feeds information to the FM&amp;O applications.</td>
</tr>
<tr>
<td>- Lack of direct integration or linking among the CMMS data with the BIM model</td>
<td>Unitec’s FM applications suite has bidirectional links with the BIM models.</td>
</tr>
<tr>
<td>- Lack of interoperability among the CAFM system and the CMMS</td>
<td>Functionalities of both CMMS’s and CAFM systems are incorporated into the web-based FM solution.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Inefficient workflow processes</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>- Manual and time-taking querying and updating routines in CAFM systems such as overlaying polygons on 2D drawings</td>
<td>FM Space and FM Space View provide access to a set of BIM-generated floor plans in various scales.</td>
</tr>
<tr>
<td>- The BIM systems and models not fully integrating with the FM&amp;O workflow</td>
<td>FM Help controls soliciting the information required for streamlining workflows from the BIM information resided in the SQL database, and channeling the query results to respective workflow applications, e.g., FM Actions, FM Security, FM Cleaning, and FM Vehicles. More specific applications such as FM Maintenance Costs and FM PropLease extract accurate and current information from BIM models for each FM&amp;O task.</td>
</tr>
<tr>
<td>- Issues with updating as-built models after construction</td>
<td>A custom-made software synchronizes the Revit model with the SQL DBMS after each construction project. FM Projects performs the synchronization procedure.</td>
</tr>
</tbody>
</table>
6  PRACTICAL IMPLICATIONS

In addition to their theoretical significance, the results provide in-depth insight into prevailing issues with BIM-based IT solutions for the FM&O sector as well as examples of how those technical issues can be resolved. The results will be useful to DBMS implementers and database designers active in the FM&O sector, as well as decision-making buddies in the field.

7  CONCLUSION

According to our findings, the most important issues in implementing BIM for streamlining FM&O activities are lack of guidelines and efficient technologies for capturing BIM models of existing facilities, coping with non-consistent terminologies and taxonomies used by different actors, accurately defining and specifying requirements in BIM applications, and identifying which information and what level of detail is desired by the FM&O teams. Current open formats for transferring building information (e.g. IFC and COBie) should be enhanced and complemented or new open formats be developed for maintaining interoperability among the wide variety of proprietary tools and systems used through the entire life cycle of the building in an efficient and sustained manner.

No earlier research has so thoroughly described the overall architecture and functionalities of different components of an integrated BIM FM system based on the portal solution with regard to the status quo of the subject area in both theory and practice. Nevertheless, more research with a focus on FM&O business processes and regulatory aspects of building information hand-over are required so as to complement the findings of this paper on efficient use of BIM for FM&O.

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FORMALIZED REQUIREMENTS MANAGEMENT IN THE BRIEFING AND DESIGN PHASE, A PIVOTAL REVIEW OF LITERATURE

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SUMMARY: The aim of this article is to provide a knowledge base for developing further theoretical frameworks and conceptual models that support IT-implementation for formalized requirements management in the briefing and design phases. Related standards or technology-supported methods are not within the immediate focus area of this article. During the briefing and design phase, a wide range of requirements are articulated, documented, communicated and iteratively evaluated and modified. Issues with addressing and implementing such requirements are more common to the architecture/engineering/construction/operational (AECO) industry compared with other industries. Earlier theoretical propositions mainly originating from cognitive science could shed new light on how information technology (IT) developments may be best exerted for formalized requirements management. For conducting this literature review, a framework suggested by vom Brocke et al. (2009) and a taxonomy developed by Cooper et al. (1998) were implemented. This review has its focus on the central issues of the reviewed articles. The analysis process follows an espousal position and the organization of the findings is conceptual. Through analysis and synthesis of literature, major characteristics and dynamics intrinsic to requirements management in the AECO industry have been identified. Moreover, a number of theoretical views on design and validation processes namely Pattern Language, Schema Theory (Chan, 1990) and the theory of axiomatic design (Suh, 2001) have been revisited with the aim of disclosing their take on formalized requirements formulation and modification. As a prerequisite for developing further theoretical grounds for formalized requirements management, terminological and taxonomic ambiguities throughout the requirements management discourse have been notified. Inconsistent interpretations of such terms as objective, goal, constraint, criteria, variable, parameter and attribute throughout literature have been extracted and presented in both verbal and diagrammatic formats.

KEYWORDS: Building requirement, Formalized requirements management, Design, Briefing, Constraint, BIM, object-based


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1. INTRODUCTION

A client-centric approach to production and its associated routines for quality control has for long been a central concept in industrial fields (Akao, 2004, Lindahl and Ryd, 2007, Tzortzopoulos et al., 2006). Accurate documentation, analysis and communication of the clients’ requirements on final products are essential to this approach. To realize this, issues such as undecided technical contents, never-ending changes of specifications and divergent interpretations by different actors should be overcome (Almefelt, 2005, Karlsson et al., 1998).

A parallel can be drawn to the AECO industry: while a shift from project-centric to product-centric processes in construction is inevitable (Karrbom Gustavsson et al., 2012, Koskela and Kagioglou, 2005), current routines for requirements management do not yet support such a shift. The AECO industry needs to become more industrialized and automated (Warszawski, 2003), which calls for more effective methodologies and systems for requirements management and progressive evaluation and validation of design alternatives.

During the briefing and design phase, a wide range of requirements are elicited, articulated, documented, communicated and iteratively evaluated. Issues with addressing and implementing such requirements have been more prevalent in the AECO industry compared with other industries (Ahmed et al., 2003, Jansson et al., 2010a). Consequently, the actual performance of the final products often largely diverge from the initial goals of projects (Kiviniemi, 2005). This could be attributed to the temporary nature of construction projects, one-of-a-kind products, lower and more dispersed levels of IT (Information Technology) literacy, conservatism and insufficient innovation in construction (Turk, 2006). For whatever reason the divergence from the initial goals of the construction project occurs, formulation and documentation of the specifications in formal and clear terms would facilitate further evaluation of requirements fulfilment.

Formalized requirements management in building design is not a new topic for scholars in the field of design methodology. Already in the mid-twentieth century, abrupt social, cultural and technological changes in societies and introduction of new building materials and systems called for a more transparent, democratic and scientific approach to design as opposed to the established though unjustified design traditions of the time (Lawson, 2006). In response and with the aim of maintaining a collective control over designers through inspection and evaluation of their design choices (Jones, 1992), a wealth of new design theories were devised mainly grounded in contemporary research (Tse et al., 2005). There are many indications in the literature that new building information management technologies such as Building Information Modelling (BIM) could also be used for formalized requirements management i.e. as an integrated part of the iterative design and validation procedures (Arayici et al., 2005, Kiviniemi, 2005, Teicholz, 2013). Kiviniemi (2005) first introduced the concept of linking the formalized and machine-readable requirement models to building models. Other scholars have also emphasized the potentials of object-based requirements management and design validation for minimizing the deviation between the initial goals of construction projects and the final built entities and thereby promoting a more client-centric AECO industry (e.g. Arayici et al., 2005, Eastman et al., 2011, Eastman and Siabiris, 1995, Ekholm, 2011, Haymaker and Fischer, 2008, Jansson et al., 2013, 2010a, Parsanezhad and Tarandi, 2013, Tarandi, 2012). Even a number of commercial software applications such as dRofus, Solibri Model Checker and Onuma Systems have been developed for this purpose.

The urge for formalized requirements management has been echoed also in contemporary research (Tse et al., 2005). The theoretical grounds for formalized requirements management need, however, to be developed further. Based on the results of a survey distributed among AECO professionals in Hong Kong, Ugwu (2005) identified the urge for developing a robust knowledge management framework for documenting multidimensional user requirements during the early phases i.e. briefing and design. The AECO-specific theoretical grounds for IT-based information management such as BIM frameworks (Jung and Joo, 2011, Succar, 2009) have been articulated at such generic levels that could hardly be applied to such specific fields as requirements management. On the other hand, BIM-based applications are becoming more widespread across the AECO industry at an increasing pace and the failure to establish theoretical grounds that address the new trends in sufficient level of granularity could result in widening the gap between theory and practice.

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The aim of this article is, thereby, to provide a knowledge base for developing further theoretical frameworks and conceptual models that support IT-implementation for formalized requirements management in the early phases i.e. briefing and design. To realize this, a diverse set of earlier theoretical takes on building requirements management and design methodology have been revisited and reviewed in search of theoretical grounds that could clarify:

- How building requirements could be documented in a formalized way and communicated in an automated fashion.
- How the initial building requirements could be updated during the iterative design process.
- How the documented building requirements could be continually acknowledged by designers and integrated into the design process and incremental validation of design alternatives.

As declared earlier in the aim statement, the temporal scope of this study is limited to the initial briefing and design phases where around 80% of the costs of construction projects are determined (Bruce and Cooper, 2000). The rationale is that a whole-life approach to construction has essential implications for formalized requirements management in the early phases i.e. briefing and design (Jansson et al., 2010a, Owen et al., 2010, Tarandi, 2011). Moreover, the theoretical focus of this article is the cognitive aspects of building requirements management. The organizational and social aspects of the phenomenon have just been touched upon here. So are related standards or technology-supported methods for formalized requirements management.

In section 2, the methodological framework governing how this literature review has been conducted is clarified. Section 3 embraces the major characteristics and dynamics that are intrinsic to requirements management in the AECO industry. Section 4 provides theoretical insights into the design and validation process and its relation to requirements formulation and modification. Sections 5 and 6 respectively address terminological and taxonomic ambiguities throughout the requirements management discourse which precede a short report on more recent advances in formalized requirements management presented in section 7. Section 8 provides a brief critical reflection on this study as a whole which is followed by a summary of the findings in section 9.

2. METHODOLOGY

A framework for reviewing literature developed by vom Brocke et al. (2009) was used in the conduct of this research. Using a framework for conducting this literature review was per se a response to the plea for more rigor in performing literature reviews by vom Brocke et al. (2009). Their proposed framework comprises five consecutive stages which could be iterated for improving the findings: 1) definition of review scope, 2) conceptualization of topic, 3) literature search, 4) literature analysis and synthesis, and 5) research agenda.

2.1 Definition of review scope

As recommended by vom Brocke et al. (2009) and demonstrated in Table 1, the scope of the review (stage 1) has been defined based on the taxonomy developed by Cooper et al. (1998): the focus of the review in this study (1-1 in Table 1) is the theories as well as the outcomes of the reviewed works; the goal of the study (1-2 in Table 1) is integrating the central concepts introduced or implemented in the reviewed works in search of the theoretical grounds beneficial for IT-based formalized requirements management; the findings have been organized and presented through different sections and subsections primarily with regard to the central concepts they convey. In section 7.2, different initiatives are presented in a historical order (1-3 in Table 1); this work is not a neutral representation of the contents, rather aims to highlight those theoretical propositions around formalized requirements management that could support use of new IT developments in construction for requirements management (1-4 in Table 1); the target audience of this study is scholars in the fields of construction IT and building information management (1-5 in Table 1); and finally, only those articles that embrace central and pivotal contents in the subject area of requirements management in the AECO industry have been covered here (1-6 in Table 1). Organization of the findings of literature reviews in a concept-centric fashion has been recommended by Webster and Watson (2002).

Through Table 1, primary choices for this study have been marked with grey backgrounds, bold texts and surrounding frames; while secondary choices have been marked merely with grey backgrounds.

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TABLE 1: Definition of the review scope (stage 1 of the framework for literature review)

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Categories</th>
</tr>
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<tbody>
<tr>
<td>1-1- Focus</td>
<td>Research outcomes</td>
</tr>
<tr>
<td>1-2- Goal</td>
<td>Integration</td>
</tr>
<tr>
<td>1-3- Organisation</td>
<td>Historical</td>
</tr>
<tr>
<td>1-4- Perspective</td>
<td>Neutral representation</td>
</tr>
<tr>
<td>1-5- Audience</td>
<td>Specialized scholars</td>
</tr>
<tr>
<td>1-6- Coverage</td>
<td>Exhaustive</td>
</tr>
</tbody>
</table>

Scope: intended scope (primary)  Scope: intended scope (secondary)

2.2 Conceptualization of topic

The main themes deployed for structuring the findings (stage 2 of the framework for literature review) are building requirements and the design formation and validation processes. These concepts were designated with regard to the aim of the article and delimited to the scope of this study as articulated in section 1.

2.3 Literature search

As previously clarified through Cooper’s taxonomy for definition of the scope of the review, it was not intended to provide an exhaustive coverage of the articles in the subject area of building requirements management here. The literature search process (stage 3 of the framework for literature review) was, therefore, not limited to such structured routines as keywords search. Instead, investigation of each of such distinguished theories as Schema Theory and Pattern Language was done through their corresponding literature as well as further complementary reading for each theory. Such resources date back to around half a century ago.

Moreover, a search for all types of materials published in the last 20 years was performed using a combination of the search terms ‘requirements management’ and ‘construction’ on the web-based database, Google Scholar. Top results were screened initially with regard to their titles. Where titles were relevant and sources were reliable, full-text versions were retrieved. Through a careful monitoring of the abstracts, articles that appeared to have some potential to support formalized requirements management were identified and reviewed thoroughly and relevant contents were extracted. When necessary, backward search was conducted through articles and books that had been cited by the reviewed articles.

