

BIM COMMUNICATION WASTE

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I would like to express my sincere appreciation to my mother, Irene, for her love and support.

ABSTRACT

Developments in Information and Communication Technology can bring about significant improvements in the efficiency of the Architecture, Engineering and Construction and Facilities Management industry. Building Information Modelling (BIM), is a term which encompasses a type of software but more importantly a set of processes which, at their core, support an approach for integrated project delivery enabled by interoperable software systems. The last three years have seen intensified and coordinated adoption of BIM in the UK mainly as a result of the mandate of the UK government.

One facet of these developments is the growing need for BIM collaboration tools which can interoperate effectively with the various BIM software systems, support the required standards and codes of practice and provide for requirements of construction project information production and management such as model-based workflows, model-based communication, model-based procurement, role-based data access and role-based privileges. The pre-requisites for collaboration can be broadly divided into two categories: (1) coordination of information and responsibilities, and (2) communication. This research recognises the strong focus of recent and ongoing efforts to provide for coordination and aims to support the communication aspect. Additionally, successful collaborative practice results from (1) the "softer" or "human-aspect" issues: collaborative culture, software training and adherence to protocols as well as from (2) the provision of appropriate, intuitive and configurable collaboration tools and, more generally, digital collaboration environments. This research focuses on the latter.

Despite efforts from a variety of software-as-a-service (SaaS) collaboration tool vendors to achieve dominance in the market, there is still uncertainty as to what type of solutions would best support BIM collaboration. Additionally, there is considerable variation in software configurations and a lack of a universally applicable method for evaluating the communication capabilities of BIM collaboration tools in a meaningful way. Vendors lack a robust conceptual framework to guide the long-term development of their tools and evaluate them. The process of requirements engineering, which in this context involves a diversity of stakeholders and involves projects at different BIM maturity levels would benefit significantly from a robust, context-specific conceptual model-ontology.

The aim of this research is to produce a context-specific conceptual model-ontology which can support the discourse of requirements engineering and provide a robust and widely applicable framework for evaluating the communication capabilities of BIM collaboration tools. It is anticipated that this would help reduce "BIM communication waste". To meet this aim, BIM collaboration tools were studied from five perspectives:

1. **Users:** their opinions, requirements and requests were collected through an online questionnaire survey.
2. **Vendor:** their perspective was captured through semi-structured interviews.
3. **Schemata for interoperability:** effectiveness of tools and schemata was evaluated through analysis of software by data fidelity study and scenario-based testing.
4. **Tool use:** patterns of digitally-enabled communication were explored through an analysis of communication data and meta-data collected from a collaboration tool.

5. **Tool improvement:** a successful approach in improving a collaboration tool was examined through the development of a context-specific requirements engineering process. This process was evaluated through semi-structured interviews with collaboration tool implementation consultants.

Each perspective helped produce more specific requirements from the model as well as elements of the model itself. The end result was the 'Model for communication waste in BIM process interactions' (WIMBIM). WIMBIM has the "BIM process transmission" as the fundamental unit of analysis and focuses on "BIM communication waste" and how it results from suboptimal collaboration tools and schemata. The ultimate purpose of WIMBIM is to support the development of technology which would reduce this waste.

This model was converted into a communicable format and was related to BIM standards to aid contextualisation and gap identification. To evaluate the validity and utility of this model, interviews with BIM experts were conducted, and the proposed model was found to be a valid approach to address aspects of BIM waste, which is not usually examined and could potentially complement the existing model for BIM maturity. Additionally, the model provides a useful lens for further academic research into BIM collaboration tools.

Keywords: BIM, collaboration tools, communication, requirements engineering, communication waste, model-ontology.

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LIST OF ABBREVIATIONS

BIM – Building Information Modelling

OCP – Online Collaboration Platform

IFC – Industry Foundation Classes (data exchange schema)

SaaS – Software-as-a-Service

cBIM – collaborative BIM

IAI - Alliance for Interoperability

OCPs - Online Collaboration Platforms

CPEs - Construction Project Extranets

OCPM - Online Construction Project Management

CDE - Common Data Environment

COBie – Construction Operations Building Information Exchange

NBS – National Building Specification

MPDT - Model Production and Delivery Table

KM – Knowledge Management

PLM – Product Lifecycle Management

PDM – Product Data Management

RFI – Request for Information

NIST – National Institute of Standards and Technology (US)

1 INTRODUCTION

This chapter introduces the context for the research undertaken. A brief overview of the subject matter is presented, followed by the background to the research. The sponsor company and its software product, with which the research has been concerned with are introduced. Research questions are presented to provide motivation. Justification for the research is explained, and then followed by the aim and objectives of the research. A summary of the adopted research methodology is provided. Additionally, a summary of the main conclusions is presented. The chapter concludes with the guide to the report which outlines the chapters of the thesis.

1.1 Introduction to subject matter

The Architecture, Engineering, Construction and Facilities Management industry (“AEC-FM”) industry is traditionally slow on the uptake of Information and Communication Technology (“ICT”) compared to other industries. This phenomenon is closely related to the generic traits of the industry:

- Low levels of standardisation hinder interoperability in software systems
- Low skilled personnel and culture hinder uptake of new technology and associated methods of working
- Project-specificity and project-led nature leads to great variability in software configuration across projects, making it difficult to enjoy economies of scale from a proven and re-usable software configuration.

Building Information Modelling (BIM) is an integrated project delivery method, enabled by interoperable software systems. BIM promises significant efficiencies through improved information flow and elimination of the various kinds of waste within the construction process. The BIM process has been conceptualized by many parties over the last few decades, who were inspired by the capabilities of software as well as the potential for improved efficiency by adopting a more collaborative culture within construction projects.

Collaboration tools such as Online Collaboration Platforms (or Construction project extranets) have been used to deliver a part of this potential in efficiency improvement. They serve as a central repository for project information, making communication and resource sharing between geographically distributed teams easier. Recent advances have seen the incorporation of BIM modules in many Online Collaboration Platforms for example: online model viewers offering the functionality to interrogate and communicate around a shared Building Information Model.

1.2 Background

1.2.1 *UK BIM Adoption overview*

The decision of the Government to “introduce a progressive programme of mandated use of fully collaborative Building Information Modelling for Government projects by 2016”, communicated in May 2011 through the Government Construction Strategy (Cabinet Office, 2011) was the start of an industry-wide push for BIM adoption, which when compared to previous efforts has been more formal, coordinated and inclusive. Apart from feeding into the existing momentum in utilising the potential of BIM technology to improve efficiency, this decision coincided with a period of low performance in the

industry. The drive has also been powered by the fact that the US and many Northern European countries were seen to be further advanced in terms of their BIM adoption.

1.3 The sponsor company: Asite solutions

This research has been partly funded by Asite. The researcher was based in Asite's head office in London for the majority of the project's duration and contributed to some Asite-specific tasks like software configuration and requirements engineering for product development.

1.3.1 *Asite overview*

Asite offers Software-as-a-Service ("SaaS") predominantly to the Construction and Facilities Management industry. It was founded in 2001 and has managed to establish itself in the UK construction collaboration tool market as well as reaching out to the US, Australian and Middle-Eastern markets. Its service offering covers Document Management, Project Management, Sourcing and Procurement as well as Collaborative BIM (cBIM).

1.3.2 *Asite document management and workflow modules*

The most established and widely used functions of the Asite service offering are those based on online document management, online forms and workflow automation. The range of functionalities supporting document management include cloud storage, contextualised search, version tracking, online file viewing (e.g. 2D drawings in pdf), email integration, role-based file access. Project management is enabled by task tracking, a configurable audit trail, workflow automation, design of custom forms as well contract management, project risk registers and financial tracking. Sourcing and procurement as supported by an online supplier directory, prequalification and supplier relationship management. Asite aims to provide an online environment with extensive functionality which leverages on the advantage of keeping project information centrally and performing associated functions around it.

1.3.3 *Asite cBIM module*

The Asite cBIM module is an online BIM model viewer which offers the users the ability to share, view, interrogate and perform communication and workflow tasks around a BIM model. It supports the Industry Foundation Classes, ("IFC") open standard. The vision to incorporate the functions presented above to the cBIM module so that required operations can be performed under a model-based paradigm. In this respect, cBIM is not merely an additional functionality but an additional dimension in functionality as the envisioned way of working involves a significant change in which users interact with information, communicate amongst them and share actions and assign responsibilities.

1.4 Domain of research and research questions

The domain of this research can be described by the following hierarchy of domains:

- Construction industry
 - Information and Communication Technology in the Construction industry
 - Building Information Modelling (BIM)
 - Collaboration Tools for BIM

The research has been motivated by a set of relatively broad questions from the outset:

- What are the challenges in adopting BIM?
- How can be BIM support collaboration? What is this process of BIM-based collaboration?
- What is the role of collaboration tools within the BIM process?
- What are the challenges in developing BIM collaboration tools?

Following the literature review and scoping study, the research has been concerned with developing a conceptual model to support Requirements Engineering for BIM collaboration tools. Additionally, the research has focused more on the communication aspect of BIM collaboration. The research questions have been directed and concentrated to:

- What is the nature of Requirements Engineering for BIM collaboration tools?
- What is needed to support Requirements Engineering for BIM collaboration tools?
- What concepts should this model contain?
- What characteristics and principles should it have?

The domain, therefore has been narrowed down to:

- Communication through BIM collaboration tools
- Requirements Engineering for BIM collaboration tools
 - Conceptual models to support Requirements Engineering for BIM collaboration tools

1.5 Justification of research

The outcomes of the research aim to benefit multiple parties:

- The AEC-FM industry required a better understanding of the BIM process and its requirements in terms of technology, standards and processes.
- Asite required to better understand the BIM adoption landscape in order to define the role of its software within the BIM process and develop its software accordingly. No robust way to evaluate its software is currently exists.
- The construction ICT knowledge domain would benefit from additional examples of BIM and collaboration tool-enabled collaboration in practice as well as from improved models capturing the key concepts in this process in a useful way.

Initially, the research project was undertaken as part of a four year Engineering Doctorate (EngD) programme, where the researcher was based in industry for 75% of the time. Therefore, any outputs were required to contribute to both improving domain knowledge and the sponsoring organisation's business. This was to be achieved by way of a minimum of 2 conference papers and a peer-reviewed journal paper. Conversely, at 2.5 years, and after producing 3 conference papers and while working towards a journal paper, the researcher took a decision to withdraw from the EngD programme in order to focus solely on the research element. The completed project was then to be submitted as an MPhil thesis.

1.6 Aim and Objectives

The overall aim of the project is to develop a conceptual model to support requirements engineering for BIM collaboration tools.

This would be achieved by the following objectives:

1. Identifying and addressing the key aspects in the process of Requirements Engineering for BIM collaboration tools.
2. Identifying the challenges faced in the Requirements Engineering for BIM collaboration tools and which specific areas could benefit from improved and more explicit conceptual models.
3. Identifying the key elements in this process (which concepts are universal and persist through time).
4. Identifying the relationships between these concepts and relating them to concepts found in current standards, literature and used in the discourse of Requirements Engineering for BIM collaboration tools.

1.7 Summary of research methods

A mixed method approach was used where both qualitative and quantitative data was utilised. The research was designed based on the aim and objectives as well as the nature of the domain, which is characteristically multi-faceted and dynamic, as well as the setting of the research. The ethnographic element of the research (i.e. the researched observing BIM Requirements Engineering by being based in a collaboration software company) also contributed to the development of the model.

1.8 Summary of contribution to knowledge

The main outcome of the research is the WIMBIM, the model for Waste in BIM process interactions. This is a conceptual model, in the form of visuals and descriptive text which consists of a set of interrelated concepts which aid in better understanding waste within BIM communication. The WIMBIM has the single BIM process transmission as its unit of analysis, focuses on communication waste and how to eliminate it and is constructed in a logical way. By improving understanding on BIM communication waste, i.e. the different types and how they are brought about, WIMBIM can help evaluate BIM collaboration tools. Such a model is evaluated against its universality, ability to provide a common reference, robustness and usability. Semi-structured model evaluation interviews with BIM experts have proved the overall validity and utility of the model. It was also found that WIMBIM provides a useful way for expressing BIM maturity. Additionally, it provides a useful lens for academia to study BIM in more standardized way.

1.9 Guide to the thesis

The Literature Review introduces the most important concepts in the domain and their relationships. Important effects and gaps in knowledge are identified. The Literature Review chapter also includes a Review of Developments in BIM adoption in the duration of the project (2011-2014) which helps understand the dynamic context. The Methodology chapter reviews the approaches and tools available to the researcher and justifies the selection of methodology for this research based on nature of the project and the aim.

Chapter 4, explains how data was collected and analysed in order to form a draft conceptual model. It is split in to five “perspectives-focuses”. These examine the domain of Requirements Engineering for BIM collaboration tools from different angles. In Chapter 5, WIMBIM is formalized and evaluated. In the Conclusion, a summary of conclusions are provided as well as a brief critical evaluation of the limitations of the research. Finally, recommendations for research and industry are provided.

2 LITERATURE REVIEW

2.1 Overview

This chapter explores the basic themes relating to the study and sets the ground for research presented in later chapters. The nature of the AEC-FM industry, its chronic traits and challenges, are explored as well as the opportunities offered by BIM technology. The specific requirements for collaboration and the fundamental prerequisites for communication and coordination are analysed. Subsequently the proposed software tools and relevant approaches for developing their functionalities are proposed. A review of BIM developments in the UK and the relevant standards is provided. Finally, a preliminary framework is formed as the first step of a scoping study. The conclusions of this chapter inform the decisions for designing the research which are explained in Chapter 3 (Methodology).

2.2 The AEC-FM industry

2.2.1 Purpose and process

A useful way of understanding an industry is by its generic purpose and process. On a project level, the purpose of the construction industry is to produce:

- A tangible product; a built artefact,
- A service; the activities involved in designing, constructing, operating, modifying and maintaining the product
- The *information* that supports the operation of the product.

Traditionally, the tangible product has been the purpose of the AEC industry while producing the service and information to support the operation of the product has been the purpose of the FM industry. More recently, with increasing more integration between the AEC and FM industries there is increasing reference to a single “AEC-FM industry” with an increasingly joint responsibility for all three purposes.