2.4 Literature analysis and synthesis

Subsequently, extracted materials were summarized and re-organized using the main concepts as introduced in section 2.2. Analysis and synthesis of the material in each subject area was performed with regard to the choices of focus, goal, perspective, audience and coverage as stipulated in section 2.1.

2.5 Research agenda

The themes introduced in section 2.2 were used as the main headings for structuring and reporting the findings. With regard to the overall aim and scope of the research, further sections were added to address uncovered issues. As specified in section 2.1, the findings have been mainly organized and presented conceptually. The contents of section 7.1 are, however, presented in a chronological order.

3. REQUIREMENTS MANAGEMENT IN THE AECO INDUSTRY

Requirements on buildings may pertain to different lifecycle stages. Some requirements are applicable to the entire lifecycle of buildings e.g. sustainability, environmental consequences and energy consumption; some are specific to the construction phase e.g. constructability and logistics (Wikberg, 2011); some requirements address general qualities of the final product such as aesthetics and attractiveness; while some other requirements are
more detailed functional criteria on the final product e.g. light intensity, air quality and acoustic (Eastman and Siabiris, 1995). Whichever temporal stage the requirements are attributed to, they should all be considered, defined and addressed early in the briefing and design phase in order to curb the costs later in the process.

According to the findings of a study by Ye et al. (2009), the top major concerns among practitioners in the AECO industry in order of importance are energy reduction (during operation of the building), sustainability (with a lifecycle approach), building lifecycle economy, building performance, end-user productivity, end-user comfort and wellness, flexibility (e.g. adaptability, multi-functionality), quality of construction (e.g. material durability), safety, social acceptability, construction methods (i.e. on-site or prefabrication), construction time, cost efficiency and capital cost of construction (Ye et al., 2009). They regard the above as the major categories of through-life requirements on buildings and suggest a methodology for subsequently capturing, analysing, verifying, consolidating and actualizing requirements as such. Their methodology does, however, not offer concrete guidelines for measuring and evaluating the above requirements at an operational level. The categories of requirements and the methodology suggested by Ye et al. (2009) are built upon the findings of survey questionnaires and interviews with actors from seven different groups of stakeholders i.e. infrastructure, regulatory bodies, support services, occupants, constructors, professional teams and clients.

According to Fiksel and Dunkle (1992), ‘requirements management’ could be defined as “the process of creating, maintaining, and testing requirements” (Fiksel and Dunkle, 1992, p. 231). This definition is sourced from the integrated enterprise management domain. This compendious definition covers both the important areas of requirements formulation (as addressed in this section) and validation of design alternatives against requirements (to be addressed in section 4). Requirements management in the AECO industry is sometimes regarded as a subset of the broader domain of industrial manufacturing requirements management (Arayici et al., 2006). However, the significance and nature of the role of the client in the AECO industry is largely different from that of the corresponding role in other industries. In more automated industries, the roles of the non-technical customers and the semi-expert clients are often separated giving space to more technical and sophisticated requirements management routines. In the AECO industry, however, the distinction between the client and customer roles is often blurred (Lawson, 2006) which calls for different approaches to requirements management compared with other industries.

Even though the most fundamental requirements are formulated by the client, the eventual set of requirements is collaboratively developed by a broad spectrum of stakeholders. The client, per se, could be a user client (often in the case of smaller projects) or a paying client (common to larger building or infrastructure projects). The latter serves as the middleman between end-users and AECO actors (Lawson, 2006). The end-user group itself could comprise inhabitants, building administration staff, operations and maintenance personnel and external service providers. Such an extensively heterogeneous group of stakeholders would impose diversified and sometimes conflicting requirements on both the product and the process of construction (Christiansson et al., 2009). The AECO actors such as the architect, engineers and construction manager will, in turn, contribute to refining the initial requirements and also suggesting further requirements themselves. The scope and magnitude of the contribution of each of the above actors to formulation and elaboration of requirements is largely different from one project to another and often rests on such project-specific factors as procurement method, financing structure, and the stakeholders’ attitudes, expertise and organizational traits (Winch, 2012, Yu et al., 2010). Such a broad diversity of actors involved in requirements formulation and their varying levels of involvement in the requirements definition process is a major challenge to formalized requirements management.

Moreover, the process of defining and refining requirements is incremental and iterative (Fu et al., 2007). Goals and obstacles to achieving goals are not always clearly acknowledged in the beginning (Lawson, 2006). Clients often have a vague perception of their needs and preferences (Kamara et al., 2002, Zeiler and Savanovic, 2007). Architects try to concretize and document such obscure ideas via design protocols as verbal and visual descriptions. Design protocols often include valuable but unstructured information that could not always be expressed in formal terms (Akin and Lin, 1995, Gero and Mc Neill, 1998, Jansson et al., 2010a).

Any theoretical framework for conceptualizing and supporting formalized requirements management in the AECO industry should appropriately address the challenges mentioned above. Moreover, it is through the iterative processes of formation, evaluation and validation of design alternatives that requirements are comprehended, implemented, developed further and consolidated. It is therefore crucial to theoretical frameworks for requirements management to also embrace the procedural aspects of the design and validation.
processes. Fiksel and Dunkle (1992) emphasize the interrelationship between requirements definition and validation by defining ‘requirement’ as “a description of a set of testable conditions applicable to products or processes” elaborating that “a requirement is said to be satisfied by a product (or process) if a test reveals that the described conditions are met by that product (or process)” (Fiksel and Dunkle, 1992, p. 231). Cavieres et al. (2011) also address the fact that requirements development is closely intertwined with evaluation of design alternatives. The demand for testability of the requirements is, in fact, one of the major motives for implementing formalized requirements management in the AECO industry (Kiviniemi, 2005). This will be addressed in more details in section 7.

4. THE DESIGN FORMATION AND VALIDATION PROCESS

Stated briefly, design is an interaction between what is needed i.e. requirements and how that need is satisfied i.e. the designed solution (Kals and van Houten, 2013). Arguing that the design work is a mix of systematic and chaotic ways of thinking, designers have for centuries preferred to prioritize the outcomes of their intellectual enterprise over its formation process and regarded their work as untraceable processes and unaccustomed workflows (Lawson, 2006). Despite all the fuzziness about the design process, the basic characteristics of conventional building design practices have been extensively studied (e.g. by Chan, 1990, Darke, 1979, Galle and Kovács, 1992a, Schoen, 1988) and many efforts have been made to develop models and theories that conceptualize the building design discipline (e.g. by Akin, 1978; Akin and Lin, 1995; Gero and McNeill, 1998).

Lawson (2006) portrays design as the process of seeking an integrated solution for a given problem. The design problem, according to him, is hierarchical, multidimensional and interactive. The solution is often sought through a perpetual span comprising drawing and redrawing. The iterative attribute of design has also been accentuated by other scholars. Eastman and Siabiris (1995), for instance, describe the design process as an iterative sequence of problem formulation, synthesis and analysis. Lera (1983) asserts that the outcomes of each round of developing and evaluating solutions informs the successive round. Eberhard (1970) clarifies how escalation and regression of design problem further provokes the iterative cycles of the design process. Escalation implies reconsidering the initial problem at a broader scope and taking other elements from the surrounding environment into the design problem at hand; whereas regression implies downsizing the problem to a smaller part of it (Eberhard, 1970). Escalation and regression of the design problem are necessitated when new information or insights are revealed to the designer.

The Marcus/Maver representation of building design as summarized by Lawson (2006) demonstrates a simultaneously iterative and progressive process. According to this model, the consecutive steps of analysis, synthesis, appraisal and decision-making are iterated as the level of detail of the proposed solution escalates from outline proposals through scheme design to detail design: through the analysis phase, the design problem is refined and reorganized; one or more solutions are generated through the synthesis phase; suggestions are critically evaluated during the appraisal phase; and then the suggested solution is finalized (Fig. 1). Even though the Marcus/Maver model explains some fundamental features of the design process, it is based on two underlying assumptions that do not always hold in real-world design practices: that the iterative loops occur exactly as presented in the model; and that the level of detail of the proposed solution constantly increases over time (Lawson, 2006). Lindahl and Ryd (2007) notify that during the iterative process of developing the final design solution, many trade-offs among goals and objectives could be made which are motivated by the results of evaluation of design alternatives as well as the unending interplay of the involved actors and their changing priorities and preferences.

![FIG. 1: Marcus/Maver representation of the building design process drawn after Lawson (2006)](image)

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Models for building design and validation of design alternatives as conceptualized in this section were apparently simplified abstractions of real-world processes. A more in-depth understanding of such processes requires more profound and inclusive theoretical frameworks.

4.1 Some theoretical stances on building design

4.1.1 A systems approach to design

Ekholm (2011) emphasizes that the building design process should be understood as a sociotechnical system. The three major areas of system development according to Ross and Schoman (1977) are:

- Context analysis: why the system should be designed and what its boundary conditions are;
- Functional specifications: what the system and its functions are; and
- Design constraints: how the system is constructed and implemented.

Building requirements could be associated with any of the above fields. According to this model, the point of departure for requirements definition would be the contextual concerns followed by a more detailed description of the functional specifications of the envisioned building and eventually formulating the more concrete constraints pertaining to construction and implementation. In the case of functional specifications of buildings, Markus (1967) suggests a four-function model. In his model, building as a system could be conceptualized in four different ways: as a system of physical components, an environmental system, an activity or behaviour system and an organizational system. A systems approach to building proclaims that a building is not a mere industrial product; rather is conceived, realized and deployed by human actors in an organizational context. Other theoretical approaches to building design process are often more illuminative about formation and transformation of information at a micro level, but could be inattentive to the social and organizational attributes of building design.

4.1.2 A cognitive approach to design

A considerable share of theories on building design has its roots in cognitive science (e.g. theories developed by Goldschmidt, 1991, Schön and Wiggins, 1992, Stenning and Oberlander, 1995, Suwa et al., 1998). The rationale is that design alternatives are to a great extent shaped through humans’ intellectual feats (Gero and McNeill, 1998). In a like manner, Lawson (2006) asserts that design “involves a sophisticated mental process capable of manipulating many kinds of information, blending them into a coherent set of ideas and finally generating some realisation of those ideas” (Lawson, 2006, p. 14). Cognitive theories on design methodology try to unravel the building design process and develop concepts and constructs that help comprehending, analysing and eventually cultivating building design as an influential sequence in the AECO industry.

4.1.3 Schema Theory

Heuristic design methods (Lawson, 2006) involving unverifiable routines result in accumulation of design knowledge in tacit forms. Conceptualizing conjectural units of information is a common theoretical approach for promoting the shift from heuristic design methods to more rational and formal ways of designing buildings. A prominent example of theoretical approaches as such is the ‘Schema Theory’ which was developed by Rumelhart and Ortony (1976) based on the principles of the ‘Semantic Network Theory’ introduced a decade earlier by Collins and Quillian (1969). Schema Theory suggests conceiving small inter-linked bundles of information called ‘schemata’ which are appropriate to humans’ cognitive abilities. The concept of schema has also been used by experimental psychologists such as Bartlett and Bartlett (1995) as a means for presenting an internalized mental image of the external world: an articulated organization of past experiences with the aim of orchestrating future events.

Chan (1990) suggested using schemata as an information management structure for buildings. According to him, design solutions are produced by activating design constraints and their associated rules in memory. Thereby, he introduced a set of guidelines termed as ‘perceptual tests’ for evaluating design alternatives against project goals. Chan (1990) was in fact the very first theoretician who used the Schema Theory for developing an integrated model for building requirements management, building design and validation of design alternatives (see Fig. 2). According to him, design constraints could be considered as the most important schemata in the design phase. Carrara et al. (1994) extended the Schema Theory to explain how to simultaneously capture descriptive and operational building design information through schemata. Objectification of building elements, their properties

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and – more recently – building requirements in semantic building models through BIM environments follows the same principles for building information management as conceptualized through the Schema Theory: devising small perceptible units of information called ‘objects’ for representing the real world. The notion of ‘object’ in this sense will be elaborated in more details in section 5.

Fig. 2: The integrated model for building requirements management, building design and validation of design alternatives based on the Schema Theory; drawn after Chan (1990)

4.1.4 Pattern Language

Another influential theory in the field of building design is Christopher Alexander’s ‘Pattern Language’. By and large, the Pattern Language theory promotes use of rational and explicit rules for building design (Galle and Kovács, 1992a). The theory suggests a set of structures for compiling architectural design knowledge in a modular and yet customizable and reusable form (Alexander et al., 1977). The Pattern Language theory regards building design alternatives as responses to specific structures or ‘patterns’ of given problems (Chermayeff and Alexander, 1963). Lawson (2006) refers to Alexander’s suggestion for developing graphical representations of the structures of non-visual problems as a rational alternative for architects’ drawing boards. Rational approaches as such were intended as a means for demystifying the design process, facilitating evaluation and validation of design alternatives and thereby maintaining collective control over designers’ activities (Jones, 1992).

Pattern Language inspired a vast number of other theoreticians in the field of design methodology and was subjected to both appraisal and criticism (Dovey, 1990, Galle and Kovács, 1992b, Schoen, 1988): Galle & Kovács (1992a), for instance, envisioned design systems that were capable of automatically identifying whether an evolving design solution satisfied some specific ‘pattern’ or not. Broadbent (1973), however, described Pattern Language as a mechanistic view of design. Some potential drawbacks of Pattern Language according to Lawson (2006) are:

- Some requirements are not decisive in forming the final solution.
- Due to correlated or missing values, no distinctive or exhaustive list of requirements could be set in the beginning.
- There are not always clear and explicit methods or metrics available for evaluation and validation of requirements.

Yet, the Pattern Language theory established a new paradigm in building design and could be considered as a significant step towards formalized requirements management. However, such deficiencies and inadequacies as mentioned above compelled development of further theoretical frameworks.
4.1.5 The theory of axiomatic design

The theory of axiomatic design is a systems design methodology developed by Suh (2001). It is mainly grounded on two axioms: the independence axiom prescribing independent functional requirements and the information axiom ruling that the information content of design should be minimized. The independence axiom is realized through a diagonal or triangular matrix of requirements. The ambition is to minimize the number of off-diagonal elements in design matrices of design alternatives (Jansson et al., 2013). There is one other central concept in the theory of axiomatic design: the concept of zigzagging implies moving back and forth between functional requirements and design parameters through the hierarchical decomposition of the two categories. According to this view, the level of detail of design solutions increases incrementally as functional requirements are iteratively transformed to design parameters and implemented into the final integrated solution over the entire course of the briefing and design phases (Suh, 2001). Jansson et al. (2013) expanded the vision offered by the theory of axiomatic design so as to also cover the earlier and later stages of the supply chain of buildings. They introduce four consecutive domains of ‘customer’, ‘functional’, ‘physical’ and ‘process’ together with their associated requirement types respectively ‘customer attributes’, ‘functional requirements’, ‘design parameters’ and ‘production variables’. Bidirectional transformation of design information across these domains, according to the authors, is enabled through architectural, engineering and production views as well as formal constraints (Jansson et al., 2013). As a means for minimizing unnecessary iterations through the design process, the concept of concurrent engineering (Prasad, 1996) has been deployed as the basis for developing a broad range of recent design methodologies. A prominent example is Virtual Design and Construction (VDC) as conceptualized by Kunz and Fischer (2005) which deals mainly with the construction phase.

There is an abundance of theories that underpin a formalized requirements management practice. However, a fundamental challenge is that the terminologies and taxonomic structures that are used in the literature on requirements management in the AECO industry are not consistent.

5. TERMINOLOGICAL VARIATIONS IN THE FIELD OF REQUIREMENTS MANAGEMENT

Terms common to the literature on requirements management namely ‘objective’, ‘goal’, ‘constraint’, ‘criteria’, ‘variable’, ‘parameter’ and ‘attribute’ connote requirements at different levels of abstraction and maturity. These terms have though not always been used consistently which could deter a holistic conceptualization of the domain of requirements management in the AECO industry. Below, you will find a summary of taxonomic variations in the field of requirements management through literature:

The term ‘objective’ is quite often used for requirements on building at the highest granularity and the most abstract level. Carrara et al. (1994, p. 163) define ‘objectives’ as “desirable performances of a sought solution”. The definition of ‘objective’ as such directly addresses the performance rather than the specifications of the final product i.e. the building. Whereas terms such as ‘goal’ and ‘constraint’ are often used to explain the more detailed requirements on the final product in more concrete terms. Kalay (2004) defines ‘goals’ as subsets of interconnected constraints that designate specific performances in a formalized way. This view clarifies how each of the concrete and tangible descriptions of performances that constitute an overall design solution are realized through a corresponding set of constraints. Each set of constraints as such is aggregated into a distinct goal upon the briefing phase (Fig. 3).
The term ‘constraints’, in turn, is defined as the “predicates that evaluate to true or false” (Eastman and Siabiris, 1995, p. 290). Constraints are used as restrictions that eliminate unacceptable solutions or as “bounds on acceptable solutions” (Kals and van Houten, 2013, p. 2). In this sense, constraints are different from other concepts that define requirements mostly in affirmative ways. Lottaz et al. (2000) suggest defining each requirement directly through its constituent constraints (Fig. 4). According to their proposed model, constraints are defined as “mathematical equations on continuous variables for specifying requirements” (Lottaz et al., 2000, p. 2). At a more detailed granularity, Lottaz et al. (2000) introduce ‘variables’ as mathematical constructs that enable defining each constraint in a formal way.

A common view is that requirements can be demonstrated as a set of constraints to be satisfied by proposed design alternatives (Chan, 1990, Eastman, 1994, Galle and Kovács, 1992b, Varejão et al., 2000). Chan (1990) designates different components of a design constraint schema as an ‘identifier’ (the name tag for the constraint), a ‘variable’ (which is attributed to the schema), a set of ‘rules’ (on how the constraint should be satisfied), and a ‘value’ for the variable (which is bound to a specific design unit) (see Fig. 5). According to Fiksel and Dunkle (1992), the rules within a constraint are the conditions that should be met by the final product through the requirements validation process and could be of textual (descriptions as text), pictorial (described with forms and diagrams), numerical (described as an acceptable range/set of values for specific variables) and logical types (described as an acceptable range/set of values for specific variables).

Constraints as such and their constituent rules are defined at building entities’ level. For the sake of comprehensibility for human users, building entities are represented by ‘objects’ in contemporary building information management systems. The notion of ‘object’, which is now fairly established through BIM applications and databases, is in fact a present-day equivalent to the earlier concept of ‘schema’ as conceptualized by the Schema Theory (Rumelhart and Ortony, 1976). Based on the ontological clarifications provided by Bunge (1977), Ekholm (2003) defines the concept of ‘object’ as concrete or abstract entities for representing ideas, feelings or activities. Objects need to be defined together with their associated properties and are linked to other objects throughout their encompassing system via a number of relations. It is also possible to conceptualize constraints themselves as objects of the requirement type. Such an approach was implemented by...
Jansson et al. (2010b) within a lifecycle-support building information management system using the Product Life Cycle Support (PLCS) standard (ISO, 2005).

Such terms as ‘variable’, ‘parameter’ and ‘attribute’ are deployed at a more detailed level of granularity. A prominent example is the terminology used by Jansson et al. (2013) in their elaborated model of requirements formation and evolution based on the theory of axiomatic design developed by Suh (2001). Through their procedural view, customer needs are determined as ‘attributes’; ‘requirements’ denote functional traits; ‘parameters’ are used for describing the designed solution; and ‘variables’ are associated with production of the finalized design solution. ‘Constraints’, on the other side, are considered as conditions that facilitate formalizing and transforming production variables through design parameters and functional requirements, backwards to customer attributes (see Fig. 6).

**FIG. 6: The procedural model of building requirements according to Jansson et al. (2013) based on the theory of axiomatic design by Suh (2001)**

The term ‘criterion’ is sometimes used as a synonym for requirement. According to Portillo and Dohr (1994), constraints are more restrictive and explicit; whereas criteria are more flexible and evaluative. In this view, requirements are used for defining the design solution at earlier stages; whereas criteria are applied a bit later for examining those solutions.

Table 2 demonstrates a brief glossary of the major terms in the domain of formal requirements management. The table embraces all terminological variations disclosed in this section. Each term – which is assumed to be the identifier for a certain concept – is coloured in a distinct way for highlighting how differently it has been used by different scholars.

6. TAXONOMIC VARIATIONS IN THE FIELD OF REQUIREMENTS MANAGEMENT

The epistemological ambiguities in the requirements management domain are not limited to inconsistent terminologies. Categorization breakdowns of the central concepts in the field by different scholars are also broadly divergent. A common criterion for classifying building requirements is how strict or flexible they are. Varejão et al. (2000) also Lawson (2006) designate two major types of requirements as hard (mandatory) and soft requirements. According to Varejão et al. (2000), examples of hard requirements are legislations, codes and standards; while soft requirements are project-specific ones that could be reformulated or mitigated. Hard requirements are often fairly detailed and focused on some specific aspect of design; whereas soft requirements could be of a more general nature (Lawson, 2006).

Concepts connoting requirements at lower granularity levels i.e. constraints and criteria are per se classified into different categories. A common measure for categorising constraints is whether they are originated from within the design problem or imposed by the surrounding environment. The former are, according to Lawson (2006) and also Kalay (2004), called internal constraints; while the latter are termed as external constraints. Internal constraints address the interrelations among building parts and elements such as room adjacency relationships. They constitute the main part of brief documents and are often presented as bubbles or flowcharts. External constraints, on the other hand, are used when one side of the relationship is outside the object to be designed e.g. constraints on production processes and site conditions. Internal constraints are generally more flexible than external constraints (Lawson, 2006). Kalay (2004) mentions gravity, wind resistance and building codes as examples of external constraints, and budget and number of rooms as examples of internal constraints. Candy and Edmonds (1997) refer to internal and external constraints respectively as performance and contextual constraints.
### TABLE 2: Terminological variations in the domain of formal requirements management

<table>
<thead>
<tr>
<th>Term</th>
<th>Relation (definition)</th>
<th>Term</th>
<th>Relation (definition)</th>
<th>Term</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Attribute</td>
<td>is defined as</td>
<td>Needs</td>
<td>of customers.</td>
<td>Jansson et al. (2013)</td>
<td></td>
</tr>
<tr>
<td>Constraint</td>
<td>is defined as</td>
<td>Predicate</td>
<td>that take the values of true or false.</td>
<td>Eastman and Saabirs (1995)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>is defined as</td>
<td>Design solutions</td>
<td></td>
<td>Kals and van Houten (2013)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>is defined as</td>
<td>Variables</td>
<td>for specifying</td>
<td>Lottaz et al. (2000)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>is made up of</td>
<td>Variables</td>
<td>and</td>
<td>Chan (1990)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>is defined as</td>
<td>Condition</td>
<td>for transition from production</td>
<td>Jansson et al. (2013)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>goal</td>
<td>Constraints</td>
<td>that specify</td>
<td>Kalay (2004)</td>
<td></td>
</tr>
<tr>
<td>Object</td>
<td>is defined as concrete or abstract entities</td>
<td>Performance</td>
<td>of a Design solution</td>
<td>Carrara et al. (1994)</td>
<td></td>
</tr>
<tr>
<td>Objective</td>
<td>is defined as a desirable</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Parameters</td>
<td>describe</td>
<td>Design solutions</td>
<td></td>
<td>Jansson et al. (2013)</td>
<td></td>
</tr>
<tr>
<td>Requirement</td>
<td>is made up of Constraints</td>
<td>to be satisfied by Design solutions</td>
<td>Chan (1990), Eastman (1994), Galle and Kovács (1992b), Varejão et al. (2000)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>is defined as a</td>
<td>Functional trait</td>
<td></td>
<td>Jansson et al. (2013)</td>
<td></td>
</tr>
<tr>
<td>Rule</td>
<td>is defined as</td>
<td>Condition</td>
<td>to be satisfied by Design solutions</td>
<td>Fiksel and Dunkle (1992)</td>
<td></td>
</tr>
<tr>
<td>Variable</td>
<td>is used for</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Constraints could also be categorized based on their more intrinsic features: Lawson (2006) suggests a model of design constraints comprising the following types:

- formal constraints e.g. proportion, color and texture;
- symbolic constraints i.e. those conveying a message;
- radical constraints i.e. the very fundamental and influential constraints; and
- practical constraints e.g. those imposed by manufacturing, construction methods, maintenance and durability.

Varejão et al. (2000) suggest a more simple taxonomy for constraints comprising functional, formal and objective-based categories. They, however, use the more general term of ‘requirement’ instead of ‘constraint’. Another term that is occasionally used by scholars for suggesting alternative classifications of requirements is ‘criteria’. Portillo and Dohr (1994) enumerate five major categories of criteria used by designers as follows:

- symbolic criteria which address divine intentions of designers;
- compositional criteria which are related to forms and shapes;
- behavioral criteria originating from the users’ behaviors;
- preferential criteria reflecting the users’ preferences; and
- pragmatic criteria e.g. rules and costs.
For conceptualizing the object properties upon which constraints and criteria are defined and applied, Ekholm (2003) suggests a number alternative classification models: properties could be primary (those which are determined in objective ways indifferent of the observers) or secondary (those which are experienced and interpreted through the observers’ senses); properties could also be classified as intrinsic (defined exclusively in relation to the host object) or reciprocal (defined based on the host object’s relations with other objects). Through a different approach, properties could be considered as physical or cultural; where physical properties could be of functional, comparative and compositional types and cultural properties are divided in experimental, symbolic and administrative subcategories (Ekholm, 2003). Table 3 demonstrates a summary of the taxonomic variations for different concepts across the domain of formal requirements management.