It follows that the above generic purposes are the *outputs* when considering the AEC-FM *process*. The *inputs* are not as well defined and understood and typically more varied across projects. Key inputs include:

- Client requirements
- Building regulations
- Information from previous projects
- Building materials
- Land

Koskela et. al (1997) propose conceptualizing the design process in the construction industry simultaneously in three different ways; (1) Conversion, (2) Flow and (3) Value Generation. They argue that, for the purpose of waste reduction, the Flow view and Value Generation view can offer more suitable representations over the, traditionally more established, Conversion view.

2.2.2 *Nature and traits*

The construction industry in the UK, as in most developed countries, is known to suffer from some enduring problems. A number of reports dating back to 1950 have been published in an effort to improve efficiency and effectiveness which would ultimately lead to greater value to the client (Murray and Langford, 2003). These traits, even though often highly interdependent, are listed individually below:

- Low profit margins
- No barriers to unskilled personnel
- Client focus on capital cost rather than value
- Inability to estimate life-cycle costs (“short sightedness”)
- Horizontal (discipline) fragmentation
- Vertical fragmentation (i.e. supply chain-related)
- Adversarial contracts
- Low innovation
- Slow adoption of Information and Communication Technology (ICT)

Researchers have given various accounts to these problems. Dubois and Gadde (2002) who view the construction industry as a “loosely coupled system”, suggest that this characteristic “favours productivity in projects, while innovation suffers”. This phenomenon is commonly referred to as “the project-led nature” of the industry. Congruently, Harty (2005) suggests that the notion of “unbounded innovations”, where the effect of an innovation could be enjoyed across the organisation or the industry, has not been given adequate attention. Koskela and Vrijhoe (2001) call for the need to devise a more explicit theory of construction for the purpose of transferring innovation (within the industry and from other industries) and removing fragmentation and short-sightedness.

Fernie et al. (2006) suggest that adversarial contracts and opportunistic behaviours might be legitimate actions and that “simplistic calls” for more collaboration are going to be ineffective. Instead they recommend “ongoing connection between the reform movement and organizational scholars”

2.3 Information and Communication Technology in the AEC-FM industry

The AEC-FM industry is traditionally slow on the uptake of Information and Communication Technology (ICT) compared to other industries. This phenomenon is closely related to the generic traits of the industry:

- Low levels of standardisation hinder interoperability in software systems
- Low skilled personnel and culture hinder uptake of new technology and associated methods of working
- Project-specificity and project-led nature lead to great variability in software configuration across projects making it difficult to enjoy economies of scale from a proven and re-usable software configuration.

2.3.1 Descriptions of ICT-driven Vision

Figure 1 presents how four different sources envision how ICT can transform the industry. There is congruence that we ought to walk the path towards greater integration enabled by interoperability.

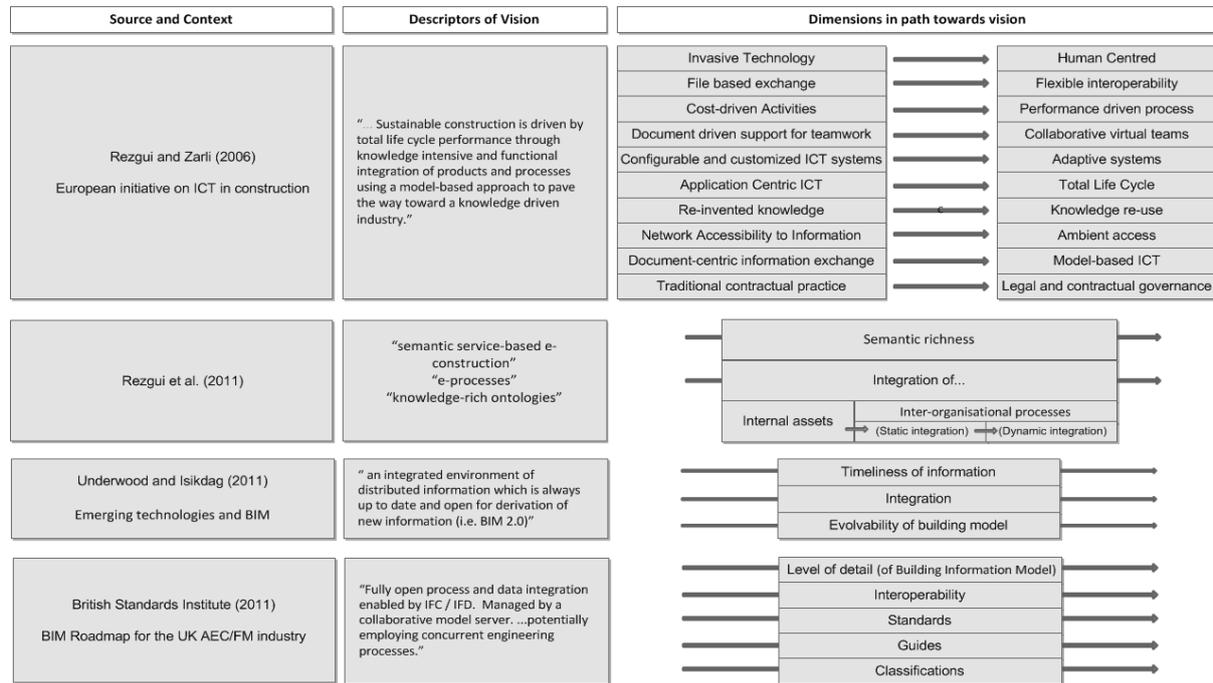


Figure 1. Descriptions of ICT-driven vision for the AEC-FM industry

2.4 Building Information Modelling (BIM)

The term Building Information Modelling (BIM) has been assigned with an astounding plethora of definitions from various sources. A number of these are presented fully or partially in Table 1.

Explanations for the multitude of definitions for BIM” across academic and industrial publications include:

1. BIM's span of influence across disciplines and building lifecycle phases
2. BIM's trait to appear as a software system, a process, a 3D model (“M” can stand for “model” or “modelling”) or as other construction documents (e.g. bill of quantities, Gantt chart etc.)
3. BIM's emergence through gradual evolution rather than at one distinct stage (Holzer, 2007)

Table 1. Multiple definitions of BIM

Source	Definition
Building Information Model	
NBS (2011)	“a rich information model, consisting of potentially multiple data sources, elements of which can be shared across all stakeholders and be maintained across the life of a building from inception to recycling (cradle to cradle). The information model can include contract and specification properties, personnel, programming, quantities, cost, spaces and geometry”.
Building Information Modelling	
Laiserin (2003)	“a process of representation, which creates and maintains multidimensional, data-rich views throughout a project lifecycle to support communication (sharing data); collaboration (acting on shared data); simulation (using data for prediction); and optimisation (using feedback to improve design, documentation and delivery).”
Eastman et al. (2008)	“An activity rather than an object”
Lachmi Khemlani in (Eastman et al., 2008)	“...not just a technology change but also a process change”
Succar (2009)	“a set of interacting policies, processes and technologies”
BIS (2011)	“...desire not to attempt to try and define what BIM is, rather than focus on the outputs of BIM.”
Information Delivery Manual (British Standards, 2010)	“Provides a concept for describing and displaying information required in the design, construction and operation of constructed facilities. It can bring together the diverse sets of information used in construction into a common information environment - reducing, and often eliminating, the need for the many types of paper documentation currently in use.”
Coates et al. (2010)	“...the language of construction...”
Smith et al. (2009)	“ nothing more and nothing less than a systems approach to the design construction, commissioning, ownership, management, operation, maintenance use, demolition and reuse of built assets”

2.4.1 *The multiple uses-purposes of BIM*

BIM software can be used for a very wide range of purposes. This multiplicity of uses and purposes can also account for the variation in definitions of BIM. Kreider and Messner (2013) as a response to this need for delineation and agreed common terms, produce an ontological framework for the BIM Use Purposes. These fall under five main categories: “Gather”, “Generate”, “Analyse”, “Communicate”

and “Realise”. The BIM Use Purposes of Kreider and Messner are presented in Table 2. A universally agreed set of BIM Use purposes can provide significant clarity both in company-wide BIM adoption programs as well as project BIM execution plans.

Table 2. BIM Use Purposes as defined by Kreider and Messner (2013)

Gather	Generate	Analyse	Communicate	Realize
Qualify	Prescribe	Coordinate	Visualize	Fabricate
Monitor	Size	Forecast	Draw	Assemble
Capture	Arrange	Validate	Transform	Control
Quantify			Document	Regulate

2.4.2 BIM maturity

BIM can better be understood through the concept of successive maturity levels. The B/555 Roadmap (BSI, 2011) defines the most established maturity model adopted in the UK. This maturity model defines four BIM maturity levels (0, 1, 2 and 3) with Level 2 becoming a requirement in 2016 for all projects with UK government as a client. A maturity model is defined by:

- A brief description of the generic method of working
- The standards which support it
- The technologies which support it

The US National BIM Standard (NIBS, 2011) defines the BIM Capability Maturity Model. It examines BIM maturity through defined “Areas of Interest”: Data Richness, Lifecycle Views, Change Management, Roles or Disciplines, Business Process, Timeliness/ Response, Delivery Method, Graphical Information, Spatial Capability, Information Accuracy and Interoperability/IFC Support.

2.5 Interoperability

Interoperability is arguably the most important enabler of BIM. It manifests itself on three levels: Data Interoperability, Semantic Interoperability and Business/Organizational Interoperability (Cerovsek, 2011 and Grilo and Jardim-goncalves, 2020).

2.5.1 Data Interoperability

The NIST (2004) study, which defined data interoperability as “the ability to manage and communicate electronic product and project data between collaborating firms’ and within individual companies’ design, construction, maintenance, and business process systems”, estimated the cost of inadequate (data) interoperability in the US Capital Facilities Industry in 2002 to be \$15.8billion.

The lack of data interoperability is still the most critical challenge within BIM adoption, despite a two-decade long consortium-led movement for its resolution. The variation in BIM software packages and corresponding BIM model formats results to significant data loss and need for data re-entry within information exchanges. The solution for this problem is common data formats:

2.5.1.1 *Industry Foundation Classes*

Building Smart was set up in 1994 as the International Alliance for Interoperability (“IAI”) by a consortium of US organisations. The vision was to build upon the existing ISO Standard for the Exchange of Product model data (“STEP”) standard in order to “enable software interoperability in the AEC/FM industry” (Laakso et al. ,2010) Its core activity is the development of the Industry Foundation Classes (IFC), an international standard for interoperability. IFC, now an official ISO standard ISO 16379:2013 (ISO, 2013) is the de-facto common data format for BIM models.

2.5.2 *Semantic Interoperability*

Semantic interoperability exists when “the precise meaning of exchanged information is preserved and understood by all parties” (European Commission, 2010). Across all industries and application types, semantic technology promises significant productivity improvements along with a paradigm shift in the way technology users interact with information.

Within BIM processes semantic interoperability is the “ability of enabling multi-disciplinary design applications to understand and utilize semantics of BIMs and meanings of model data, and to map between commonly agreed concepts to establish a semantically compatible information interchange and sharing environment” (Yang and Zhang, 2006). The AEC-FM industry, characterised by a geographically distributed, multi-disciplinary workforce generating and exchanging a vast amount of diverse project information and can benefit significantly from semantic technology. Abanda et al. (2013) provide an extensive review of research relating to Semantic Web for the built environment since 2000, demonstrating the variety of intended application domains (e.g. project management, smart homes, urban planning), intended software media (e.g. software for design, simulation, coordination, facilities management) and functionalities (e.g. reasoning, code checking, archiving, retrieving and model extraction).

Semantic technology is effective when the meaning of the information exchanged is understood across heterogeneous applications. This is achieved by utilising shared semantic models of the information across different applications. The IFC schema provides such a semantic model as it defines the types of elements within the AEC-FM industry and relationships between them.

2.5.3 *Business (or organisational) Interoperability*

As explained by Grilo et al. (2011) the collaborative, multi-organisational BIM environments do not only require interoperability across software platforms but across “social, procedural, legal and strategic aspects of collaborations.” Business interoperability within the BIM context is not a well-established concept and further mobilisation from industry and academia is expected as BIM adoption progresses.

Cerovsek’s (2011) ‘BIM cube’ framework identifies the relationships between the three levels of interoperability with BIM models, BIM technologies, building projects and the development, implementation and deployment of standards. The framework explains that data interoperability enables technology intelligence, whilst semantic interoperability enables business intelligence while organisational interoperability enables collective intelligence.

2.6 Lifecycle management

A continuing trait of the AEC/FM industry is the inability to account for the whole lifecycle of a built asset during the design phase of a project. This results to unanticipated operational costs in the form of:

- Rework in obtaining information on appliance and material specifications for maintenance or modification purposes
- Operational energy
- Non optimal business performance as a building is not optimised for its function

The BIS (2011) BIM report identified “Whole life cost” as one of the two important performance variables (together with “Carbon Performance”). Saxon (2002) suggests that the ratio of Construction Cost to Maintenance and Building Operating Costs to Business Operating Costs is 1:5:200, (even though criticised for unsupported data by Hughes et al., 2004 who suggest that 1:0.4:12 is more realistic). Regardless, these figures give an indication of the unexplored potential to increase value by employing a lifecycle management approach from the early design phase. The industry has only recently been mobilised in delivering value to the end user throughout the built asset lifecycle. The reasons for the lag in adoption of lifecycle management approaches can be outlined as:

- Discipline fragmentation
- Client focus on capital asset value rather than life cycle costs
- Use of design-bid-build contracts.

2.6.1 *The role of BIM in Lifecycle Management*

The adoption of BIM can address the above issues by:

1. Enabling communication between disciplines
2. Elucidating life cycle costs to the client
3. Drawing/demanding contracts and delivery methods of the form of Design and Build and Integrated Project Delivery (Sebastian, 2011).

The 2010 Building Smart Investor’s Report (Building Smart International, 2010) proposed that “use” phase has the biggest “upside potential” by the adoption of BIM even though, its measured benefit in real projects had been low.