### TABLE 3: Taxonomic variations in the domain of formal requirements management

<table>
<thead>
<tr>
<th>Term (concept)</th>
<th>Types</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constraint</td>
<td>internal and external</td>
<td>Lawson (2006); Kalay (2004)</td>
</tr>
<tr>
<td></td>
<td>performance and contextual</td>
<td>Candy and Edmonds (1997)</td>
</tr>
<tr>
<td></td>
<td>formal, symbolic, radical and practical</td>
<td>Lawson (2006)</td>
</tr>
<tr>
<td></td>
<td>functional, formal and objective-based</td>
<td>Varejão et al. (2000)</td>
</tr>
<tr>
<td>Criteria</td>
<td>symbolic, compositional, behavioural, preferential, pragmatic</td>
<td>Portillo and Dohr (1994)</td>
</tr>
<tr>
<td>Properties</td>
<td>primary and secondary</td>
<td>Ekholm (2003)</td>
</tr>
<tr>
<td></td>
<td>intrinsic and reciprocal</td>
<td></td>
</tr>
<tr>
<td></td>
<td>physical and cultural</td>
<td></td>
</tr>
<tr>
<td>Requirement</td>
<td>criteria and constraints</td>
<td>Portillo and Dohr (1994)</td>
</tr>
<tr>
<td></td>
<td>hard (mandatory) and soft</td>
<td>Varejão et al. (2000); Lawson (2006)</td>
</tr>
<tr>
<td>Rule</td>
<td>textual, pictorial, numerical and logical</td>
<td>Fiksel and Dunkle (1992)</td>
</tr>
</tbody>
</table>

### 7. TOWARDS A FORMALIZED DEFINITION OF REQUIREMENTS

#### 7.1 Building requirements management through mathematical expressions and formal methods

Despite all terminological and taxonomic ambiguities in the requirements management domain, the potential benefits of formal definition of requirements have been acknowledged by many scholars (see section 1). Arayici et al. (2006) suggest a fundamental shift from sequential thinking to structural thinking for facilitating formalization of requirements through the AECO industry. Lottaz et al. (2000) recommend using mathematical expressions for specifying constraints as a means for making information explicit and eventually avoiding conflict among stakeholders (Lottaz et al., 2000). Below, some examples of earlier attempts for defining building requirements as mathematical expressions are presented:

Varejão et al. (2000) define building requirements (R) as a set of individual requirements (r) which possess requirement qualifications (q) and requirement relationships (l):

\[ R = \{ < r_1, q_1, l_1 >, < r_2, q_2, l_2 >, ..., < r_n, q_n, l_n > \} \]  

(Varejão et al., 2000) [1]

Requirement qualifications within this equation can be of the three types of requirement source (sc; the actor who sets the requirements), requirement importance (im; hard or soft requirements), and requirement type (t; functional, formal or objective-based):

\[ q ::= < sc, im, t > \]  

(Varejão et al., 2000) [2]

Despite its clarity and focus in expressing the concept of building requirement and its attributes in formal terms, the formula presented by Varejão et al. (2000) does not recognize the dynamic nature of requirements formation and evolution and the fact that requirements are incrementally defined through an interplay among the envisioned product and the designed solution. Through his theory of axiomatic design, Suh (2001) illustrates this dynamic aspect of requirements definition using the concept of design matrices. The coupling between functional requirements (FR) and design parameters (DP) is defined mathematically as:

\[ \{ FR \} = [A]\{ DP \}; \]  

where A is the design matrix (Jansson et al., 2013) (see section 4.1.5).
Defining building requirements in such explicit forms as mathematical terms paves the way for developing comprehensive methods for formalized requirements management. Some examples of such methods according to Kamara et al. (2002) are Quality Function Deployment (QFD), Client Requirements Processing Modelling (CRPM), Total Quality Management (TQM) and Failure Mode and Effects Analysis (FMEA). CRPM consists of identifying client’s requirements, sorting out requirements with regard to the priorities of the project, identifying design attributes and technical features of each requirement, specifying target or desired values, developing correlation matrices and determining absolute and relative weights of building requirements. The output for a requirements management procedure based on the CRPM method will be an ordered list of requirements where their corresponding attributes, units of measurement and desired values have been mentioned. CRPM has been presented using the IDEF-0 (Integration Definition Level 0) notation (Kamara et al., 2002). A major problem with such methods as CRPM is that implementing them could be time-consuming (Kamara et al., 2002). Integrating such methods into IT applications and object-based building models could be a viable fix to this problem.

7.2 Towards IT-based formalized requirements management

Augenbroe (1992) asserted that conventional design processes are inverse, interrogative and incremental. He contended that the IT-based building performance evaluation technologies of the time did not fulfil the demands of the design processes as such. Carrara et al (1994) suggested developing computational models that had the capacity to capture great numbers of prototypical design objectives and solutions to integrate the three main stages of a conventional design process i.e. definition of objectives, developing alternative design solutions, and evaluating alternatives against objectives. Gero and Mc Neill (1998) introduced a coding scheme for capturing information scattered around design protocols and channelling that information to validation procedures. In their proposed scheme, the design process is composed of three episodes: proposing solution, analysing solution and explicit strategies. Lottaz et al. (2000) developed a web-based application called SpaceSolver for expressing design constraints and their interdependencies in a formal way. Their model was implemented through two construction projects. Tarandi (2002) suggested a new type of space object that supported the iterative process of definition of requirements through versioning. Examples of requirements to be attached to space objects in his proposed initiative were spatial proximity and minimum required area for different rooms and spaces. As part of the CIFE’s (Center for Integrated Facility Engineering) VDC framework, Kiviniemi (2005) proposed a requirements model specification consisting of 300 requirements in 14 main categories and 35 subcategories. The model was based on Industry Foundation Classes (IFC) specifications and aimed to link formally expressed requirements to object-based design-intent models.

Another parallel effort for formalizing requirements documentation and validation using object-based models is the nD-modelling initiative developed at the University of Salford: Tse et al. (2005) conducted a pilot research aiming to integrate time, cost, buildability, accessibility, sustainability, maintainability, acoustics, lighting and thermal requirements with an object-based 3D model. Fu et al. (2007) developed a space centered computer-aided design (CAD) tool for requirements management in briefing and conceptual design phases for healthcare buildings. The tool was embedded in Autodesk AutoCAD. The focus was using visual tools for documenting and communicating design guidance. Assuming costs of the project as the central criteria, Lee et al. (2008) developed an information model and its associated digital application for cost-based decision making for the interior design of large-scale apartments. Tarandi (2011) conceptualized a model server based on IFC (ISO, 2013) and PLCS (ISO, 2005) standards called BIM Collaboration Hub for supporting continual documentation, updating and communication of building information through the entire lifecycle of buildings. The principles of this model had been previously implemented for classification and transformation of performance requirements (Jansson et al., 2010a). Christiansson et al. (2011) presented a method for actively involving end-users in expressing their expected requirements on the building and then consolidating and integrating those needs in the form of a design alternative with the aid of a collaborative virtual reality environment. Jansson et al. (2013) proposed an IT-based framework for requirements management of energy performance of design alternatives. Their framework was based on the theory of axiomatic design (Suh, 2001) as previously clarified in section 4.1.5.
8. FURTHER REMARKS

A formalized approach to requirements management could also have its downsides: activities that would occur in the designed building could be difficult to define accurately (Eastman and Siabiris, 1995) which impedes accurate definition of the requirements imposed by those activities. Moreover, high degrees of formalization may hamper flexibility (Christianssson et al., 2009). The level of maturity of building requirements should therefore be designated with regard to the specific attributes of each project such as social and organizational factors. As an example of the organizational aspects, the level of maturity of requirements could be closely linked to the level of maturity of the client’s business operations (Barrett and Stanley, 1999, Tzortzopoulos et al., 2006). Social aspects are not of lesser importance: consecutive communication, comprehension and realization of the requirements occur through constant interaction and collaboration among different actors. Success of such interactions could, in turn, be a subjective matter (Siva and London, 2012). Conflict and tension over more control is a constant element of planning and design activities (Lawson, 2006). Such social and organizational dynamics as authority distribution, conflict negotiation and trade-offs between design criteria and truth maintenance (Augenbroe, 1992) will inevitably influence the process of formulation, documentation, communication, validation and reformulation of building requirements. As specified earlier in section 1, however, the organizational and social aspects of building requirements management were not the focus of this article and were just briefly touched upon in section 4.1.1.

9. CONCLUSION

For avoiding wasteful expenditures later in the process, requirements pertaining to different lifecycle stages should be fully or partially addressed already in the briefing and design phase. A multitude of actors often with conflicting needs and objectives are engaged in requirements definition. The final definitions of requirements are often scattered around a wide variety of documents and resources in different formats. Capturing requirements is an iterative and incremental process which is closely intertwined with the design formation and validation process – which is itself an iterative and fuzzy process.

There is an abundance of earlier theories in design methodologies that could be beneficial for conceptualizing IT-based formalized requirements management. A systems approach to design provides the capacity for covering all different aspects of the design process, but may not be as useful when implementing in more detailed contexts. For the latter purpose, such cognitive theories as Schema Theory (Chan, 1990) and Pattern Language (Alexander et al., 1977) provide more relevant insights in the context of formalized requirements management. The theory of axiomatic design (Suh, 2001), however, better covers the procedural aspect of defining and refining building requirements. At the implementation level, concrete methodologies such as concurrent engineering (Haymaker and Fischer, 2008, Prasad, 1996) have been developed more recently to improve requirements formulation and implementation in real-world construction projects.

The discourse of formalized requirements management relies on a broad range of notions such as ‘objective’, ‘goal’, ‘constraint’, ‘criteria’, ‘variable’, ‘parameter’ and ‘attribute’ which are used in different ways by different scholars. The types of requirements, criteria, constraints and object properties as enumerated by different scholars also vary significantly. A prerequisite for developing theoretical frameworks that underpin leveraging IT for formalized requirements management is stipulating standardized terminology and taxonomies for this domain.

In recent decades, a significant number of initiatives for IT-based formalized requirements management have been introduced. Almost all such initiatives have their roots in mathematical expressions of building requirements. Nevertheless, not all efforts as such are grounded on established theoretical frameworks or, if so, unequivocally clarify how they correspond to their underlying theoretical grounds. This article could help strengthening the theoretical rigor of future conceptual models and implementation initiatives for IT-based formalized requirements management through presenting a number of potentially beneficial theories and their associated concepts in a comprehensive and concise fashion.

ITcon Vol. 21 (2016), Parsanezhad et al., pg. 286
10. REFERENCES


11. **APPENDIX A: ABBREVIATIONS**

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>AECO</td>
<td>architecture/engineering/construction/operation</td>
</tr>
<tr>
<td>BIM</td>
<td>Building Information Modelling</td>
</tr>
<tr>
<td>CAD</td>
<td>computer-aided design</td>
</tr>
<tr>
<td>CRPM</td>
<td>Client Requirements Processing Modelling</td>
</tr>
<tr>
<td>FMEA</td>
<td>Failure Mode and Effects Analysis</td>
</tr>
<tr>
<td>IDEF-0</td>
<td>Integration Definition Level 0</td>
</tr>
<tr>
<td>IFC</td>
<td>Industry Foundation Classes</td>
</tr>
<tr>
<td>IT</td>
<td>information technology</td>
</tr>
<tr>
<td>PLCS</td>
<td>Product Life Cycle Support</td>
</tr>
<tr>
<td>QFD</td>
<td>Quality Function Deployment</td>
</tr>
<tr>
<td>TQM</td>
<td>Total Quality Management</td>
</tr>
<tr>
<td>VDC</td>
<td>Virtual Design and Construction</td>
</tr>
</tbody>
</table>
eWork and eBusiness in Architecture, Engineering and Construction

Editors: Symeon E. Christodoulou & Raimar Scherer
Implications of a BIM-based facility management and operation practice for design-intent models

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ABSTRACT: The aim of this paper is to investigate how beneficial contemporary design-intent BIM deliverables could be to FM&O activities and what should be changed with regard to their structure and content for further development of FM&O-intent BIM hand-over. Deliverables of the detailed design phase of a middle-sized educational building were evaluated against requirements derived from a diverse set of resources and directives. The most crucial qualities for the detailed design BIM hand-over documents to be used in FM&O are general concerns about the overall structure of the models as well as classification, attributes and relations of objects. Flexibility and extensibility of the models is also decisive for suitability of the models for FM&O. A number of deficiencies and insufficiencies with the structure and content of the BIM deliverables of the case project have been disclosed. Findings could provide valuable insights for improving the quality of future BIM hand-over documents.

1 INTRODUCTION

1.1 Background
Facility Management and Operation (FM&O) constitutes around 5-10 percent of the gross domestic product (GDP) of advanced industrialized countries. The FM&O profession comprises a wide range of activities at strategic, tactical and operational levels from facilities planning, capital budgeting and space optimization to performance evaluation and maintenance. A robust information logistics system for FM&O activities would enable firms to perform activities as such in a more coordinated and resource-effective manner and, thereby, increase their productivity and the quality of their services (Parsanezhad 2014). Devising and implementing such systems has implications for information modelling and management during the earlier life cycle phases of the supply chain of buildings i.e. the planning and design phases.

1.2 Problem formulation
Interoperable building information management initiatives based on national and international standards have been widely adopted by design firms in recent decades. Yet, design companies tend to prioritize their short-term needs, economic constraints and contractual considerations over the implications of a total-life approach to buildings. They are often pre-occupied by such concerns and constraints when developing building models and their associated databases, also when stipulating their inter- and intra-disciplinary information transfer protocols and formats.

Over the past decades, a number of standards such as Industry Foundation Classes (IFC) (Laakso & Kiviniemi 2012), Construction Operations Building information exchange (COBie)(East & Carrasquillo-Mangual 2012) and fi2xml (fi2 2012) have been developed by global and regional actors for supporting and promoting seamless accumulation, evolution and flow of information across the consecutive temporal stages of the building’s lifecycle and eventual use of information by FM&O actors. Any further attempt for reconstructing ill-structured models or including missing information later in the process when contracts with the design firms are terminated would be extremely costly, onerous and ineffective. Yet, no research has been done for evaluating availability and suitability of the required FM&O information within design-intent building models. Currently, the required FM&O information of existing facilities is spread among a mix of digital and paper documents in diverse set of forms and formats (Parsanezhad 2014). Ideally, an integrated collection of BIM deliverables including all required information in a neutral format should be handed over to the FM&O team.
1.3 Aim of the paper

The aim of this paper is to investigate how beneficial contemporary design-intent BIM deliverables could be to FM&O activities and what should be improved with regard to their structure and content so that they could form the basis for prospective FM&O-intent BIM deliverables.

2 THEORETICAL DOMAINS AND CONCEPTS

The concepts addressed and used in this paper have their origins in the two domains of FM&O and BIM. The ontological approach and delimitation of the scope of the paper builds upon two major frameworks in the aforementioned domains, respectively the built environment management model (BEM2) developed by Ebinger & Madritsch (2012) and the BIM Framework developed by Succar (2009). A framework, in this context, could be defined as "the gestalt, the structure, the anatomy or the morphology of a field of knowledge or the links between seemingly disparate fields or sub-disciplines" (Reisman 1994 p.92). The FM&O activities as regarded in this paper span all the four key performance areas (KPIs) of BEM2 at all the three strategic, tactical and operational levels. Among the three fields conceptualized within BIM Framework, this study mainly lies within the technology field. The depth of inquiry, here, corresponds to the microscopic lens as stipulated within BIM Framework. The BIM stage implemented in the case project discussed here is the approximate equivalent of stage 2 according to BIM framework i.e. model-based collaboration. Some actors, however, merely fulfilled the requirements of BIM stages 0 (mere 2D or 3D CAD) or 1 (mere object-based modelling).

Moreover, the two following concept definitions borrowed from COBie specifications are crucial to interpreting parts of the findings:

- Zones “contain groups of spaces that, when connected, provide specific capabilities to the owner” (East & Carrasquillo-Manguel 2012 p.21);
- Systems are “groups of components that, when connected, provide specific required services” (East & Carrasquillo-Manguel 2012 p.22);

Definitions of other terms and concepts used for describing the findings could be found in IFC2x3 specifications (buildingSMART 2016).

3 METHOD AND RESEARCH DESIGN

Initially, the requirements on building models imposed by needs of the FM&O sector were derived from a variety of data sources i.e. national and international standard specification documents and classification initiatives, earlier research, directives of the client organization for design deliverables as well as BIM guideline documents of the studied project. Next, BIM deliverables of the detailed design phase of the case project (a middle-sized educational building) were comprehensively monitored and evaluated against the requirements mentioned above.

Out of the 12 original BIM deliverables of the case project, building models for major disciplines were selected and analyzed using Solibri Model Checker (Solibri 2016), text-editing software, an application for diagramatic visualization of IFC models called Graphical Instance (Eurostep 2016) and an IFC-explorer providing a simple yet interactive two-dimensional viewer called Floorshow. A Swedish initiative for classification of properties of building components called BIP (BIP 2016) was consulted for this purpose. Figures 1 and 2 demonstrate two snapshots of the procedure mentioned above.

Figure 1. A snapshot demonstrating visual analysis of the data structure of an instance of a ‘wall’ object using Graphical Instance
As a complementary step, the possibility of producing COBie deliverables in a low-level format (Excel spreadsheets) for facilitating identification of FM&O information through BIM deliverables was investigated. Solibri Model Checker v9.5 and the COBie extension for Autodesk Revit (Autodesk 2016) were considered for this purpose. Though not all required information was captured in the COBie spreadsheets produced by the two applications.

The findings of analysis of models using the methods and applications mentioned above were complemented with the data collected from the actors participating in the project. The main author was present during BIM coordination meetings of the project and thereby collected the required background data through personal notes and informal talks with the BIM coordinator of the project as well as BIM representatives of the participating firms. The findings were then summarized and presented in tabular form. The resulting table was validated with the BIM-strategist of the project through an in-depth interview session. Figure 3 demonstrates the temporal phase at which the case has been studied as well as the major sources of data used for retrieving information requirements.
4 CASE PROJECT DESCRIPTION

Undervisningshuset (UH) will serve as an educational facility located in the main campus area of the Royal Institute of Technology (KTH) in Stockholm. In the brief document for the project, UH has been envisioned as a flexible and innovative learning environment for students. The building would comprise 7 floors with a total gross floor area (GFA) of 937 m². The preliminary studies for the project were initiated in 2013 and the building is expected to be completed by late 2016. At the time of writing this paper, the building is under construction.

4.1 Data sources and data description

The findings of this paper are based on a diverse set of data sources. Of all sources checked initially for identifying FM&O-specific information needs and requirements (see section 3), three sources included the requirements applicable to the detailed design BIM-deliverables: COBie specifications (East & Carrasquillo-Mangual 2012), IFC2×3 specifications (buildingSMART 2016) and the BIM manual of the project (Jongeling et al. 2014). Another source of information was a cloud-based BIM repository where project documents including disciplinary models were shared and successively updated. Table 1 demonstrates a list of the original BIM deliverables of the detailed design phase together with the BIM-authoring tools originally used by the consultant groups for creating those models. Figure 4 shows an overlaid visualization of all disciplinary models.

Table 1. Original BIM deliverables of the detailed design phase

<table>
<thead>
<tr>
<th>Discipline</th>
<th>Denomination</th>
<th>Original modeling software</th>
<th>Version</th>
</tr>
</thead>
<tbody>
<tr>
<td>Architecture</td>
<td>A 1</td>
<td>Revit</td>
<td>2013</td>
</tr>
<tr>
<td>Structural engineering</td>
<td>K 1</td>
<td>Tekla</td>
<td>19</td>
</tr>
<tr>
<td>MEP engineering</td>
<td>W 2</td>
<td>AutoCAD/MagiCAD</td>
<td>2012/2013.4</td>
</tr>
<tr>
<td>Ventilation</td>
<td>V 1</td>
<td>AutoCAD/MagiCAD</td>
<td>2012/2013.4</td>
</tr>
<tr>
<td>Electrical engineering</td>
<td>E 3</td>
<td>AutoCAD/MagiCAD</td>
<td>2012/2013.4</td>
</tr>
<tr>
<td>Fire suppression</td>
<td>S 2</td>
<td>AutoCAD/MagiCAD</td>
<td>2012/2013.4</td>
</tr>
<tr>
<td>Interior design</td>
<td>P 1</td>
<td>not specified</td>
<td>not specified</td>
</tr>
<tr>
<td>Landscape architecture</td>
<td>L 1</td>
<td>AutoCAD</td>
<td>not specified</td>
</tr>
</tbody>
</table>

5 FINDINGS

5.1 Requirements on BIM deliverables with regard to the FM&O phase

Prerequisites for an effective use of building models in the FM&O phase could be formulated at two distinct levels: a) requirements on the models’ overall structure; and b) requirements on the contents of the models. The latter category could apply to objects, attributes or relations within models. The following section demonstrates the results of evaluation of the detailed design BIM-deliverables of UH against the requirements mentioned above from an FM&O perspective.

5.2 Results of evaluation of the structure and contents of the detailed design BIM deliverables of UH

Table 2 demonstrates a summarized account of the findings of this study. Since the studied deliverables are the outcomes of the detailed design phase, requirements pertaining to the ensuing phases i.e. the contents that should be added during procurement and construction were not considered in this evaluation. Below, a summarized explanation of the findings is provided.

Mismatch of the coordination systems used in different models could be partially explained by disparities among the technical approaches taken by different software manufacturers e.g. using local or global coordination systems.
Table 2. Results of evaluation of the structure and contents of the detailed design BIM deliverables of UH (Part 1)

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Source</th>
<th>Discipline(s)</th>
<th>Evaluation result</th>
</tr>
</thead>
<tbody>
<tr>
<td>a) The overall structure of the model</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Models should use SWEREF 99 18 00 as coordination system and RH 2010 as the height system with a local origin.</td>
<td>B</td>
<td>A,K,SP,V,W</td>
<td>F</td>
</tr>
<tr>
<td>Floors should be unique and consistent across disciplinary models.</td>
<td>B</td>
<td>A,K,SP,V,W</td>
<td>F</td>
</tr>
<tr>
<td>Models should not include duplicate geometries.</td>
<td>C</td>
<td>All</td>
<td>F</td>
</tr>
<tr>
<td>Names through deliverables should be unique and consistent.</td>
<td>C</td>
<td>All</td>
<td>NA</td>
</tr>
<tr>
<td>GUIDs should be unique and consistent.</td>
<td>I</td>
<td>A,K,E,SP</td>
<td>F</td>
</tr>
<tr>
<td>V,W</td>
<td>E</td>
<td>PF</td>
<td></td>
</tr>
<tr>
<td>Each 3D model should only contain one building.</td>
<td>B</td>
<td>All</td>
<td>F</td>
</tr>
<tr>
<td>Divisions of 3D objects should be in accordance with the divisions of the building with regard to levels and spaces i.e. 3D objects should not extend across several floors or several spaces unless in specific cases such as prefabricated components.</td>
<td>B</td>
<td>A,W,K,SP</td>
<td>F</td>
</tr>
<tr>
<td>3D objects should be modelled as closely as possible to how the building is thought to be built (The aim is to develop a model that is closest to a production model).</td>
<td>B</td>
<td>All</td>
<td>NA</td>
</tr>
<tr>
<td>b-1) Objects</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>All architectural components that are decisive to the building’s design, form and function should be modelled.</td>
<td>B, C</td>
<td>A</td>
<td>F</td>
</tr>
<tr>
<td>All structural components should be modeled.</td>
<td>B</td>
<td>K</td>
<td>F</td>
</tr>
<tr>
<td>HVAC assets such as chillers, boilers, air handling units, fan coil units, filters, pumps, fans, motors, compressors, Variable Air Volume (VAV) boxes, valves, traps and strainers should be modelled.</td>
<td>C</td>
<td>V,W</td>
<td>F</td>
</tr>
<tr>
<td>Plumbing system assets such as water treatment assemblies, valves and plumbing fixtures should be modelled.</td>
<td>C</td>
<td>W</td>
<td>F</td>
</tr>
<tr>
<td>Fire suppression system assets such as pumps, valves, sprinkler heads and fire extinguishers should be modelled.</td>
<td>C</td>
<td>SP</td>
<td>F</td>
</tr>
<tr>
<td>Electrical system assets such as light fixtures, outlets, switches, distribution panels, switchgear and generators should be modelled.</td>
<td>C</td>
<td>E</td>
<td>F</td>
</tr>
<tr>
<td>Electrical wires and cables with a diameter more than 40mm should be modelled.</td>
<td>B</td>
<td>E</td>
<td>F</td>
</tr>
<tr>
<td>Food service system assets such as sinks, water disposers, dish-washers, refrigerators, ice-makers, ranges, fryers and freezers should be modelled.</td>
<td>C</td>
<td>A</td>
<td>F</td>
</tr>
<tr>
<td>Site assets such as site water distribution system, site fire suppression system, water supply wells and site sanity sewer equipment should be modelled.</td>
<td>C</td>
<td>L</td>
<td>NF</td>
</tr>
<tr>
<td>Building components should be modelled with correct modelling tools.</td>
<td>B</td>
<td>K,E,SP,V,W</td>
<td>F</td>
</tr>
<tr>
<td>Spaces, systems and zones should be modelled.</td>
<td></td>
<td>A</td>
<td>PF</td>
</tr>
<tr>
<td>Production results such as panels should be modelled when it is required for 3D coordination.</td>
<td>B</td>
<td>All</td>
<td>F</td>
</tr>
<tr>
<td>Reserved spaces for maintenance, transportation of equipment and logistics should be modeled as space objects.</td>
<td>B</td>
<td>All</td>
<td>NF</td>
</tr>
<tr>
<td>b-2) Attributes</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Project and magnetic north directions should be included in models.</td>
<td>C</td>
<td>All</td>
<td>F</td>
</tr>
<tr>
<td>Facility geo-location (longitude, latitude, elevation, rotation) should be specified.</td>
<td>C</td>
<td>All</td>
<td>F</td>
</tr>
<tr>
<td>Regional, national and/or client-specific property sets should be included.</td>
<td>C</td>
<td>All</td>
<td>PF</td>
</tr>
<tr>
<td>Space, system and zone asset types and attributes should be included.</td>
<td>C</td>
<td>A</td>
<td>F</td>
</tr>
<tr>
<td>Room objects should have geometric information, room types and numbers according to project descriptions as well as classification codes according to the national BSAB96 classification system.</td>
<td>B</td>
<td>A</td>
<td>F</td>
</tr>
</tbody>
</table>
Table 2. Results of evaluation of the structure and contents of the detailed design BIM deliverables of UH (Part 2)