A BIM model will therefore act as:

1. A facilitator and reminder/motivator/instigator of early design decisions to account for lifecycle costs. Succar (2009) suggests that an indicator of BIM maturity is the level by which information flows from the construction and operations phase to the design phase.
2. A central data repository for facility management during the operations phase.

2.7 Collaboration

Son et al. (2011) define collaboration as “a reciprocal process in which two or more individuals or organizations work together. It assumes that participants have common objectives. In general, they

seek more benefits, by forming a collaborative relationship in which they are required to share resources and knowledge, than by working alone.”

2.7.1 **Nature of collaborative process in AEC**

The design and construction of a built asset necessitates the contribution of a number of professional disciplines which are very often assigned to different organisations. The contribution from each agent (e.g. architect, structural engineer etc.) often occurs at different times and places. Anumba et al.(2002) introduced the concept of “collaboration models” to AEC; explaining that as collaboration can occur at the same or different places and at the same or different times, four different collaboration modes can be perceived (table 3). This simple categorization is helpful in understanding the implications of each model and its corresponding medium of communication on the effectiveness of collaboration and its appropriateness to the desired project phase

Table 3. Collaboration models. Adapted from Anumba et al.(2002)

	Same time	Different times
Same place	Face-to-face Collaboration	Asynchronous Collaboration
Different place	Synchronous Distributed Collaboration	Asynchronous Distributed Collaboration

The nature of a typical construction project, especially during the design phase, prescribes that the starting point and time period of the contribution from each agent cannot be determined from the beginning. Additionally, the ability of concurrent contribution from two or more agents is often limited because of the interrelatedness of their inputs (Froese, 2010). As a result, significant bottlenecks in information flow occur.

Current practice is often criticised for hindering the lack of early contribution of all disciplines to design decisions. Industry and academia account several effects to this. The most prominent are:

- Design rework: e.g. it might take several iterations in order to agree on a suitable structural layout. It is important however, and often challenging, to distinguish between positive and negative iteration (Ballard et al., 2001, Tribelsky and Sacks 2010).
- Constructability issues and construction rework: these result from the lack of contribution of the contractor and subcontractors in early design decisions.
- Non-optimal design decisions: since synergies between disciplines have not been fully explored in the early design phase

2.7.2 **Models of the AEC-FM process**

The “RIBA Plan of Work” (RIBA, 2007;, RIBA 2013) represents the generic scheme that is widely adopted in the UK AEC-FM industry. This is a descriptive model in that it outlines the sequence of activities in the way it predominantly occurred within the industry. This model has formed the basis for a BIM process framework, the “BIM Overlay to the Plan of Work” (RIBA, 2014). This framework is

useful in broadly understanding the information requirements of each stage. However, this model does not account for issues relating to development of technology and information management and collaboration tools developments. This signifies significant gaps in the BIM framework which this study aims to address. The “BIM Overlay to Plan of Work” is therefore viewed as a reference or as a starting point but not as a prescriptive resource in this study.

2.7.3 ICT, BIM and Collaboration

The last decades have seen significant effort to utilise ICT as a tool to facilitate collaborative practices. Yeomans (2005) examined how ICT-enabled working methodologies were implemented in construction. Even though the term “BIM” was not widely used in the study, elements of BIM such as a “shared 3D model”, “integrated project teams” and “collaborative prototyping” were examined as to their adoption by the industry at the time. Yeomans (2006) highlighted the need for companies to perfect their collaboration processes before implementing collaborative prototyping.

BIM technology is seen to have the potential to solve the collaboration issues identified. This is mainly achieved by opening channels of communication and, at the same time, “instigating” early contribution from agents of different disciplines (Succar, 2009) resulting to a better informed design from the early phases. A BIM model automatically changes communication patterns as it acts as a central building information repository. The traditionally chaotic state of information exchanges would transition to a more ordered state. The contribution of Online Collaboration Platforms to this transition is discussed later on in this chapter.

2.7.4 Collaboration, Communication and Coordination

From the above it can be deduced that there is a close relationship between collaboration with communication and coordination. In the domains of BIM research and practice, where an explicit understanding of collaboration is critical, it is important that the terms should not be used interchangeably. Rather, communication and coordination should be viewed as necessary conditions for collaboration. As noted by Isikdag and Underwood (2010) “...effective collaboration can only be achieved through effective coordination and communication”.

2.7.4.1 Interdependence between the main collaboration requirements: Communication and Coordination

BS ISO 29481-2:2012 Building information models - Information delivery manual - Part 2: Interaction framework (BSI, 2012) states that “coordination is dependent on communication, which should be well structured, unambiguous, explicit, and prompt.” It is argued that coordination and communication tasks within a collaborative BIM process can never be understood as entirely distinct since every effective coordination task requires communication to take effect and every effective communication task requires coordination. The resultant state of BIM software configuration suggests that the implications of this effect are often disregarded by most software vendors and standards authors. As discussed later on in this chapter, it is evident from the review of literature and the review of developments in BIM adoption in the UK that most effort has been in creating coordination tools such as the BS 1192:2007 and Governance Models whereas communication tools have not been given the equivalent attention.

2.7.5 Towards collaborative BIM practice

Shelbourn et al. (2007) explain that “good collaboration does not result from the implementation of information technology solutions alone, the organisational and people issues, which are not readily solved by pure technical systems, need also to be resolved”.

2.7.5.1 Critical factors

The identification of the critical factors both technical and non-technical is the first step towards achieving collaborative BIM practices. Table 4 presents how different studies have approached collaboration and which factors they have identified. The common themes are vision, clarity on responsibilities, software interoperability and intuitiveness of software.

Table 4. Factors related to ICT-enabled collaboration

Source and context	Factors
Shelbourn et al. (2006) - “ Planning and Implementation of Effective Collaboration in Construction ”	<p><u>Key areas</u></p> <ul style="list-style-type: none"> • Vision • Engagement • Trust • Communication • Processes • Technologies <p><u>Barriers</u></p> <ul style="list-style-type: none"> • Differing visions • Differing cultures • Inadequate delegation of tasks • Imbalance of resources • Confidentiality, Intellectual Property and legal considerations • Technological incompatibility (Interoperability) • A lack of understanding of the expertise, knowledge and language of the other collaborating participants. (business interoperability)
Lee and Eastman (2008) - 3-D Model-based collaboration	<p><u>Critical factors</u></p> <ul style="list-style-type: none"> • Technical competency of the building components • Definition and relief of liabilities
Son et al. (2011) - Evolution of Collaboration within Temporary Project Teams	<ul style="list-style-type: none"> • <u>Correlations</u> Lack of familiarity and time for reaching stable state • Effort to form relationships with outside partners and tendency of cohesion • Effort needed to form relationships with those from other organizations and inefficiency of networks

Simatupung and Sridharan (2005) - Supply chain collaboration	<u>Dimensions</u> <ul style="list-style-type: none"> • Information sharing • Decision synchronisation • Incentive alignment
Underwood and Isikdag (2010) - Model-based synchronous collaboration	<u>Necessary conditions</u> <ul style="list-style-type: none"> • Coordination • Communication
Shelbourn et. al (2006) - “Planning and Implementation of Effective Collaboration in Construction”	<u>Issues raised at interviews</u> <ul style="list-style-type: none"> • Ease of use of software • Changing project culture • New forms of contract <u>Needs and requirements</u> <ul style="list-style-type: none"> • Model for collaborative working • Process enabling common vision and procedures promoting trust • Standards for interoperability • Evidence of good practice • Intuitive software interface • Clear responsibilities for generated information

2.7.5.2 The two types of effort “streams” towards collaborative BIM practices

The efforts undertaken by industry and academia towards collaborative BIM practices can be categorized into two, distinct in nature yet principally interdependent and strongly reinforcing, “streams”:

1. Efforts to improve collaborative *culture* and *process* through initiatives and integrated delivery methods.
2. Efforts to improve BIM communication and coordination *tools*.

The latter is easier to track and measure and it is naturally primarily the main responsibility of a collaboration software vendor. These are acknowledged here since they are used to identify the specific domain of the research later on.

2.8 Communication

The critical role of communication for effective collaboration has been identified in the previous section. The multi-disciplinary nature of construction projects, the transient nature of project teams and the persistent lack of adequate standardisation make project communication particularly challenging. BIM offers the opportunity for new communication paradigms. This section does not

attempt to provide an exhaustive review of communication theory and its applications within AEC-FM. Rather, the aspects most relevant to this study are captured.

2.8.1 ***Classifying communication within AEC-FM***

Communication is defined as the exchange of information between two or more different entities. There are various ways to classify communication within construction ICT systems. These classification approaches can serve as appropriate analysis tools for different purposes. They include:

- the type content of the information exchanged (e.g. building information or instructions)
- the actors engaged in the communication
- formality and structure of communication
- whether communication is recorded, tracked and formally categorized
- purpose of communication (e.g. RFI, RPQ, query on scheduled time or geometry)
- project phase context (design, construction or operation)
- reference/locus of communication (to a document or a model)
- level of integration of communication within virtual environment (“not all information on a project will be originated, exchanged or managed in a BIM format” (BSI, 2013))
- the communication medium

2.8.2 ***Tools for communication in AEC-FM***

The multiplicity of media for communication adds a significant challenge if the purpose is to achieve an adequate level of control and standardisation in project communication. The main media and corresponding paradigms are outlined as follows:

- Non digitally-mediated communication:
 - Spoken real-time communication
 - Real-time communication over telephone
 - Written/printed communication
- Digitally-mediated communication:
 - E-mail communication
 - Video conference
 - Communication through a project extranet/collaboration platform
 - Communication via design/analysis/review software using proprietary standards
 - Communication via software using open standards e.g. BIM Collaboration Format, BCF (Building Smart, 2014)

2.8.3 ***Towards “lean communication”***

The last two decades have seen considerable research work towards adapting the principles of lean manufacturing for application in construction (Koskela, 1997; Ballard and Howell, 1998). More recently, the relationship between BIM and Lean has been explored (Sacks et. al., 2010; Dave et al., 2013). The basis of these approaches is to understand the construction process as flow, create systems that favour flow, eliminate waste in time and material and maximize value to client.

Despite communication being an essential enabler for “lean construction”, it is not the focus of lean approaches as the key objective is to eliminate waste in the form of time and material. However, there has been work on construction communication which lays the ground for equivalent, metrics-based and waste elimination-focused approaches. Communication can be observed, tracked, evaluated (Becerik and Pollalis, 2006) and quantified more distinctly and effectively than collaboration can be. Tribelsky and Sacks (2006) have developed and implemented performance indices for information flow within construction projects. These have been adopted by others such as Manzione et.al (2011) and Demian and Walters (2013).

2.8.4 *Depicting communication patterns*

A communication pattern demonstrates common characteristics amongst communications. Process maps are used as the delineators of interactions between actors. For example, BS ISO 29481-2:2012 (BSI, 2012) “provides a process context for information flow”, formalizing the description of communication patterns hence fostering a common understanding around them. Alternatively, communication patterns can also be represented in network graphs (Pryke, 2012). Such representations can reveal different characteristics of communication patterns such as directionality, centrality of actors, network density, sequence, communication intensity and clustering (grouping) between actors.

2.8.5 *The basics of communication theory and the construction industry*

Communication theory enables examiners to study communication through a more rigorous, and universal set of concepts. It views communication explicitly as an act with a purpose and allows, to some degree, the evaluation of the efficiency of a given communication act. The fundamental elements of communication theory, as it has been defined by Shannon and Weaver (1949) are the:

- source (or information source)
- sender (or transmitter)
- channel
- message
- receiver
- destination
- (noise)

Dainty et al. (2007) adapted these concepts to the context of construction projects, accounting for the relevant traits such as project specificity, transience, unknown organisations, conflicting objectives, referenced information and the chaotic nature of information sources.

2.9 Coordination

Coordination can be generally understood as “the orderly arrangement of group effort, to provide unity of action in the pursuit of a common purpose” (Mooney, 1947). Similarly to communication, coordination is a very broad concept whose manifestation could be tracked universally across studies on project management. Isikdag and Underwood (2010) designate BIM coordination issues as versioning, data ownership, model breakdown, information consistency, workflow management and conflict management. Studies such as Goes and Santos (2011) and Sawhney and Maheswari (2013)

demonstrate the utility of BIM technology in design coordination. Within online collaboration (Asite, 2014) coordination relates to scheduling, user action, user responsibility, model versioning and spatial co-ordination of models (clash detection).

2.9.1 **Coordination tools**

This literature review identified three main categories of coordination in the context of BIM: (1) coordination of information, (2) coordination of access to and rights to modify information and (3) coordination of (collaborator) effort. These are highly interdependent (e.g. well-coordinated project information facilitates coordination of information access and coordination of effort). There exist a variety of resources, which either help at project level or at an individual user level to improve coordination. A number of these resources have been examined and this research classifies them collectively as “coordination tools”. In practice, these are typically not formally defined as coordination tools and not clustered into a particular category. Additionally they exist in various forms; from standards to templates, all of which aim to improve the coordination of BIM information and/or collaborative effort and/or access to information. These are listed below:

- BS 1192:2007 (effort and information coordination):
- Model Production and Delivery Tables (effort and information coordination):
- Information Delivery Manual (coordination of collaborator effort by coordinating communication and interaction)
- Model View Definitions (information coordination)
- Access Rights tables (information access coordination)
- BIM Governance Models (Rezgui et al., 2013) (information, access and effort coordination)

As mentioned earlier, the appropriate coordination of information, access rights and effort facilitates efficient communication in a digital BIM environment.

2.10 **Online collaboration platforms**

Online Collaboration Platforms (OCPs) are the combination of web-based technologies “that create a shared interface, to link multiple interested parties, to share, exchange and store project information in digital form, and to work collaboratively, on the basis of subscription fee, license plus maintenance, negotiated fixed cost or exclusive business partnership agreement” (Liu et al., 2011). These are have also been referred to as Construction Project Extranets (CPEs) (Yeomans, 2005), Online Construction Project Management (OCPM) (Becerik, 2006) or “web-enabled project management” (Alshawi and Ingirige, 2003). In the last 15 years, the UK construction industry, has increasingly embraced this kind of solution, more typically for large projects. Results have often been very positive, quantifiable and repeatable like in the case of the Heathrow Terminal 5 refurbishment project (Riley, 2007). With increasing capabilities of technological infrastructure, developments in industry standards and legislation and continuously developing user requirements, the functionalities of OCPs have been under demand for continuous development (Wilkinson, 2005; Wilkinson, 2014).