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Source</th>
<th>Discipline(s)</th>
<th>Evaluation result</th>
</tr>
</thead>
<tbody>
<tr>
<td>b-2) Attributes (cont.)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Classification (category) codes should be included.</td>
<td>C, B</td>
<td>A,K,V,E,SP</td>
<td>PF</td>
</tr>
<tr>
<td>All building components should have tag number-codes and descriptions.</td>
<td>B</td>
<td>All</td>
<td>F</td>
</tr>
<tr>
<td>Units of measurement should be included.</td>
<td>C</td>
<td>All</td>
<td>F</td>
</tr>
<tr>
<td>Doors and windows should be accompanied with their geometric information (dimensions), material, function (e.g. hinged door, folding door, sliding door or rotating door), fire class, security class and swing direction.</td>
<td>B</td>
<td>A</td>
<td>PF</td>
</tr>
<tr>
<td>b-3) Relations</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Relations such as spatial containment, zone association, systems association, spatial placement (e.g. under-floor, above-ceiling, in-wall, on-roof, in-space or on-site) and site spatial containment (e.g. parking lots, loading docks) should be specified.</td>
<td>C</td>
<td>All</td>
<td>PF</td>
</tr>
<tr>
<td>Relations of objects should be consistent.</td>
<td>I</td>
<td>A,K,V,E,SP</td>
<td>F</td>
</tr>
<tr>
<td></td>
<td></td>
<td>W</td>
<td>NF</td>
</tr>
</tbody>
</table>

Abbreviations:

B = BIM Manual - Undervisningshuset (Jongeling et al. 2014)
C = COBiE specifications (East & Carrasquillo-Mangual 2012)
I = IFC2x3 specifications (buildingSMART 2016)

A = Architecture
E = Electrical engineering
K = Structural engineering
L = Landscape architecture
SP = Fire safety systems
W = Water supply system
V = Ventilation systems

All models fulfill the requirement on unique and consistent floor definitions (as stipulated in Jongeling et al., 2014) except the electrical model that consisted of 20 floors. The multiple floor definitions for different categories of elements i.e. lighting fixtures, cables and under-floor cables could have been merged together. The only occasions where the requirement on unique GUIDs (as stipulated in buildingSMART, 2014) is not fulfilled are the MEP model with 279 duplicated GUIDs for the water supply system elements and 74 duplicated GUIDs through the ventilation model.

In architectural, structural and water supply system models, several occasions of elements associated with wrong floors were observed. Some exterior and interior walls in the architectural model extend across several floors (Fig. 5) which contradicts the requirement of correct spatial association of elements. The structural model includes an additional floor called ‘Floor 7’ which contains miscellaneous elements such as holes, frames of the skylights and stairs. Divisions of objects within the electrical engineering, ventilation systems and fire safety systems models are in accordance with the divisions of the building with regard to levels and spaces (as stipulated in Jongeling et al., 2014).

Figure 5. Interior walls of the first floor of the architectural model extend across upper floors.

Two requirements on the overall structure of models were deemed unnecessary and not checked: building elements are and will be primarily identified by their GUIDs for all future uses including FM&O. Object names could, on the other hand, be discipline-specific or colloquial and need not be
unique as required by COBie specifications (East and Carrasquillo-Mangual, 2012). Also, the requirement on models being as close as possible to production models as stated in the BIM manual of the project (Jongeling et al. 2014) was deemed irrelevant for the purpose of this study. In practice, the requirements for enabling future development of the design-intent models to construction-intent models and those of developing FM&O-intent models should be balanced against each other. A practical tool for regulating such a trade-off is providing extensive specifications of the levels of detail/development (LODs) for all major elements in the BIM manual of the project (Jongeling, 2016).

All models are fairly complete and include all major building elements (Figure 6 depicts an example) with the exception of the landscape architectural model. The landscape consultant worked exclusively with a two-dimensional application (AutoCAD). This was because the BIM software at the time did not include landscape object types. Technologies for creating semantic models of site and infrastructure components in formats that are compatible with BIM deliverables are still in their infancy (Jongeling, 2016).

Figure 6. Electrical system assets and wires and cables with a diameter more than 40mm have been modelled.

BIM operators are directly responsible for some of the violations from the modelling rules and requirements such as incorrect semantic definitions of some architectural components. The upper roof has, for example, been modelled with the ‘beam’ tool. Required spaces (IfcSpace) and systems (IfcSystem) have been modeled. No zone (IfcZone) has been modeled. Fire compartments, for example, are missing. This could be attributed to the relatively lower BIM competency of fire safety consultants. In the case of the studied project, fire safety system components specifications were handed over in two-dimensional drawings which could hamper interoperability when the contents of the deliverables need to be integrated and used for FM&O purposes. Reserved spaces for maintenance, transportation of equipment and logistics are other examples of the missing zone objects that would be required in the FM&O phase. The majority of components are modeled in a sufficiently high level of detail to represent production results.

Most of the requirements on object attributes have been fulfilled. In accordance with the requirements outlined in COBie specifications (East and Carrasquillo-Mangual, 2012), ‘room’ objects contain attributes representing volume, area, perimeter, room type and room number in compliance with the Swedish classification system, BSAB96.

All major building elements have tag number codes and descriptions. With the exception of the water system components, all objects have BSAB classification codes. The codes, however, appear as different attributes for different objects often depending on the modelling software that has been used. Dimensions of doors and windows are specified through attributes such as OverallHeight and OverallWidth. IfcMaterial holds material types. Function and swing direction have been captured by the enumeration, IfcDoorStyleOperationEnum with a range of selectable values e.g. SINGLE_SWING_RIGHT. Values for fire rating, security rating and sound rating are however missing. Attributes of IfcGeometricRepresentationContext show indications that the north direction could be retrieved from the content of the models. Attributes of IfcSite show indications that the facility geo-location could be retrieved from the content of the models. Units of measurement are often included within the value of quantitative attributes. Some occasions of project-specific property sets were observed in models e.g. KTHU in the structural model.

With the exception of the water supply system elements that have duplicated relations (IfcRelContainedInSpatialStructure), all other relations among objects are consistent. Spatial relations and zone association are not explicitly specified in models, but can be retrieved from names, attributes and attribute values of components.

Of totally 32 requirements considered here, 17 were fully met by the BIM deliverables of the studied case, 10 were partially met, 3 were not fulfilled at all and 2 were deemed non-relevant for this study.

6 CONCLUSIONS

Findings of this study demonstrate that the most important concerns about the detailed design BIM hand-over documents to be used in FM&O are general issues with the overall structure of the models (e.g. mismatch of coordination systems and incorrect spatial association of objects), semantic definition and classification of objects and their attributes (e.g.
duplicated names, inconsistent attribute names for different objects, missing values of attribute) and relations (e.g. duplicated relations).

Developed through an in-depth monitoring and examination of BIM deliverables of a case project, this study discloses major deficiencies and insufficiencies with the structure and content of BIM deliverables of the case project with regard to future use of models in FM&O. The findings could, thereby, provide valuable insights for improving the quality of future BIM hand-over documents.

7 FURTHER REMARKS

It should be noted that some of the requirements on BIM models were excluded from this study. Project-specific requirements corresponding to traditional CAD deliverables e.g. specifications of annotations, external references and drawing blocks were, for instance, not considered. Moreover, a substantial amount of the required FM&O information is submitted during the procurement and construction phases and could therefore not be expected to be included within the deliverables of the design phase. Flexibility and extensibility of the models is also a decisive criterion for accommodating the information that would be submitted during consecutive phases and eventually leveraged by FM&O agents. This quality could, however, not be evaluated by the methods used in this study.

Different types of requirements on the commissioned facility are yet another category of information to be archived together with other information and eventually transferred to FM&O agent. Requirements could be retrieved from the design guidelines of the client organization of the case project (Hallen 2011). Such information could be used within KPI 3 (project transaction management) for verification of the building’s performance (Ebinger & Madritsch 2012). In the case project studied here, requirements specifications e.g. space program, relationship chart, functional requirements of the building as a whole and individual spaces, accessibility requirements for services and maintenance as well as cost and rent estimations were registered in the cloud-based requirements management system, dRofus (dRofus 2016) and largely implemented during the planning, system design and detailed design phases. Contemporary formats for building information transfer do however not yet possess the capacity for capturing building requirements information. There are some industry standards (e.g. PLCS) that offer such capacities and could thus be also implemented in the AECO industry (Tarandi 2011).

8 REFERENCES


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fi2 2012. Handbok, fi2xml version 1.3 Del 1 Översikt, fi2 Förvaltningsinformation.

9 PERSONAL COMMUNICATION

Abstract
Purpose- To develop a conceptual framework consisting of a consolidated list of benefit and cost indicators for assessing the benefits of BIM-implementation in the FM sector at the operational level; also to make further contributions to the body of literature on FM through providing a summarized account of the central concepts.

Design/Methodology/Approach- Two conceptual models were derived based on the findings of an exhaustive and selective literature review. The models were validated, modified and evolved into a conceptual framework. An alternative case study design was then put forward for further implementation of the framework.

Findings- A framework including a set of benefit and cost indicators for assessing the benefits of BIM-implementation in the FM sector at the operational level has been developed. Based on the principle of the strategic value chain across FM key performance areas, the framework also captures the strategic and tactical benefits accrued.

Research limitations/implications- BIM-implementation is considered as a distinct process with explicit start and end points in time. In reality, it is a continuous change process consisting of numerous socio-technical dynamics that never completely cease.

Practical implications- Findings derived from implementing the suggested framework on real-world cases would assist FM firms with making decisions about future investments on BIM-implementation based on the knowledge elicited from early adopters.

Originality/value- Previous frameworks for assessing the benefits of BIM pertain merely to design and construction firms. Moreover, the majority of earlier benefits realization assessment studies aim to collect perceptual data that could be inaccurate and subjective.

Keywords Building Information Modelling; BIM; facility management; operation; FM; key performance indicators; KPI; maintenance; benefits realization; efficiency; effectiveness, conceptual framework.

Paper type Research paper
1. Introduction

Facility and Real Estate Management (FM/RE) activities account for around 5-10 percent of the gross domestic product (GDP) of advanced industrialized countries. Costs of executing facility management (FM) functions are the third largest costs for organizations after the costs of personnel and the costs of production asset (Brandt, 1994). The FM sector is sometimes considered as a constituent part of the construction industry. Then (1999) postulates that “the practice of FM is concerned with the delivery of the enabling workplace environment, the optimum functional space that supports the business processes and human resources” (Then, 1999, p. 469).

The construction industry suffers from inefficient practices, poor performance and low productivity which could be partly associated with expenditures induced by lack of interoperability across life cycle stages and disciplines (Fallon and Palmer, 2006; Gallaher et al., 2004). A more integrated and automated approach to information management using high-end information technologies has been repeatedly uttered as a potential solution for the above problem (e.g. by Tarandi, 2012; Eastman et al., 2011; Halfawy and Froese, 2007; Kiviniemi, 2005). Information technology (IT) investments are perceived to lead to cost savings, process efficiency, competitive advantage and improved information logistics (Lin and Pervan, 2003). Yet, the level of investment in IT in construction is lower than other industries (Andresen et al., 2000).

Building Information Modelling (BIM) is one of the most distinguished information management methodologies which is perceived to promote more collaboration and coordination among actors (Azhar, 2011; Gu and London, 2010; Howard and Björk, 2008; Owen et al., 2010; Penttilä, 2006). The notion of BIM initially introduced as ‘building product modelling’ (Eastman, 1999) or ‘building data modelling’ (Penttilä, 2006) could be briefly defined as “a modelling technology and associated set of processes to produce, communicate, and analyse building models” (Eastman et al., 2011, p. 16). The essential components of BIM are digital representations of building elements containing geometry, functional and behavioural attributes and parametric rules modelled and communicated through a non-redundant, coordinated and consistent environment (Eastman et al., 2011).

BIM is often mentioned as the most viable solution for efficient information management in the FM sector (e.g. by Becerik-Gerber et al., 2012; Jylhä and Suvanto, 2015; Love et al., 2014; Lucas et al., 2013) mainly through facilitating access to the required information in a timely manner (Irizarry et al., 2014). According to Eastman (2008), the FM fields where BIM-implementation could be beneficial are space management, emergency management, monitoring energy and maintenance. Becerik-Gerber et al. (2012) mention quality control and assurance, locating building components, visualization and marketing, planning, feasibility studies for non-capital construction and personnel training as other areas where BIM could be beneficial. Love et al. (2014) suggest labour utilization savings, utility cost reduction, fuel and material savings, improved inventory of installed components and spare parts and guaranteed regulations as examples of perceived benefits of BIM. Results of a survey involving 77 facility managers and owners in the U.S. revealed that 32% of the respondent
organizations were using BIM in operation and 40% of the non-users had planned to use BIM in the future (Becerik-Gerber et al., 2012).

Despite all indications of the benefits of BIM for the FM sector as mentioned above and ubiquity of technical initiatives to realize such benefits (e.g. Golabchi et al., 2016; Rui and Raja, 2014), there are not so many empirical evidences that support this proposition (Becerik-Gerber et al., 2012). There are, in fact, even very few empirical evidences on the benefits realized by IT investments in general (Ashurst et al., 2008); whilst FM actors need to be sufficiently convinced that BIM is beneficial to their business before they adopt it (Barlish and Sullivan, 2012). The concerns about the hazards of ‘silver bullet thinking’ and the risks for the ‘red queen syndrome’ phenomena in the context of BIM-implementation (as addressed by Lin and Pervan, 2003; Love et al., 2014; Peppard et al., 2007), should be examined through more real-world case analyses and empirical data from early adopters (Becerik-Gerber et al., 2012). This, in turn, demands establishment of FM-specific indicators for benefits realization assessment (Barlish and Sullivan, 2012).

Of the few BIM-implementation evaluation frameworks, the majority is based on perceptual and thus subjective data and none of them addresses the FM phase. The FM field, itself, is under-researched and its theoretical foundations need to be developed (Ventovuori et al., 2007). According to Love et al. (2014), there is no theory that guides FM firms through implementing BIM. Overcoming epistemological shortcomings as such is one of the major challenges to developing a robust benefits realization assessment framework for BIM-implementation in the FM sector.

2. **Aim and focus of the paper**

This paper mainly aims to develop a conceptual framework consisting of consolidated lists of benefit and cost indicators for evaluating BIM-implementation in the FM sector at the operational level. The secondary aim of this paper is to make further contributions to the body of literature in the field of FM through providing a summarized account of the central concepts in this field. These two aim statements address, respectively, the real-world problem and the research gap identified and clarified in Section 1.

The benefits addressed above in the aim statement could be accrued by any of the numerous actors in the FM sector, namely owners, facility managers and FM service providers. The focus of this paper rests on the effects of BIM-implementation on the performance metrics of FM activities. Findings may, therefore, appeal to any FM actor who performs those activities.

The findings also make a contribution to the existing body of literature in the field of FM. The target audience of this paper consists, therefore, of both scholars and practitioners in the FM sector.

3. **Methodology**

Through this study, two conceptual models for benefit and cost indicators were initially developed (presented in Section 5). The models were then validated against the requirements articulated by Ritter (2010), modified accordingly and composed into a
A conceptual framework for evaluating BIM-implementation in the FM sector (presented in Section 6). The outlines of the framework were stipulated through answering the seven questions posed by Cameron and Whetten (1983). As a complementary phase, an alternative case study design was then put forward (presented in Section 7). This could be used as the basis for future empirical research implementing the framework presented in this paper. Fig. 1 depicts the overall research process.

The conceptual models and the conceptual framework were developed through screening, analysing and synthesizing previous literature (as recommended by Dubin, 1969; Lave and March, 1993; Meredith, 1993). For this purpose, an exhaustive and selective literature review was performed following the framework introduced by vom Brocke et al. (2009). For increasing the efficiency of the literature review phase, only FM literature review papers were searched. This was done through using the keyword ‘review’ successively combined with five verbal variations of FM in the five largest web-based academic databases. In total, 9 papers were retrieved (demonstrated in Table I) and thoroughly studied. Findings were complemented through backward and supplementary search and then analysed and re-organized with regard to the aim of the paper. The central concepts in the fields of FM and benefits realization revealed through the literature review process have been presented in Section 4.

![Fig. 1. Research process](image)

Table I. The retrieved papers resulting from literature search

<table>
<thead>
<tr>
<th>Paper</th>
<th>Authors</th>
<th>Journal</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>A classification framework for facilities and real estate management</td>
<td>Ebinger and Madritsch (2012)</td>
</tr>
<tr>
<td>2</td>
<td>Information technology and systems justification A review for research and applications</td>
<td>Gunasekaran et al. (2006 European Journal of Operational Research)</td>
</tr>
<tr>
<td>3</td>
<td>Outsourcing in Facilities Management- A Literature Review</td>
<td>Kurdi (2011)</td>
</tr>
<tr>
<td>4</td>
<td>The role of maintenance and facility management in logistics a literature review</td>
<td>Mangano and De Marco (2014)</td>
</tr>
<tr>
<td>5</td>
<td>A critical review on innovation in facilities management service delivery</td>
<td>Noor and Pitt (2009)</td>
</tr>
<tr>
<td>8</td>
<td>A review and classification of academic</td>
<td>Ventovuori et al. (2007)</td>
</tr>
</tbody>
</table>
A conceptual framework embracing benefit and cost indicators of BIM in the FM sector

A conceptual model – as implied in this paper – is a simplified representation of a phenomenon. It facilitates understanding and derivation of insights (Lave and March, 1993; Ritter, 2010; Turban and Meredith, 1991). A conceptual framework could, in turn, help identifying, describing, classifying and mapping relevant variables needed for analysing a stereotyped situation (Meredith, 1993) – here a BIM-implementation project.

4. Theoretical grounds

4.1. Central concepts in facility management

Buildings are among the most common assets for corporations. The facility management practices are thus crucial to the success of organizations (Noor and Pitt, 2009). Therefore, central concepts in facility management are closely linked with the business goals and activities of the organizations acquiring and using facilities as assets. The trinity of the strategic/tactical/operational decision-making levels (e.g. as articulated by Gunasekaran et al., 2006) and the polar concepts of core/non-core businesses and insourcing/outsourcing approaches are some prevalent concepts in the field of FM.

Strategic decisions such as asset allocation and market competition are made at the top management levels and entail long-term planning. Operational activities, on the other hand, comprise day-to-day tasks that often involve resource consumption. Such activities are usually repeated periodically e.g. daily, weekly or monthly (Shang and Seddon, 2002). Operational activities produce tangible, identifiable and measurable outcomes that could be reaped in the short run (Gunasekaran et al., 2006).

Scholars have long encouraged taking a strategic approach to FM as a means for transforming this field from a mere practice to a comprehensive profession (Irizarry et al., 2014). In like manner, Noor and Pitt (2009) consider FM as a strategic tool for companies for reducing overheads, increasing operational efficiency and gaining business advantage over competitors. FM activities at the strategic level are sometimes associated with core businesses or competences; whereas activities at the operational level are bound to non-core competences of organizations (Goyal and Pitt, 2007; Mangano and De Marco, 2014; Noor and Pitt, 2009).

4.2. Scope of the research and the criteria for delimitation of scope

Across the broad domain of facility management, the scope of this study is delimited to the operational level within the forth key process area (KPA) of the built environment management model (BEM2) developed by Ebinger and Madritsch (2012). This subdomain comprises services management, maintenance management and operations management (see Table II). The rationale for outlining this study as such could be clarified as follows (often called the vertical strategic chain of value realization): the strategic level forms the basis of actions for the tactical level; which in turn defines the
conditions and requirements for day-to-day operations. In other words, FM activities that are executed on the operational level are coordinated on the tactical level and appreciated on the strategic level (Ebinger and Madritsch, 2012).

Table II. The expanded view of BEM2 (drawn after Ebinger and Madritsch, 2012, p. 192)

<table>
<thead>
<tr>
<th></th>
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<th></th>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Strategic Level</strong></td>
<td>Strategic Planning</td>
<td>Optimized Investment Decisions</td>
<td>Optimal Capital Project Results</td>
<td>Optimal Enterprise Performance</td>
</tr>
<tr>
<td><strong>Portfolio Level</strong></td>
<td>Facilities Planning</td>
<td>Project Portfolio Management</td>
<td>Facilities Portfolio Management</td>
<td></td>
</tr>
<tr>
<td><strong>Operational Level</strong></td>
<td>Project Transaction Management</td>
<td></td>
<td>Operations, Maintenance and Services Management</td>
<td></td>
</tr>
</tbody>
</table>

4.3. Assessing the benefits of BIM in the FM sector, a hierarchical approach

As BIM is primarily an IT initiative, literature on assessing the benefits of IT could also be applicable to assessing the benefits of BIM. Fig. 2 demonstrates a hierarchical representation of the categories of literature that have been consulted in this work. Sources were derived from such a broad subject area of the benefits of IT systems to the much focused field of the benefits of BIM in FM.
Farbey et al. (1999) describe IT-evaluation as a process that continuously searches for and reveals quantitatively or qualitatively all impacts of an IT project. Existing benefits realization assessment methods do not conveniently fit into and are therefore not quite common in the construction industry (Andresen et al., 2000). Tailor-made frameworks should therefore be developed. A common approach for developing benefits realization assessment frameworks is identifying and analysing performance assessment metrics (Breese, 2012; McNaughton et al., 2010).

**Metrics for performance assessment**

Shohet and Lavy (2004) suggest considering metrics that address performance and cost-effectiveness in the FM sector for this purpose. Barlish and Sullivan (2012) mention ‘productivity’ as a quasi-tangible benefit metric which is often quantified in non-consistent and subjective ways. Sacks et al. (2010) measured productivity gains accrued by BIM-implementation in designing precast façade pieces as \((\text{saved time}/\text{benchmark time}) \times 100\).

‘Efficiency’ and ‘effectiveness’ are two other metrics alongside with productivity for assessing benefits realization (Andresen et al., 2000; Shang and Seddon, 2002). A more ‘efficient’ practice implies doing the same task with fewer resources; whereas working in a more ‘effective’ way requires prioritizing tasks that better contribute to the objectives of the firm. Efficiency could be apparently more pertinent the operational level; while effectiveness corresponds better to performance assessment at the strategic level.

Another metric for performance assessment in the construction industry is ‘Key Performance Indicators’ (KPIs). Cox and Issa (2003) define KPIs in the context of construction as “compilations of data measures used to assess the performance of a construction operation” (Cox and Issa, 2003, p. 142). KPIs could be classified as qualitative and quantitative (Cox and Issa, 2003) or tangible and intangible (Gunasekaran et al., 2006).

Appropriate metrics for performance assessment at the strategic level often lie within intangible and qualitative KPIs, e.g. motivation and reputation; while operational activities could be best assessed using such tangible and quantitative KPIs as efficiency and generated revenue. Tangible and quantitative KPIs are therefore the appropriate types of KPIs with regard to the aims and scope of this paper i.e. assessing the benefits of BIM in the FM sector at the operational level. Irizarry et al. (2014) also recommend using quantitative KPIs for monitoring and comparing performance of facilities. Table III demonstrates a list of the polar concepts central to the FM domain introduced in this paper and their associated types of KPIs for performance assessment.

<table>
<thead>
<tr>
<th>Central concepts in FM</th>
<th>Strategic level</th>
<th>Core competences</th>
<th>Insourcing</th>
<th>Operational level</th>
<th>Non-core competences</th>
<th>Outsourcing</th>
</tr>
</thead>
</table>

Table III. Pairs of the polar concepts central to the FM domain and their associated types of KPIs for performance assessment
### Types of business activities

<table>
<thead>
<tr>
<th>Organizational</th>
<th>Functional</th>
</tr>
</thead>
<tbody>
<tr>
<td>Long-term planning</td>
<td>Day-to-day activities</td>
</tr>
</tbody>
</table>

### Associated types of KPIs

<table>
<thead>
<tr>
<th>Intangible KPIs</th>
<th>Tangible KPIs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Qualitative KPIs</td>
<td>Quantitative KPIs</td>
</tr>
</tbody>
</table>

## 5. Models of benefit and cost indicators of BIM-implementation in the FM sector at the operational level

The metrics for performance assessment in the FM sector as discussed in Section 4.3 could be used as the base input for constructing the conceptual models that comprise the benefit and cost indicators for evaluating BIM-implementation. Below, the model for the cost indicators is presented through shortlisting the items derived from the literary sources outlined in Fig. 2:

- Costs of disruption to core business activities (Love et al., 2013)
- Costs of increased stress (Love et al., 2013)
- Costs of insurance (Love et al., 2013)
- Costs of Interoperability (Love et al., 2013)
- Costs of user errors (Love et al., 2013)
- Costs of user resistance to new technology (Love et al., 2013)
- Costs of learning curves (Love et al., 2013)
- Costs of hardware and software applications: licenses, warranties, maintenance and structured technical supports and upgrading systems (Olatunji, 2011)
- Costs of training including start-up triggers and in-line training (Olatunji, 2011)
- Costs of services: energy, internet access, technical support, etc. (Olatunji, 2011)

Likewise, the benefit indicators for evaluating FM activities in general have been shortlisted and presented through the following model:

- Absenteeism (Cox and Issa, 2003)
- Cost-effectiveness (Meng and Minogue, 2011)
- Effective utilization of space (Enoma and Allen, 2007; Hinks and McNay, 1999)
- Effectiveness of communication (Meng and Minogue, 2011)
- Environmental performance / sustainability (Enoma and Allen, 2007; Irizarry et al., 2014)
- Health conditions (Enoma and Allen, 2007)
- Loss of business due to failure in service (Hinks and McNay, 1999)
- Motivation (Cox and Issa, 2003)
- Operation and maintenance costs (Enoma and Allen, 2007)
- Professional approach of staff (Meng and Minogue, 2011)
- Provision of project to client/customer satisfaction (Meng and Minogue, 2011)
- Provision of safe environment (Cox and Issa, 2003; Enoma and Allen, 2007; Hinks and McNay, 1999)
• Response time / Responsiveness (Atkin and Brooks, 2014; Hinks and McNay, 1999; Meng and Minogue, 2011)
• Revenue generated / turnover (Cox and Issa, 2003; Enoma and Allen, 2007)
• Service completion: units/man-hours (Cox and Issa, 2003)
• Service reliability (Hinks and McNay, 1999; Meng and Minogue, 2011)

The two conceptual models presented above were intended as intermediate research results that were then evolved to a conceptual framework (as recommended by Meredith, 1993).