2.10.1 **Service-orientation (and Cloud Computing and OCPs)**

Online Collaboration Platforms are closely linked with the concepts of Cloud Computing, Software-as-a-Service (SaaS) and Service-Oriented Architecture (SOA). Cloud Computing is a technological

paradigm where computer processing infrastructure is made available through machines at a different location and connected through the internet. The National Institute for Standards (NIST) in the U.S. defines Cloud Computing as “a model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources (e.g. networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction. This cloud model promotes availability and is composed of five essential characteristics, three service models, and four deployment models” (NIST, 2011). Cloud Computing is seen as containing three basic concepts: Virtualization, Utility Computing, Software as a Service.

Software-as-a-Service is summarised broadly as a more user-centric, flexible and modular way of offering software to users. A service is understood as a logical representation of a repeatable business activity that has a specified outcome. Typically, applications-functions are available on demand on a subscription basis. Often the Application Programming Interface in a SaaS is relatively open, allowing users or other parties to build applications on top of the basic platform. Service-Oriented Architecture (SOA) is a type software architecture that supports service-orientation.

Some implications of the above to BIM and this study include:

- New models for paying for software by users.
- The connectability between software.
- A need for standards to harmonize the emergence of a range of heterogeneous applications.
- A characteristic flexibility and modularity which offers the potential for improved services based and added to existing, “basic” solutions.
- On a more abstract level these technological and business paradigms move the focus on providing a service and improving efficiency rather than providing a software hence eliminating some services and processes which are non-value adding.

2.10.2 **Capabilities and benefits of OCPs**

Liu et al. (2011) provide an extensive categorisation of the marketed functionalities of UK OCPs defining the four main categories as “System Administration”, “Document Management”, “Workflow Management” and “Communication Tools and Add-ons”. *Shafiq et al. (2013)*, focusing on online BIM collaboration systems, categorise user requirements as “Model Content Management”, “Model content creation”, “Viewing and Reporting” and “System Administration”. *Alshawi and Ingirge (2003)* provide a comprehensive list of OCPM benefits based on UK project case studies. *Becerik and Pollalis (2006)* study of the benefits of OCPs based on US project case studies the benefits are categorised as tangible (for which benefits were accounted to specific functions), quasi-tangible and intangible. This categorisation illuminates the fact that the benefits are perceived differently when examined on a project level compared to an organisation or industry level. The study also noted the difficulty in calculating the savings on a project as they were incurred on different agents in the supply chain. This is particularly important due to the industry’s widely acknowledged project-based/focused and fragmented nature. The benefits from this study are summarized in Table 5. The “Proving Collaboration Pays Study” (*NCCTP, 2006*) report conducted in the UK yielded very similar results with the addition of “having 24/7 access to documents”.

Table 5. Functions and benefits of online collaboration platforms (adapted from Becerik and Pollalis, 2006)

Tangible Benefits (known financial impact on cash flow)	
Electronic RFI	<ul style="list-style-type: none"> • Reduction of RFI turnaround time • Reduction in RFI numbers • Audit trail • Enforcing timely responses • Impact on overall schedule and budget
Electronic Bidding	<ul style="list-style-type: none"> • Enhancing time and cost saving for bid proposal preparation • Reducing proposal litigations after the bid by having complete audit trail • Elimination of potential bidding errors • Quick information exchange among bidders • Easier comparison of price and technical data • Easy and controlled access to archived data also increases the range of potential bidders • Standard format in bidding process
Electronic document transfer	<ul style="list-style-type: none"> • Reduction in document transfer costs • Reduction in printing costs
Quasi-tangible Benefits (not quantifiable but valuable)	
<ul style="list-style-type: none"> • Improved data information document availability • Completed audit trail • Improved information management • Faster reporting and feedback • Enabled valid and accurate decision making • Improved process automation and standardization • Improved version control • Better project/program monitoring and control • Improved timely capture of design/construction decisions • Reduction in errors and wastage/ fewer information bottlenecks 	
Intangible Benefits	
<ul style="list-style-type: none"> • Knowledge management • Process and workflow Reengineering • Supply Chain Integration • Competitive Advantage • Business Development • Forecasting • Risks management – Claims mitigation and management • Performance measuring – Setting Incentives 	

2.10.3 Barriers to uptake of OCPs

The NCCTP (2006) survey revealed that 96% of users of collaboration technology were satisfied with its service and half of them were committed to it. Eight years later, however, the industry is far from widespread utilisation of online collaboration technology. Ilich et. al (2006) ask “why aren’t we using our tools?”, attempting to give an account of the same phenomenon in the US .The barriers are summarised as follows:

- Contracting methods
- Some of the participants are forced to use new tools. This results to information disparity, long learning curves and resistance.
- Difference in goals between organisations which hamper the shared vision
- Inadequate interoperability between platforms
- Difficulty in changing workflows to match collaboration tools
- Technical inability of subcontractors
- Cost of purchase/subscription to platforms.

Based on real case studies of projects using online collaboration Alshawi and Ingirige (2003) conclude that the weaknesses of web-enabled project management are:

- The costs in securing project information
- Cultural Issues e.g. concerning architectural drawing transfer.
- The issue of ownership of drawings; some designers are uneasy with the idea of keeping the drawings centrally
- Virtual meetings not being able to replace face-to-face meetings

In the focus-group study by Shafiq et al. (2012) on the use of OCPs as BIM Model Collaboration Systems users expressed the following challenges:

- Difficulty in mastering the diversity of available OCPs.
- Adapting to varying terminology across companies’ internal standards, OCPs and industry standards.
- Training and learning curve.
- Unwanted emails generated by OCPs.
- Difficulty in controlling BIM information and ownership and responsibility.
- Data security and intellectual property concerns.
- Very low confidence in the reliability of BIM model content.

2.10.4 OCPs and BIM

There has been considerable expectation for online-based BIM solutions. Underwood and Isikdag (2010) point out that “cloud computing will enable the next generation of (full state) BIMs” (or BIM 2.0) where the “digital building model will evolve through the lifecycle of the building”. In this integrated environment (BIM 2.0) the internet will act as the medium through which the BIModel will be continuously updated and open for new information. Grilo and Goncalves (2011) explain how cloud computing in combination with BIM will transform e-procurement by enabling the mapping of

“traditional unstructured information into structured objects” hence generating interoperability. Beach et al. (2011) argue that online collaboration platforms address the universal BIM adoption issues of “data sharing, access, and processing requirements”.

OCPs have attempted to respond to this expectation by embracing BIM. Apart from the, more traditional, paradigm of storing 3D CAD and BIM files on the document management systems, increasingly more OCPs offer online IFC model servers with the ability to view, merge, interrogate IFC models and set-up workflows around them as well as automatically generate COBie spreadsheets. The level of uptake of these OCP BIM modules has not been satisfactory. This is owed primarily to the low reliability on model content as conversions from proprietary BIM software to the IFC standard tend to be associated with considerable data losses.

2.10.5 *Different types of BIM-enabled collaboration tools and platforms*

The last five years have seen a proliferation in the emergence of BIM-enabled collaboration tools. A diversity of tools which are based on a diversity of technologies and support standards to various degrees exist. Currently there is seems to be no settlement as to what type of software will gain dominance in the specific market. Clients and construction companies often choose to employ different collaboration software for different projects and often use a combination of collaboration tools for a project. This results to varying degrees of effectiveness in terms of their interoperability and the associated seamlessness in information flow. The following serve as examples of different categories of BIM-enabled collaboration tools

- Construction project extranets with a strong browser-based document management offering complemented (relatively recently) with BIM modules (most are primarily UK-based): Asite, 4projects, Conject, Aconex, Causeway.
- Primarily BIM-focused browser-based collaboration tools: Active 3D, BIM+,
- BIM Server (BIM Server, 2015) is an IFC-based online platform with no focus on user interface and no interest in direct profits. It offers a technological platform for development of extensions (e.g. tools built specifically for IFC-based quantity take off and other intelligent purposes) and is also utilised for research purposes.
- Machine-based collaboration tools: BIM Review (AceCad software, 2014)
- BIM collaboration tools from established BIM design and analysis software vendors. These are both machine-based and browser-based: Project Wise (Bentley, 2014), BIM 360 Glue (Autodesk, 2014), BIMX (Graphisoft,2014).

Despite often being treated as substitute software solutions, there are significant technological differences across online BIM collaboration solutions Cerovsek (2011). An important criterion lies in whether the BIM model is stored as an IFC-enabled online database or not. This enables easier update of parts of the model and discipline-based filtered viewing of the model.

2.10.6 *Model-centric approach vs. document-centric paradigms in collaboration tools*

A number of studies have called upon the need for project collaboration to depart from the document-based paradigm and place the structured model as the focal unit of communication. In fact, model-

based working and model-based communication are often seen as indicators for BIM maturity (or its equivalent concept). Aouad and Lee (2005) have critically described project information as “unstructured and document based”. Yeomans (2006) revealed that the “single build model” was the least adopted out of eight collaborative working techniques. In their ICT Vision mapping, Rezgui and Zarli (2006) suggest that document-centric information exchange should be replaced by model-based ICT. Succar (2009) describes progression in BIM maturity by replacing document-based workflows; Isikdag and Underwood (2010) claim that “the traditional nature of the industry is extremely ‘document-centric’” while Shafiq et. al (2012) note that “drawing is the currency”.

It is evident that the model-based paradigm has a significant effect on the efficiency of communication and coordination. OCPs and collaboration tools in general are the main catalysts for such efficiency improvements as they largely define the way in which users interact with information and interact with each other in reference to that information.

2.10.7 The Common Data Environment, CDE (as defined in BS 1192:2007)

BS 1192:2007 (BS, 2007) is one of the most significant standards which support digitally-enabled collaborative working in construction. This standard has been introduced in the Coordination section of this review as an important example of what this study calls “Coordination Tools”. BS 1192:2007 helps coordinate project information, uploading/revising project information and accessing project information. It helps establish common terms and logical understanding of processes such as “automation of drawing and document production processes, indexing and searching project material, filtering and sorting and quality checking and document comparisons”. As stated in the standard a major constituent of collaborative environments such as Online Collaboration Platforms “is the ability to communicate, re-use and share data efficiently without loss, contradiction or misinterpretation”.

The highest level concept in BS1192 is the Common Data Environment (CDE). The concept of the CDE represents any digital environment in through which project information is uploaded to, shared, accessed and revised. The standard defines four “areas” in the CDE: “Work in Progress”, “Shared”, “Public Documentation” and “Archive”. Key to the process is the management of moving the data between each of the four phases. It is here where vital checking, approving and issuing processes are executed.

The CDE is important in BIM adoption as it is widely recognized and often a requirement of users for collaboration tools (or “project extranets”). BS1192 is an important piece in the UK Government’s set of standards for BIM Level 2 i.e. it forms the definition of Level 2. Despite the significant drive, this code of practice is not yet fully adopted by the construction industry.

2.11 Requirements Engineering

Previous sections have examined the nature of the AEC-FM industry and its effect on the adoption of technology, the potential opportunities offered by BIM and OCPs as well as basic expressions of requirements which come in the form of Collaboration, Communication and Coordination. This section examines Requirements Engineering, the systematic approach which “helps determine what to develop, how to develop it, and when it should be implemented” (Aouad and Arayici, 2010).

Requirements Engineering is defined generally as “the subset of systems engineering concerned with discovering, developing, tracing, analysing, qualifying, communicating and managing requirements that define the system at successive levels of abstraction” (Hull et al. 2005). The description of such approaches can often be regarded as common sense, however proper application of Requirements Engineering that is appropriate will yield positive results. The basic principles include (Arayici et al. 2006; Hull et al, 2005):

- Making decisions traceable; striving for clarity in decisions and thought process.
- Accounting for the whole system in question and not just the technological part.
- Defining appropriate representations/models of systems and sub-systems, stakeholders and requirements.
- Acting on proper distinctions between stakeholder requirements and system and system component requirements.
- Involving stakeholders throughout the process

Arayici et al. (2006) develop Requirements Engineering Framework specifically for “Computer-integrated Construction”. They attempt to address the lack of communication between software developers and industry practitioners and formalise the otherwise typically overly diverse process.

The seven phases recommended are outline as:

1. Project Blast-of
2. Requirements Elicitation
3. Building a shared understanding
4. Process Modelling
5. System Design
6. Use Case and Object Modelling with UML
7. Incremental Prototyping with End Users Tests

In the context of OCPs, the three categories of requirements and corresponding Requirements Engineering approaches can be described as follows:

1. Requirements defined by industry/government-imposed or industry/government-proposed standards and/or methods of working (e.g. the BS1192:2007 (BSI, 2007)).
2. Requirements explicitly expressed by existing or potential users (e.g. “export COBie spreadsheet directly from IFC model through “export COBie” button”).
3. Novel features which aim to fulfil requirements expressed by existing or potential users in a broad/implicit way (e.g. “improve user experience”).

2.11.1 Requirements Engineering Issues in OCPs and BIM

In the domain of requirements engineering for BIM collaboration tools, two effects emerge as a result of the natural traits of AECFM (project specificity and project-led nature, inadequate standardisation, discipline fragmentation, life-cycle phase fragmentation) and the emergence of cloud-based solutions.

These are:

- Cross-project variation in both high-level software configuration (what combination of software to use) and low-level software configuration (which part of each software to use). The vague distinction between the roles of software calls for an approach supporting flexibility (from the perspective of project set-up) and prioritization (from the perspective of software development).
- Requirements engineering for cloud-based solutions tends to be a combination of moving existing functionality to the cloud as well as devising novel, “fit-for-cloud” functionality.

2.11.2 *The need for context-specific “language” in Requirements Engineering*

An effective Requirements Engineering process, in all fields but even more so in AEC-FM should involve the variety of system stakeholders. These stakeholders engage in a process where the high-level, user requirements are articulated and documented and transformed into system and component requirements (Hull, 2005). This poses a particular need for creating and maintaining a shared understanding amongst individuals from different disciplines who normally work in different working environments while an information system is conceptualised. Therefore, shared conceptual models which offer appropriate representations of the system and its intended attributes have an important role.

2.12 Developments in BIM adoption in the UK during the course of the study (2011-20145?)

The efforts to improve efficiency in the AEC-FM industry through the use of ICT have been ongoing for the last few decades. In the last decade, products labelled as BIM technology have been deployed in various ways by leading companies, more typically in large scale projects. What has marked the beginning of a more formal, more controlled, more inclusive, industry-wide adoption of BIM was the decision of the Government to “introduce a progressive programme of mandated use of fully collaborative Building Information Modelling for Government projects by 2016”, communicated in May 2011 through the Government Construction Strategy (Cabinet Office, 2011). Apart from leveraging on the existing drive to utilise the potential of BIM technology to address chronic industry problems, this decision coincided with a period of low performance in the industry. Additionally, the US and many Northern European countries were much further ahead in adoption of BIM. It is indicative that by that time, in the US there had been developments such as:

- A National BIM programme by the General Services Agency first established in 2003 (GSA, 2007; Wong, 2011)
- A National BIM standard first issued in 2007 (NBIMS, 2007).
- A guide by the American Institute of Architects for an approach to project delivery labelled as “Integrated Project Delivery” which set the principles for collaborative working, new forms of contract and use of BIM technology in a collaborative spirit (AIA, 2007).
- A “BIM Protocol Exhibit” by the AIA which defined BIM-specific constructs such as the “LOD, Level of Development” which were intended for use in project coordination and contracts (AIA, 2008).
- BIM Project Execution Planning Guides, with the most popular being the one developed at Pennsylvania State University, first in 2009 (CIC, 2009)

2.12.1 *The various signs of change*

The strategy communicated the Government’s intention to support similar initiatives by facilitating a BIM-driven reform movement. By far the most popular reference point throughout the industry during this time has been the “BIM Maturity Model” which was first outlined in the same year as the Construction Strategy in the “B/555 Roadmap”(BSI, 2011). This maturity model broadly defined four successive levels of BIM maturity (Level 0 to Level 3) and the corresponding Standards, Guides, Classifications and adoption Roadmap phases. The definition of Level 2 BIM, the target set for 2016, has been refined since and its final expression, together with the standards required to support are expected to be available within 2014 or 2015. Level 2 is not expected to require fundamental changes in contracts and delivery methods while Level 3 is probably expected to do so (Level 3 remains the subject of discussion). The basic requirements for Level 2 BIM are:

- The delivery of 2D plans and 3D BIM models upon project handover.
- The delivery of building information in the form of COBie spreadsheets upon project handover.
- The preparation of this information from the project team in a collaborative process which occurs through a controlled data exchange/sharing environment, the “Common Data Environment” as defined in the relevant Code of Practice, BS1192:2007 (BSI, 2007).

Mobilisation from the industry has been overall significant and continuously increasing both in degree and participation. The National Building Specification(NBS) tracked the adoption of BIM through standard survey questions which show an increase in the percentage of the respondents who are using BIM from 13% in 2010 to 31% in 2011, 39% in 2012 and 54% in 2013 (figure 2) (Waterhouse, 2014). The majority of big companies have formed BIM-specific groups and created BIM deployment-specific role who are responsible creating company BIM strategies and BIM Execution Plans. Additionally, clients are increasingly showing signs of appreciation of the value of BIM in the life-cycle of their asset.

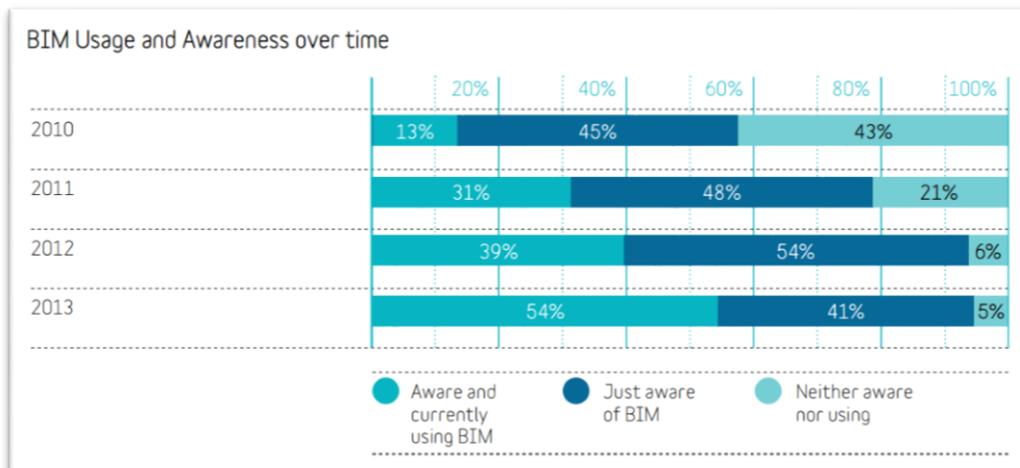


Figure 2 “BIM Usage and Awareness over time”. Results of the NBS Annual BIM Report Questionnaire Survey, From: Waterhouse (2014)

The period after the Government Strategy has seen the development of a number of BIM-related standards, specifications, guidelines and protocols in the UK. The most important are:

- PAS 1192-2:2013 (BSI, 2013)
- PAS 1192-3:2014 (BSI, 2014)
- COBie UK-2012 (Nisbet, 2012)
- COBie data drops (Cabinet Office and BSI, 2013)
- BS 1192-4 (BSI, 2014)
- The BIM Overlay to the RIBA Plan of Work (Sinclair, 2012)
- CIC/BIM BIM Protocol (CIC, 2013a) (incorporating coordination constructs/tools “Level of Detail” and the “Model Production and Delivery Table”)
- CIC/BIM Best Practice Guide for Professional Indemnity Insurance when using Building Information Models (CIC, 2013b)
- The Employer’s Information Requirements (BIM Task Group, 2013)
- The Government’s Soft Landing Policy (Cabinet Office, 2012)

Some other signs of change are the emergence of many BIM process and technology consultancies, the emergence of many BIM product libraries and the development of taught BIM programmes at UK Universities.

2.12.2 *The BIM adoption movement*

The challenging task for the government to control, maintain, record and act upon a healthy level of communication with industry has been achieved by the formation of the BIM Task Group (BIM Task Group, 2014). This has served as an official BIM hub and “housed” initiatives such as the “BIM4” groups such as “BIM4SMEs” or “BIM4FM” as well as regional “BIM Hubs”. Additionally, in 2013, the UK and Ireland chapter of Building Smart (Building Smart UK, 2014) became part of the BRE and offers BIM and COBie training as well as certification for BIM Accredited Professional status. These initiatives have produced positive results overall and have gained international recognition. The BIM Task Group and the Construction Industry Council received a Fiotech award in acknowledgement of their “world-leading BIM strategy” (CIC, 2013).

In some respects the adoption movement could be viewed as the imposition by the Government of the requirements for BIM and the mobilisation from practitioners in order to meet them. However, most would agree that it can be better described as an open two-way discussion between Government/BIM Task Group and practitioners. This has meant that the adoption movement has had a strong experimental aspect. The “early adopter project” on the Ministry of Justice, Cookham Wood facility (MoJ, 2013) produced promising results as well as some lessons for the use of COBie. The, more extensive and hence more challenging, “Open BIM / COBie trial” on the Gatwick Airport (BRE, 2014) revealed that despite the positive approach demonstrated by leading contracting, design and software companies, some technical issues regarding IFC and COBie were hindering adequate information flow.

The experimental aspect of the adoption movement was often characterized by great uncertainty in terms of what the precise requirements for BIM Level 2 are, what the supporting standards are, when they will be available and how to make use of standards such as COBie. A great number of discussions have been taking place through social media such as LinkedIn and Twitter as well as the numerous BIM blogs that have emerged. Occasional claims by companies that they are operating at

Level 2 BIM have been quickly cancelled out by the fact that BIM Level 2 hasn't been properly defined yet.

At the time of writing there seems to be convergence towards an adequate definition of Level 2 BIM and the production of the entire set of standards needed to support it. The definition, supporting technology, requirements and supporting standards for Level 3 still remains a subject of discussion at time of writing.

2.12.3 *Developments in collaboration tools and UK BIM*

The IFC data exchange standard has improved but not enough in order to produce seamless exchange of building information between different proprietary tools. For this reason, users have been reluctant to use IFC-based online BIM tools offered by OCPs. Nevertheless, there has been considerable effort to utilise OCPs as the as defined in BS 1192:2007 (BSI, 2007). There is however, a degree of uncertainty as to the exact role OCPs can have within the BIM process as a competition for a Government-funded "Digital tool for BIM" (Technology Strategy Board, 2014) is under way. This tool is expected to "support publicly available standards" and be comprised of a Digital Plan of Work" integrated with a "digitally-enabled" Classification System" which would offer "robust data validation, extensive search, analytics and modelling capabilities".

2.12.4 *BIM Standards and Specifications*

Table 6 presents the most important standards and specifications on BIM. These cover a range of aspects of BIM such as standardization of product libraries, information exchange/handover formats, strategy for BIM adoption, understanding of process and code for collaborative practice. For the purposes of this study, these resources can be used to understand what aspects of BIM have been considered worthy of requiring standardization.

Table 6. The most important Standards and Specifications on BIM

Code	Year	Title
ISO 12006-3:2007	2007	Building construction -- Organization of information about construction works -- Part 3: Framework for object-oriented information
BS 1192:2007	2007	Collaborative production of architectural, engineering and construction information – Code of practice
N/A		Construction Operations Building Information Exchange (COBIE)
BS 29481-1:2010	2010	Building Information Modelling – Information Delivery Manual Part 1: Methodology and Format
BS/555	2011	Roadmap Design , Construction & Operation Data & Process Management
BS 29481-2:2012	2012	Building Information Models – Information Delivery Manual Part 2: Interaction Framework
N/A	2012	COBie UK-2012

ISO 16739:2013		Industry Foundation Classes (IFC) for data sharing in the construction and facility management industries
PAS 1192-2:2013	2013	Specification for information management for the capital/delivery phase of construction projects using building information modelling
PAS 1192-3:2014	2014	Specification for information management for the operational phase of assets using building information modelling
BS 1192-4	2014	Collaborative production of information Part 4: Fulfilling employer's information exchange requirements using COBie – Code of practice

2.13 The need for a better conceptual framework – gaps in shared “BIM constructs”

The review of literature, the BIM adoption discourse and the multiple BIM standards reveals a lack of homogeneity in terms and definitions. This indicates a multinational research effort with common vision but lacking coordination. This phenomenon is expressed appropriately by Succar (2009) who points out that “such divergence and coverage highlights the lack of and the necessity for a research framework to organise domain knowledge”. In an effort to develop this framework Succar (2009) devises a “BIM ontology” (consisting of constructs such as BIM “fields”, “stages” and “lenses”) as well as a visual language to complement it. Furthermore, in an effort to provide metrics for assessment and improvement, Succar (2010), has identified a set of 5 components of BIM performance measurement: Capability Stages, Maturity Levels, BIM Competencies, Organisation Scales and Granularity Levels. Succar’s research has been received positively amongst research and practice, particularly within the newly formed field of BIM consultancy, as it manages to capture and synthesize the essence of the multiple facets of the BIM domain in a way (a representation) appropriate for understanding it, communicating about it and relating it to project or industry specific phenomena.

Kreider and Messner’s (2013) “BIM Uses” is a another example of a research outcome which manages to provide appropriate representations of shared BIM concepts -in their case a taxonomy of uses of BIM technology. It provides a robust set of terms which can support the much needed shared understanding amongst BIM stakeholders such as tool developers and users. The BIM Uses can be particularly helpful in constructing project-specific BIM Execution Plans (Messner et. al, 2010).

It is evident from the review of literature (including resources for the BIM framework) and the review of developments in BIM adoption in the UK that most effort has been exercised in creating coordination tools such as the BS1192 and BIM Governance Models. It is proposed by this study that the communication aspect of BIM (i.e. the perspective that BIM tools serve essentially as a communication tool) has not been given the equivalent attention. In Cerovsek’s (2011) “multi-standpoint framework for technological development” the need to recognize this is highlighted. Cerovsek’s approach in devising a BIM framework is based on the recognition that BIM is a characteristically multi-aspect domain. Cerovsek identifies two important issues within BIM:

- The need for BIM research and practice to recognise that BIM will always be an evolving field. The implication from this is that BIM frameworks need to be robust enough to accommodate this

continual evolution / change i.e. they should not be limited by the capabilities of specific technological paradigms.

- The need to understand that BIM is fundamentally about communication and the resulting need for BIM frameworks to incorporate communication theory.

It is found from the review in this study that the above two requirements from BIM frameworks are not met adequately. Therefore, a core aim of this study is to provide material to address them.

2.14 Preliminary Framework (Scoping study, part A)

A scoping study was conducted as a means for transitioning between the literature review and the data collection part of this research. This section – Part A of the scoping study- utilises existing literature and standards to construct a preliminary conceptual framework. This is used as a reference for the next steps in this study: it is chiefly used to identify any gaps and serves as a basis for improvement.

2.14.1 Mapping for BIM adoption - The need for an appropriate representation

As identified in the review of literature and standards the BIM paradigm brings about changes in different fields such as technology, policy, process and coordination tools and concepts, culture etc. This means that individuals within the industry who are to follow this change need to be presented with a model (or models) which denotes the key relationships between the different elements (or constructs) that are relevant to their own tasks (e.g. information exchanges, BIM model Level of Development etc.). The multi-disciplinary, project-based and fragmented nature of the industry makes the requirement for a shared understanding of these essential relationships ever more pressing and even more challenging. There is a need, therefore, to relate the various BIM elements and present them in a way that is appropriate for further use. Uses range from development of BIM Project Execution Plans, company BIM strategies and software development roadmaps to completion of tasks within projects such as model coordination, information exchanges and requests for information. An appropriate model would be one that would hide the complexity of the domain while highlighting the concepts and relationships which are relevant to each purpose. Succar (2009) proposes the idea of “lenses” as a tool to manage the complexity of the BIM domain: “Lenses allow the domain researcher to selectively focus on any aspect of the AEC-FM industry and generate knowledge views that either (a) highlight observables which meet the research criteria or (b) filter out those that do not”.