6. Validation of the models for benefit and cost indicators and formation of the framework

Following Shang and Seddon (2002), the seven questions of Cameron and Whetten (1983, pp. 270–274) for developing benefits realization assessment frameworks were used as an initial stage. Table IV presents the answers to questions 1 to 4. Answers to questions 5 to 7 will be provided later in this paper when the overall setup of the framework is introduced.

<table>
<thead>
<tr>
<th>Seven questions on benefits realization assessment</th>
<th>Answers with regard to the intended framework</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. What is the purpose of evaluation?</td>
<td>Use of knowledge from early adopters for assisting future decisions and investment for BIM-implementation (see Section 1)</td>
</tr>
<tr>
<td>2. From whose perspective are benefits being judged?</td>
<td>Any actor who may benefit from improving performance metrics (see Section 2)</td>
</tr>
<tr>
<td>3. What is the domain of activity?</td>
<td>BIM-implementation / Facility management</td>
</tr>
<tr>
<td>4. What is the level of analysis?</td>
<td>Operational activities (see Section 4.2)</td>
</tr>
<tr>
<td>5. What types of data are to be used?</td>
<td>Will be explained in Section 7.1</td>
</tr>
<tr>
<td>6. What time frame is employed?</td>
<td>Will be explained in Section 7.2</td>
</tr>
<tr>
<td>7. Against which referent is effectiveness to be judged?</td>
<td>Will be explained in the last paragraph of this section</td>
</tr>
</tbody>
</table>

The two requirements for a model to be an accurate representation of a phenomenon as designated by Ritter (2010) were used for validating and rectifying the benefit and cost indicator models presented in Section 5. According to Ritter (2010), it should be justified that 1) no essential component has been bypass during the abstraction and condensation process; and 2) the level of complexity of the model is optimal for facilitating understanding of the modelled phenomenon. The following paragraphs describe the rationales for condensing the models into a framework the way it has been done in this study with regard to the aim and focus of the paper (see Section 2). At the same time, it has been clarified how Ritter’s (2010) requirement have been controlled for and adopted. Evaluating the costs is not always straightforward; but evaluating the benefits could be even more difficult (Shang and Seddon, 2002). Quite often, costs occur immediately, while many benefits are not realized in the short run. Moreover, hard or quantifiable benefits and costs can be calculated easily; while it could be far trickier to capture the
indirect or intangible benefits and costs such as strategic competitive advantage or customer and stakeholder satisfaction (Love et al., 2013). Efforts for also including the intangible benefits and costs in benefits realization assessment frameworks have often failed (Lin and Pervan, 2003). Barlish and Sullivan (2012) also recommend using indicators that are fairly accurate, objective and quantifiable.

Table V – Suggested benefit and cost indicators for evaluating BIM-implementation in the FM sector at the operational level

<table>
<thead>
<tr>
<th>Benefit indicators</th>
</tr>
</thead>
<tbody>
<tr>
<td>Work order accomplishment time/cost (service completion time/cost): Examples of such work orders are:</td>
</tr>
<tr>
<td>• Time-based preventive maintenance e.g. replacing parts and lubricating parts</td>
</tr>
<tr>
<td>• Condition-based preventive maintenance e.g. regular inspections</td>
</tr>
<tr>
<td>• Corrective maintenance starting with a cold call, email or web-notification</td>
</tr>
<tr>
<td>• Cleaning</td>
</tr>
<tr>
<td>• Inventory of installed components and spare parts</td>
</tr>
<tr>
<td>Energy consumption: This item addresses utility cost reduction through energy efficiency and informed decisions. This could be broken down to figures such as costs of electricity or other energy supplies for HVAC systems.</td>
</tr>
<tr>
<td>Material consumption: Examples are fuel and material savings through less travel and waste or more coordinated maintenance and cleaning procedures.</td>
</tr>
<tr>
<td>Revenue generated: Revenues could be increased through more efficient rental/lease administration and space optimization. More accurate and automated area calculation is a substantial enabler for improving the value of this indicator.</td>
</tr>
<tr>
<td>Number of reactive maintenance work orders: Reactive maintenance is often the most costly type of maintenance and should thus be minimized.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Cost indicators</th>
</tr>
</thead>
<tbody>
<tr>
<td>Costs of hardware and software applications: licenses, warranties, maintenance and structured technical supports and upgrading systems</td>
</tr>
<tr>
<td>Costs of training:</td>
</tr>
<tr>
<td>• Startup triggers vs. in-line training (periodic and continuous)</td>
</tr>
<tr>
<td>• Training for technical staff vs. administrative or executive staff</td>
</tr>
<tr>
<td>Costs of services: energy, internet access, technical support, etc.</td>
</tr>
</tbody>
</table>

Table V summarizes the framework derived from the two benefit and cost indicator models presented in Section 5 with regard to the aim and scope of this paper and the above arguments: such benefit indicators as environmental performance, health conditions, professional approach of staff, client satisfaction and safety are realized at the strategic level and were thus set aside. Moreover, better health conditions and safety for the FM staff will curtail absenteeism and thereby reduce work order accomplishment costs. The latter indicator is already present in Table V. Likewise, professional approach of staff and improved customer satisfaction will, in the long run, increase the revenues generated by the organization using the facility as an asset (also mentioned in Table V); so do other strategic indicators such as effective utilization of space, effectiveness of
communication, service reliability and motivation. Responsiveness is a component of the broader benefit indicator, work order accomplishment time. Such broad indicators as environmental performance could be broken down to more concrete and measurable indicators such as energy consumption and material consumption (mentioned in Table V). Loss of business due to failure in service and operation and maintenance costs are cost indicators defined at the strategic level. They, too, are accounted for by the benefit indicator, revenue generation.

In the same manner, costs of disruption to core business activities and insurance are realized at the strategic level and lie, therefore, outside of the scope of this paper. Such costs will nonetheless be accounted for by the benefit indicator, revenue generated. Such non-tangible expenditures as the costs of increased stress, user errors, and user resistance to the new technology, learning curves and interoperability will also eventually have their negative impact on the values of the benefit indicators. The costs of hardware and software applications, training and services will, therefore, be the only cost indicators required for the suggested framework in this paper.

Excluding the indicators that correspond to intangible or qualitative benefits and costs, or those realized at the strategic level would not impair the validity of the framework. This is justified by the principle of vertical strategic chain of value realization as previously addressed in Section 4.2. In other words, a framework confined to tangible, quantitative and operational indicators could yet account for intangible, qualitative, strategic and tactical benefits and costs of BIM-implementation project in the FM sector.

7. Practical implications

The ultimate use of the framework developed in this paper is resolving a problematic situation in practice (Schön, 1983): in the absence of clear guidelines for BIM-implementation, FM firms would either totally dismiss implementation of BIM, invest in BIM merely as an act of faith, or simply assign arbitrary values to benefits and costs with the pre-defined aim of justifying their choices and passing the budgetary process (so called creative accounting) (Alshawi et al., 2003). When applied to real-world cases, the findings of this paper would help rectifying this situation.

As a further elaboration on how the results of this study could be used, a case study design for implementing the proposed framework has been suggested through the following subsections together with its alternative time horizons and criteria for case selection.

7.1. A suggested case study design for implementing the proposed framework

A viable research strategy for implementing the framework developed here is case study since the subject of the study is a contemporary phenomenon that could not be controlled by the investigator (Yin, 2003). Bakis et al. (2006) also assert that case study is the most appropriate method for assessing the business benefits of new information technologies. The cases to be studied here are facilities where BIM is acquired for operation.

A multiple-case setting would be a more auspicious approach since it will presumably produce more robust and reliable results through replication logic and increase the
external validity of the findings. Depending on similarity or disparity of control parameters, the findings could be - respectively - literally or theoretically replicated (Yin, 2003). An embedded design should be implemented where the main unit of analysis within each case is a BIM-implementation project and the embedded units of analysis are the benefit and cost indicators. Some alternative sources of information would be contracts, utility invoices, balance sheets, product data sheets, reports, documentation on start-up and shut-down procedures of equipment, warranty manuals, installation instructions, part diagrams, maintenance records, BIM deliverables (Parsanezhad, 2014) and on-site observation.

Fig. 3 depicts a visual representation of the suggested design of the case study research including the context, case(s) to be studied and the main and embedded units of analysis are directly derived from the framework introduced in Section 6. These could be complemented with additional case-specific items.

7.2. Time horizon and criteria for case selection
The cases to be selected are facilities being operated using BIM. In case the facility is accessible to the researcher before, during and after the BIM-implementation process, a longitudinal setup would best the most appropriate option for implementing the framework. In this case, the FM performance of the building before and after BIM-implementation will be compared and the benefits realized by BIM-implementation will
be assessed. This would have been the optimal setup, since the influence of the factors other than BIM-implementation on FM performance is minimized this way.

In case the facility being operated using BIM is accessible to the researcher only after BIM-implementation, the values of the studied indicators should be compared with benchmark measures sourced from national and international guidelines, handbooks, standards and statistics, previous research or legislative documents. The results of the comparison will then serve as the ground for assessing the benefits of BIM-implementation.

An alternative setup is to run a BIM-implementation project in an in-use facility. In order to mitigate the potential risks and losses caused by implementing the new system, this should be a pilot project performed at a limited scale and parallel to ongoing non-BIM-based FM activities. In case the researcher her/himself is also involved in the BIM-implementation procedure, the overall research design should be replaced by an equivalent ‘action research’ setup. The longer the comparison period is, the broader the range of the captured strategic-level benefits would be. Eventually, common financial methods could be used for calculating the monetary equivalent of the outcome of the BIM-implementation project in either of an ex-ante (predictive) or ex-post (prescriptive) fashion (Love et al., 2013). Some examples of such methods are Payback Period (PP), accounting rate of return or Return on Investment (ROI), Internal Rate of Return (IRR) and Net Present Value (NPV).

Different attributes of the selected cases such as the organizational and managerial specifications should be documented for further analyses and eventual hypothesis building. Some examples of such attributes as addressed in the literature are as follow:

- general organizational structure and attributes of the firm (Esteves, 2009);
- whether the firm is a public or private organization (Motawa and Almarshad, 2013);
- whether the firm has a work package or fixed price contract with the owner, minor service providers and other FM actors (Mangano and De Marco, 2014);
- weather the firm has outsourced minor operational services or has in-house staff for this purpose (Burdon and Bhalla, 2005; Gunasekaran et al., 2006; Heikkilä and Cordon, 2002; Kurdi, 2011; Lind, 2015);
- type of the core activities running in the facility (e.g. educational, governmental, healthcare or retail) (Esteves, 2009; Motawa and Almarshad, 2013);
- whether the main business is an asset-intensive industry such as processing industries or one that is not that sensitive to their assets e.g. professional services firms (Ebinger and Madritsch, 2012);
- size of the firm (Barlish and Sullivan, 2012; Esteves, 2009; Motawa and Almarshad, 2013);
- team members’ BIM competence level (Barlish and Sullivan, 2012);
- BIM maturity level that is implemented i.e. object-based modelling, model-based collaboration or network-based integration (Sucar, 2009); and
- whether open-standard or proprietary information exchange solutions have been implemented (Sacks et al., 2010; Tarandi, 2012).
Such parameters could even be used for proactively choosing cases of different types and exerting theoretical replication of the findings based on a number of initial hypotheses.

8. Further remarks

As clarified earlier in Section 7.2, for the purpose of this paper, BIM-implementation is considered as a distinct process with explicit start and end points in time. In reality, however, BIM-implementation is a continuous change process consisting of numerous socio-technical dynamics that are initiated in the aftermath of the formal IT-implementation project and never completely cease. Such dynamics continue evolving and maturing over time and their impacts on FM activities could never be fully seized. Moreover, the authors would like to acknowledge that the conceptual framework presented in this paper could – as intrinsic to all conceptual constructs – be complemented, altered, refined and expanded in the light of further research (as also emphasized by Succar, 2013).

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A conceptual framework embracing benefit and cost indicators of BIM in the FM sector


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