The need for an appropriate “mapping” (a meaningful association) of the BIM elements specifically for the purpose of OCP development is the main driver for this study. The integral yet poorly defined role of OCPs to support BIM would be interpreted more readily given an appropriate mapping of the BIM elements/constructs. In order to build a conceptual basis for the model to be ultimately developed the fundamental elements (coordination constructs/terms) typically used within academic literature, standards and guidelines were identified, as presented below:

Time-related

- Project phases (RIBA,2013 & OmniClass,2012)
- Decisions points
- Information exchange points

Purpose-related

- Purpose (or objective) of phases
- Primary deliverable of phase. (RIBA, 2013)

Location-related

- Physical location of project progress

Person-related

- Agents
- Disciplines
- Roles
- Organisations

Information-related

- Information exchange types. e.g. contracted exchange (East et al., 2010)
- Data – Information – Knowledge – Wisdom
- “Dimension” of information (as in “nD modelling”) (Lee et al., 2005)
- Supporting data structures
- Type of building element modelled

Process-related

- Type of action/process on information:
 - 1: “collect, create, correct, connect” (Coates et al. 2010),
 - 2: “versioning, derivation, composition” (Rezgui et al., 2013)
- Type of collaboration (Anumba et al., 2002) (and as a consequence if machine-based working or web-based working is primary medium)

Software-related

- Software tools
- Software tool modules

Conceptual tools

- Coordination tools used in phases (Tribelski and Sacks, 2010)
- Supporting standards

Device related

- Devices used

The concepts that follow are listed separately as they impose, in principle, a different configuration of the concepts above:

- Contract type

- Project delivery method
- BIM Maturity Level

2.14.2 ***Preliminary Models for understanding AEC-FM process in order to support BIM and OCP development***

The “fundamental ingredients” of a BIM mapping (as identified in the previous section) were used to generate a set of preliminary models. In some respects these resembled tools such as the Model Production and Delivery Table (MPDT) which are used in the CIC/BIM Protocol ((or the Model Element Table as used in the AIA Building Information Modelling Protocol Exhibit (AIA, 2008)). The following mappings are presented in Figures 3 to 7.

1. Collaboration Modes and Desk vs. Site Work (figure 3)
2. nD model development (figure 4)
3. Create –Connect – Collect – Connect (based on Coates et al., 2010) (figure 5)
4. Data – Information – Knowledge – Understanding – Wisdom (figure 6)
5. Versioning – Derivation – Composition (based on Rezgui et al., 2013) (figure 7)

These were presented and discussed both within the sponsor company and with academic supervisors. Despite being able to add some clarity and indicate some directions for research as well as development of software these models were not detailed, authoritative or validated enough to provide adequate guidance in practice for any purpose. What was observed during the process was:

- There is a big variation across different mappings found in literature (Fiatech, 2003; Lee and Eastman, 2008; OmniClass, 2012; Cersovsek, 2011 provide just some of many examples)
- The complex or “wicked” (Buchanan, 1992) nature of this challenge (as used in the field of Systems Thinking). This indicated that practical solutions would more easily come about from incremental changes (often descriptive models of emergent states would support this rather than imposed “BIM maturity states”) rather than derivations of “mapping” the solution from “first principles”. This posed the question whether such derivations from any “first principles” would add offer additional value to models such as purposefulness, universality and robustness.
- In terms of the role of OCPs: they were seen as a main enabler for bringing down the distinctions between the traditional AEC-FM project phases to reach what (Succar, 2009) describes as a “phase-less process”.

Therefore, these mappings served as a reference point for the following steps of the Scoping Study as well as providing for motivation for the development of a more appropriate framework and conceptual model.

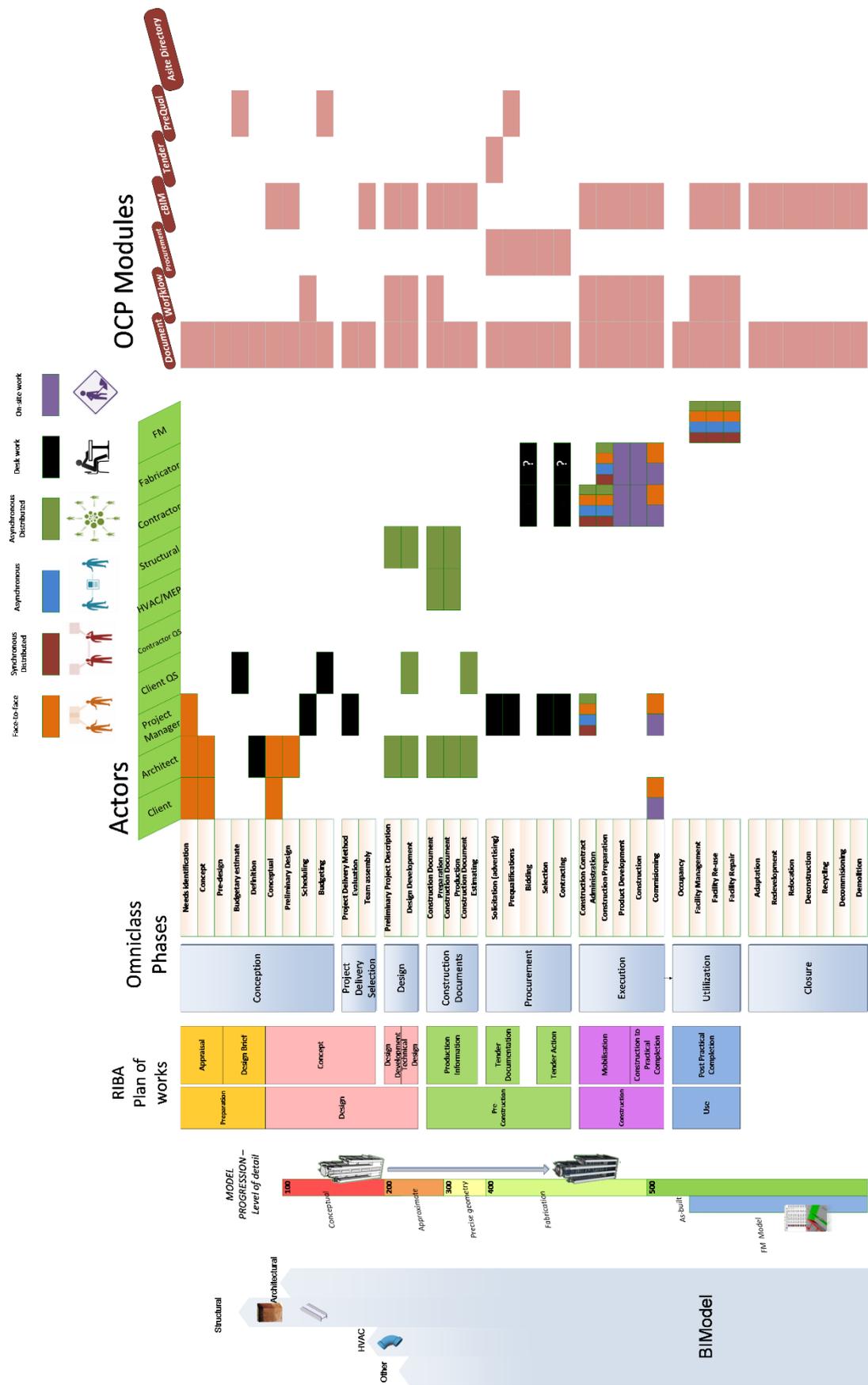


Figure 3. Preliminary “BIM element/construct mappings”: 1. Collaboration Mode and Desk vs. Site Work

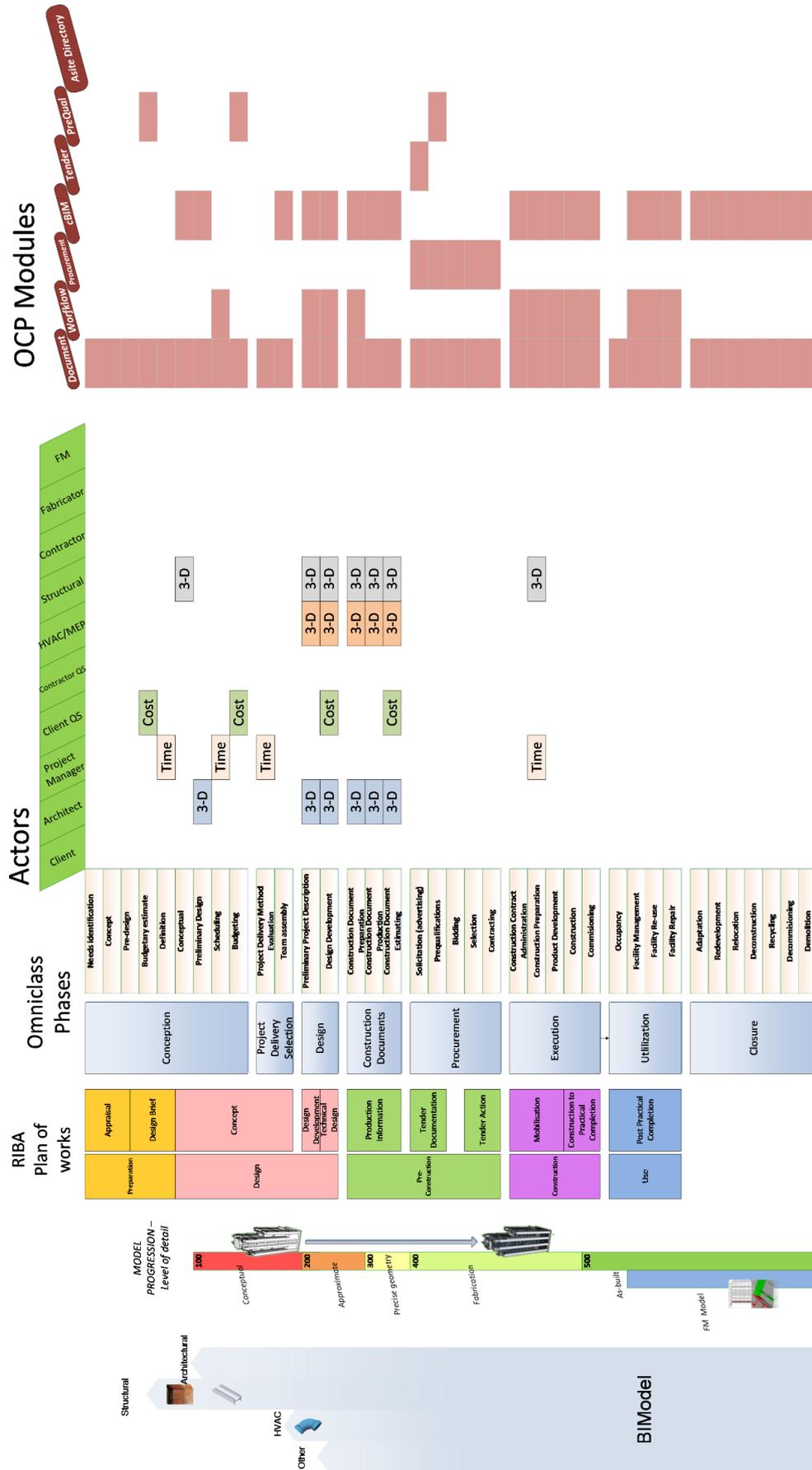


Figure 4 Preliminary “BIM element/construct mappings”: 2. nD model development

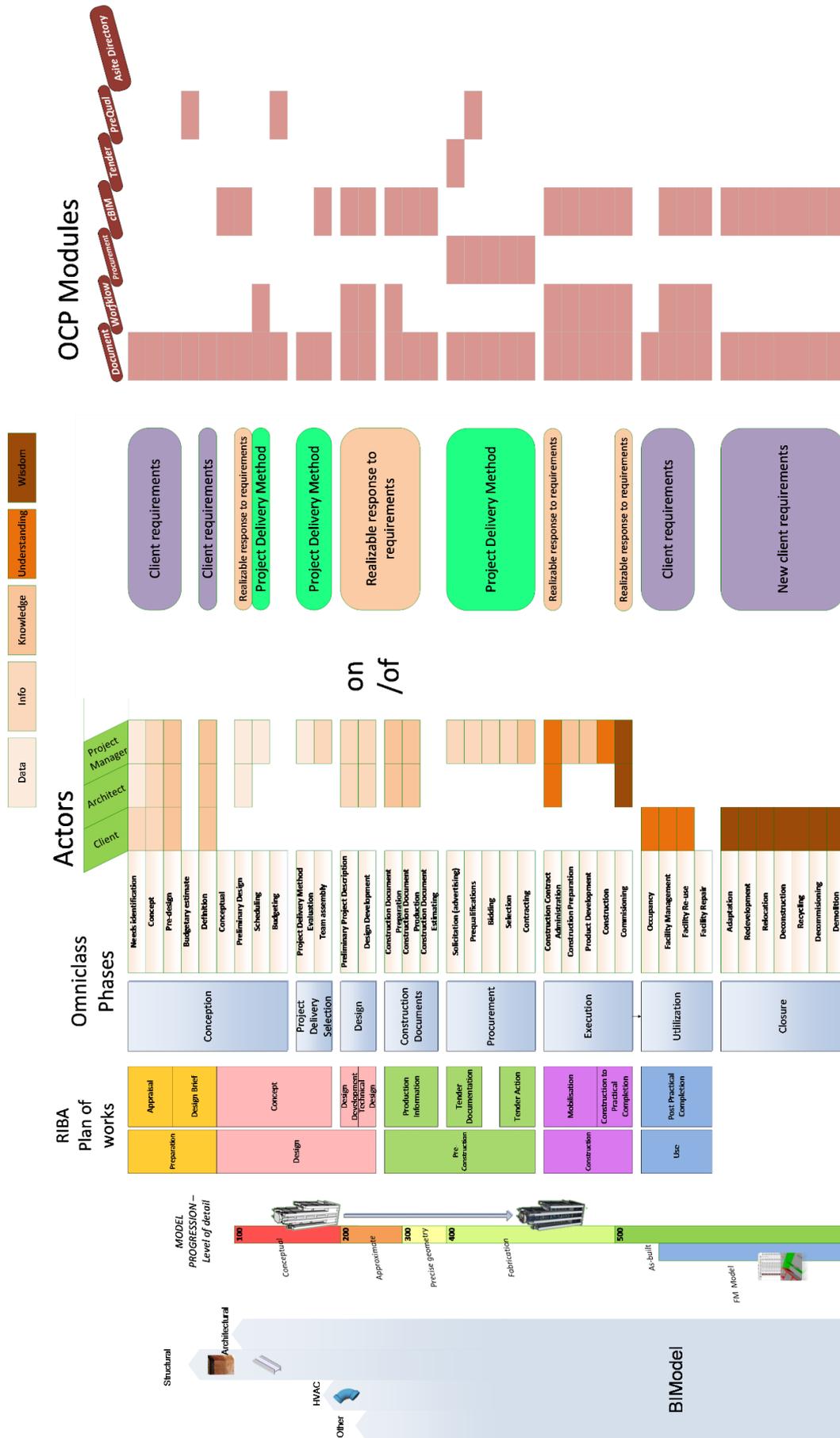


Figure 6 Preliminary “BIM element/construct mappings”: 4. Data – Information – Knowledge – Understanding – Wisdom

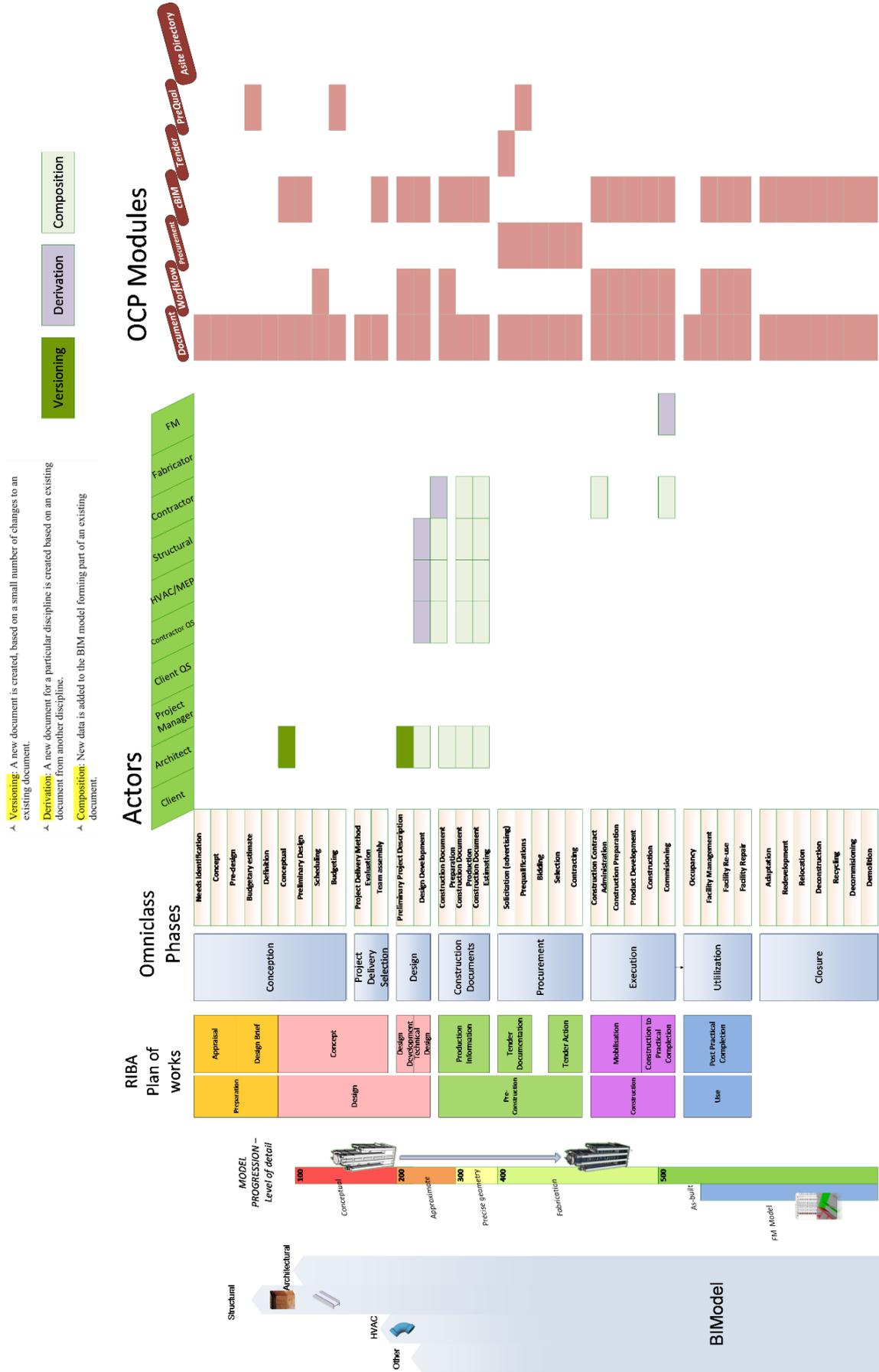


Figure 7 Preliminary “BIM element/construct mappings”: 5. Versioning – Derivation – Composition (based on Rezgui et al., 2013)



Sources: (A) Becerik (2006) , (B) Kim et al. (2011) , (C) Kagioglu et al. (2011) , (D) Nitithomyong and Skibniewski (2004) , (E) Wilkinson (2005)

Figure 8 Preliminary Framework for OCP Roadmaps

2.14.3 The role of OCPs within the AEC-FM ICT-driven vision

The different expressions for the ICT-enabled vision have been identified through a review of relevant literature. Figure 1 summarises how four sources understand the ICT-driven vision through their descriptors of this vision and the dimensions they emphasize are on the path towards this vision. The main theme was the path towards deeper integration enabled by interoperability on the data, semantic and organisation levels).

The output of this research will contribute towards the collaboration tool “effort stream”. Nevertheless, interactions between the two “effort streams”; technology and culture and process need to be understood. The characteristics of the interaction between business process and technology deserve closer consideration. Across all industries, technology and business processes could be understood as existing in a symbiotic relationship through which they co-evolve, influencing one another (Figure 3). In the last decade, through componentisation and service orientation, technology vendors are increasingly becoming an “on-demand business” (Cherbakov et al., 2005). Solutions are now more flexible, modular and hence more able to be tailored around an existing business process. Construction OCPs and the SaaS model they adopt is an example of this phenomenon. Nevertheless, as the dimensions in the Figure 1 suggest, business processes cannot remain unchanged for the AEC-FM industry to reach the long-term vision. Instead, it is argued that there has to be a shift of both technology and business processes (Figure 9)

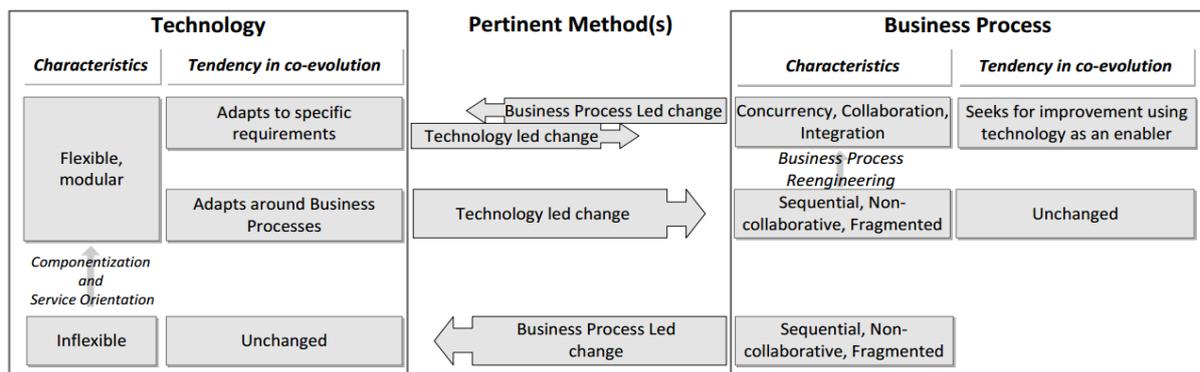


Figure 9 Symbiotic relationship between business process and technology

2.14.4 A preliminary framework for OCP roadmaps

The role of OCPs in the BIM process has been broadly identified as enabling more efficient communication channels, fostering order, control and centrality in information exchange and allowing configurable access to project information at any time and from any place. The main reported barriers have also been identified in the Literature Review. A first step towards improving OCPs for BIM was to build a preliminary framework for improvement. The highly dynamic and complex nature of the problem called for a roadmap-type of framework (as highlighted in Figure 8). The main elements of this framework are:

- The circumstantial developments
- The developing requirements of the AEC-FM industry
- The developing functionalities of OCPs as captured from five studies (Becerik, 2006; Kim et al., 2011; Kagioglou et al., 2011; Nitithamyong and Skibniewski, 2004; Wilkinson, 2005)

- The observed characteristics of these functionalities. These added a “continuum” aspect to the framework-roadmap.

This framework together with the “BIM element mappings” is used as a reference point in the following steps of the Scoping Study.

2.15 Chapter conclusions

The conclusions from the Literature Review, which included a review of developments in BIM adoption during the course of this study- are provided under the following themes:

AEC-FM, ICT and BIM

- The family of diverse tools, which include design, review and collaboration tools, labelled collectively as “BIM technology” offer the opportunity to address some of the AEC-FM industry’s chronic problems: these include fragmentation and ineffective communication between disciplines and within the supply chain, inability to estimate and manage the lifecycle cost and considerable rework in information handovers.

Interoperability and Lifecycle management

- Interoperability is the major enabler of BIM and could be viewed as almost synonymous to BIM. Interoperability manifests itself at three levels: data (or technical) interoperability, semantic interoperability (exchange of meaning) and organisational (or business) interoperability. These can be studied separately but are often interlinked: Generally, the data interoperability supports semantic interoperability and that in turn supports organisational interoperability.

The proper application of BIM technology would allow for an information management paradigm that would eliminate the considerable waste the handover of information between key asset lifecycle phases (chiefly between design and construction and construction and operation). Effectively, BIM maturity is strongly linked with “phaseless workflows” and persistency of asset information.

Collaboration, Communication and Coordination

- The diversity of disciplines of stakeholders, their objectives and the geographical locations makes collaboration in AEC-FM challenging. Collaboration technology aims to address these issues and bring about the desired efficiency improvements. Communication and coordination are the mutually reinforcing requirements for collaboration. The two “effort streams” in providing better collaborative practices in AEC-FM are: (1) Efforts to improve collaborative *culture* and *process* through initiatives and integrated delivery methods. (2) Efforts to improve BIM communication and coordination *tools*. This study focuses on the latter as its outcomes are mainly directed towards collaboration tool provider.

OCPs and Requirements Engineering

- OCPs are often the preferred collaboration tool. Despite most principally following the document-centric paradigm, they have been trying to integrate with the BIM movement by offering BIM modules which host BIM models online and allow for model-based communication and workflows.

- Requirement Engineering offers useful principles for aligning technological paradigms to address problems. Context-specific “languages” and performance metrics are required to support the discourse of Requirements Engineering for BIM collaboration tools. There are usually supported by conceptual frameworks-models.

Developments in BIM adoption

- There has been significant mobilisation in BIM in the UK, in many ways characterised by uncertainty which has had an observable impact on the OCP software development world. In the context of collaboration tools, the role of OCPs in the BIM process, has not been made explicit neither by the Government BIM roadmap (B/555) nor by its use in practice.

Need for a preliminary framework

- The multiple concepts associated to “BIM” make BIM-related change a complex, socio-technical, highly multi-faceted problem.
- A fundamental concept within the BIM adoption domain is the Common Data Environment as defined in BS 1192:2007. This mainly addresses collaborative information management and coordination issues but provides inadequate support for Communication issues.
- There is a need for improvement in the intangible elements of BIM. Particularly essential are models that would (1) acknowledge the continuously evolving nature of BIM as well as (2) support BIM-based communication concepts. These required conceptual models would help provide a context-specific language for Requirements Engineering within collaboration solutions as well as context-specific performance indicators.

Preliminary framework and the need for research in order to improve it

- The preliminary framework built was the first step in a scoping study which aims to uncover challenges and issues and identify gaps. The preliminary framework:
 - Explores the utility of mapping for BIM adoption i.e. associating the various elements of BIM and particularly the BIM process in order to create useful representations-models.
 - Explores the role of OCPs for BIM and explores the role of roadmaps for their development.

2.15.1 *Need for a conceptual model*

It is concluded that, in an effort to devise a conceptual model to support Requirements Engineering for BIM collaboration tools, the research should:

- Acknowledge the characteristically multi-aspect nature of BIM adoption and account for the continuously evolving nature of BIM adoption
- Understand the positions and needs of the various stakeholders in the domain of Requirements Engineering for BIM collaboration tools
- Identify the requirements from the conceptual model to be developed
- Aim to understand the nature of BIM-enabled communication and what are the fundamental conceptual elements to be included in the conceptual model

3 RESEARCH METHODOLOGY

3.1 Introduction

This chapter is divided into three sections: The first section reviews the research approaches and methods available for research. The second section presents the main factors behind the selection of chosen methodology (nature of problem, body of knowledge, project setting, resources available and constraints). The third section presents the methodologies adopted in order to achieve the aim and objectives of the research.

3.2 Available research methodologies

The main categorisation in research methodologies lies between quantitative and qualitative approaches. Often, a triangulation approach is adopted in order to utilise the advantages of both. These three concepts are summarized below.

3.2.1 *Quantitative research*

Quantitative research is “an inquiry into a human or social problem, based on testing a hypothesis or a theory composed of variables, measured with numbers, and analysed with statistical procedures in order to determine whether the hypothesis or the theory hold true” Naoum (2007). It is objective in that it relies on hard and reliable data whose value does not depend on the perception of the research. A quantitative approach can be used for testing existing theory (Saunders et. al, 2011) i.e. collecting values of two variables in order to examine whether and to what extent these variables correlate.

3.2.2 *Qualitative approaches*

Qualitative research relies on “meanings, experiences, description” (Naoum, 2007) and is subjective in nature. It branches out into two main categories: Exploratory and Attitudinal research. Exploratory research is performed when there is limited knowledge on a subject and aims to understand the subject without rigidly pre-imposing directions of inquiry. Attitudinal research “subjectively evaluates the opinion, view or the perception of a person towards a particular object” (Naoum, 2007). A qualitative approach can be used to generate new theory (Saunders et. al, 2011) i.e. establish the process in which two variables are correlated.

3.2.3 *Triangulation*

Triangulation is the use of more than one approach in order to study the same phenomenon (Fellows and Liu, 2015); a diversity of methods may be used in order to determine the relationship between two observables. The parameters of the approach that could be varied include: data, investigator, theory, methodology and analysis.

3.2.4 *Epistemology*

Epistemology is the study of acquiring knowledge. The two main branches of epistemology offer two different approaches in acquiring knowledge (Saunders et. al, 2011):

- Rationalism: acquiring knowledge by deductive reasoning i.e. reality is believed to be governed and therefore being able by mathematical relationships. Logic is the seen as the main driver in knowledge acquisition.
- Empiricism: acquiring knowledge from a sensory experience. Evidence and experience are seen as the main principles for knowledge acquisition and theory should be tested against observations.

While Rationalism and Empiricism are concerned with the way in which knowledge is acquired, theoretical perspectives such as positivism and interpretivism (Crotty, 1998) describe how the research fundamentally understands the domain. Positivism is concerned with laws that govern cause and effect relationships within the domain. On the other hand, intepretivism is concerned predominantly with human behaviour within the domain; how humans understand the domain and how they act within it.

3.2.5 ***Research method styles***

More specifically, there exist various research methods styles for collecting, analysing and interpreting data. The main types are explained briefly below:

- Action research: includes involvement of researcher within the process under examination and yielding of instant result. This was not adopted due to the high risk in implementing ideas.
- Experimental: involves varying some parameters within the process under examination in order to examine the outcome. This was not adopted as high risk in implementing ideas and because most factors could not be controlled.
- Surveys: involves the collection of information and opinions from a number of people which are involved in the process under examination. It offers the benefit of collecting information and opinions from a big sample (e.g. 100 people) fast. Questions can be open and closed-ended.
- Ethnographic research: involves obtaining data by interacting and observing people who are involved in the process under examination.
- Case studies: the study of particular instances of the process under examination. In the case of the construction process, a typical case study is a specific construction project. A number of case studies can be performed in order to improve the generalizability of the results. This approach offers the benefit of close examination of many factors in the process. It is often found appropriate when particular factors are known to be constant in a number of cases so that the effect of the factor under examination can be examined with greater accuracy.

3.2.6 ***Methodology in construction management and construction informatics research***

Construction management research, being a characteristically diverse domain, traditionally adopts a variety of methodologies. Construction informatics, follows similar characteristics as it is concerned with a range of fields; some more appropriate for quantitative approaches and some more appropriate for qualitative approaches.

3.3 Nature of project context and setting – Factors in selecting methodology

The aim and objectives of the study are outlined. Subsequently three characteristics of project context which governed the research design are discussed.

3.3.1 *Aim and objectives of the research*

The overall aim of the project is to develop a conceptual model to support requirements engineering for BIM collaboration tools.

This would be achieved by the following objectives:

1. Identifying and addressing the key aspects in the process of Requirements Engineering for BIM collaboration tools
2. Identifying the challenges faced in the Requirements Engineering for BIM collaboration tools and which specific areas could benefit from improved and more explicit conceptual models.
3. Identifying the key elements in this process (which concepts are universal and persist through time).
4. Identifying the relationships between these concepts and relating them to concepts found in current standards, literature and used in the discourse of Requirements Engineering for BIM collaboration tools.

3.3.2 *Ethnographic nature of project*

For approximately 85% of the duration of the project, the author was based in the sponsor company's, (Asite Solutions), office in London. The author's primary work was to conduct research but he also assisted in the Product Development and Implementation Consulting functions. The author's company-specific involvement included:

- Attending client meetings (e.g. product demonstration, project set-up or project updates).
- Analysing/interpreting requirements specifications.
- Informing company on new standards and developments.
- Attending Product Development meetings.
- Attending marketing events and conferences.
- Producing cBIM training document.
- Producing cBIM protocol document (following BS1992:2007 (BSI, 2007)).
- Delivering cBIM product presentations.
- Liaising between clients and Asite support team on emerging client issues.

All of these interactions enabled the author to collect ethnographic data and closely observe a number of issues regarding the development of collaborative technology, its configuration to meet user requirements and the general mobilisation around government-led BIM requirements.

3.3.3 *Highly-dynamic environment of application*

As explained in in the Literature Review section "Developments in BIM adoption in the UK during the course of the study (2011-2014)", and the period in which the research was conducted was characterised by significant mobilisation for BIM throughout the industry. The BIM adoption movement

displayed a highly experimental aspect bringing uncertainty as to what the exact definition of BIM Level 2 is and the content and date of availability of supporting standards.

3.3.4 *Software product development aspect of project*

Product development teams have to keep track and harmonise developments in technological paradigms, software products to be integrated with and substitute/competing software products, user requirements and enforced or recommended standards. In general, software systems that support complex processes could have two, often interacting, types of roles: (1) A dominant role where the method of working imposed by the software brings enough efficiency improvements so that user's processes develop around it and (2) a complying role where the product is configured or developed to adapt to software systems and processes followed by users. The sponsor company had both roles depending on what aspect was examined. The "cloud-based" nature of the software that new users had to adapt to sharing their content online which often meant additional discipline was required in following protocols. At the same time, the strong client-focused nature of the sponsor company meant that the company had to keep track and adapt to developments. Since one of the primary objectives of this project was to make recommendations for the principles behind product development the effects of these two roles had to be accounted for.

3.4 Research design: Adopted methods and tools, and justification

3.4.1 *General approach*

After consideration of the aim and objectives of the research, the opportunity for ethnographic data capture afforded by the sponsor, the highly dynamic domain and nature of software product development it was decided that a mixed method research approach would be followed. Both quantitative and qualitative approaches were adopted; the quantitative approach helped identify whether and to what extent variables within the domain are correlated and the qualitative approach helped answer how they are correlated (i.e. what the process is). As there is limited availability of resources which could constitute a "theory of BIM communication" the qualitative approach helped create a model which could be the bases for theory generation.

Some parts adopted an empirical epistemology while some adopted a rationalist epistemology. The conceptual model created aims to make phenomena observed within the domain more conducive to positivist, scientific methods i.e. in Systems Thinking terms it helps tame a wicked problem (Buchanan, 1992).

The research included various research styles. A variety of data types, information sources, collection methods and analyses were utilised.

It should be noted that the aim to develop a conceptual model had a considerable effect on the chosen methodology. It could be argued that the research was not concerned with discovering new knowledge per se but about gathering, relating and ultimately re-representing concepts (some informally acknowledged, some partially acknowledged, some not acknowledged) in a way that would aid the processes in Requirements Engineering for BIM collaboration tools. Throughout the research the premise often used in Systems Thinking and Requirements Engineering that "solving a problem

simply means representing it so as to make the solution transparent” (Simon, 1969) was used as a guide.

It could be argued that methodological triangulation was adopted but not strictly in the conventional sense; various approaches and research styles were used but, in most cases, to examine different phenomena within the domain. This is mainly because each research stage focused on a different perspective of Requirements Engineering for BIM collaboration tools (as explain in 3.4.1.1).

The objective was to assess the current models used to inform requirements engineering, identify gaps and requirements from the missing model and at the same time fill in those gaps with the main elements and characteristics of the missing model. This process is inherently subjective and complex.

3.4.1.1 Multiple “Perspectives” approach

A strategy used to partly address the above challenges was to employ various research perspectives (or research focus points). The main characteristic of the structure of the research was that it examined the domain of Requirements Engineering for BIM collaboration tools from various Perspectives. These were selected so as to account for a representative enough set of different aspects of BIM. As shown in Figure 10, the main perspectives-focus points were: BIM collaboration tool *users*, BIM collaboration tool *vendors*, BIM collaboration *tool*, BIM collaboration tool *use* and a BIM collaboration tool *improvement*.

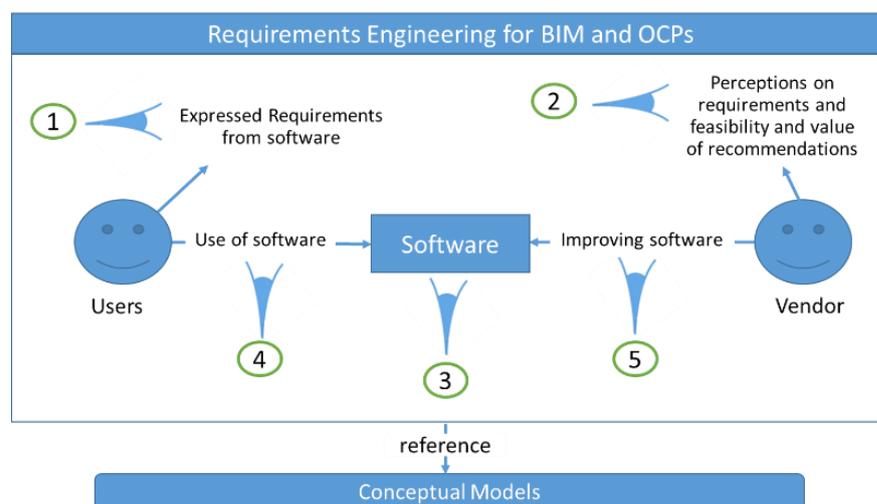


Figure 10 The five perspectives examined in Chapter 4. All concepts fall within the Requirements Engineering domain. Every perspective-process references Conceptual Models.

Figure 11 shows the sequence of the main research stages. After the literature review, a preliminary framework was built. Research was split into five perspectives which helped develop the draft conceptual model (both more precise requirements from it, its main elements and characteristics). This was subsequently formalised and finally evaluated.

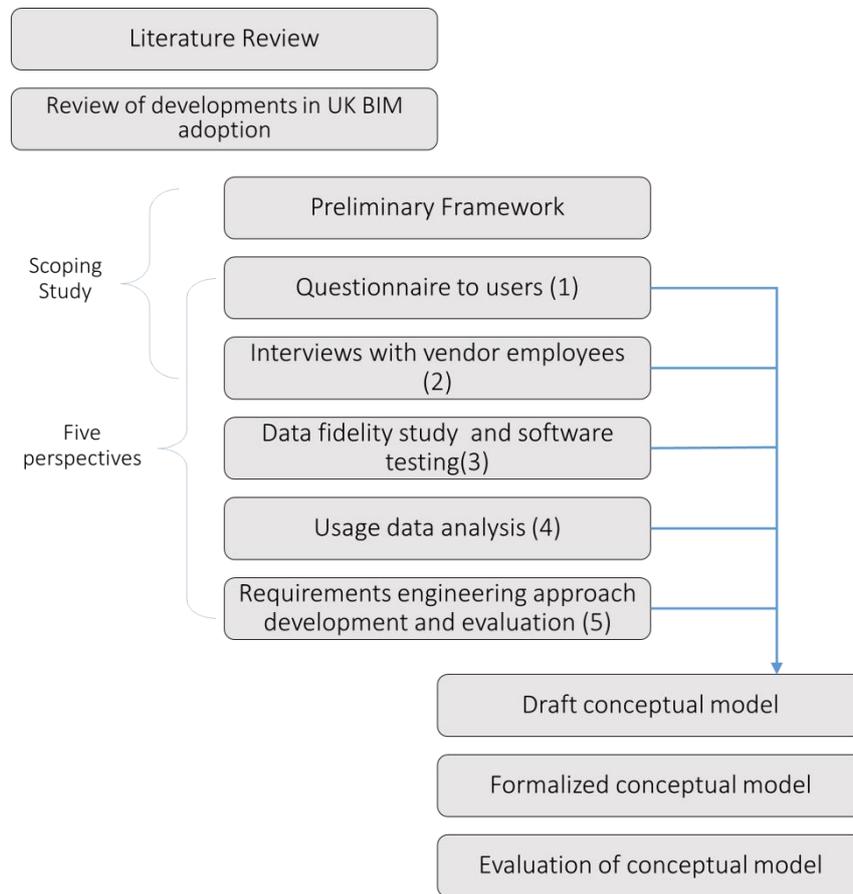


Figure 11 Sequence of main research stages

3.4.2 Main research stages: justification and evaluation of methods

Table 7 provides a different way to understand the sequence of research stages; it shows the main research stages, their inputs and outputs, their research type/style and the questions answered through them.

Table 7. Main research stages their research type and contribution

	Stage	Type	Questions Answered/output(s)
Pre-model	Literature Review and Review of Developments in BIM adoption	Literature Review (and tracking of events and publications)	What are the main themes? What are the gaps in knowledge? What kinds of tools are required?
	Framework and proposals	Literature interpretation	What are the challenges in creating conceptual frameworks?
	Questionnaire survey	Quantitative and qualitative	How are tools used? What are the requirements and perceptions? What are the challenges?
	Interviews	Qualitative	What defines the plans for product development?

	Data fidelity study and software review	Quantitative	What are the challenges in using IFC models for collaboration?
	Software review	Qualitative	What are the areas requiring attention in collaboration tools?
	Usage data analysis	Quantitative	What are the universal patterns in digital communication? What deters fluidity in communication?
	Network Analysis	Quantitative	What are the structural properties of emergent communication? How can network theory be adapted to BIM communication?
	Interviews	Qualitative and quantitative	How can the role of semantic technology in improving BIM collaboration be expressed appropriately?
Model	Standards review	Qualitative	What concepts are shared amongst standards? Which concepts are not represented and should be?
	Model development	Qualitative	How can the model elements be represented appropriately?
	Model evaluation	Qualitative	Is the model valid? Useful? Actionable? Usable?

The methods adopted in the different research stages are justified and evaluated below.

3.4.2.1 Literature review

The extensive review of literature helped understand the relevant research and existing knowledge within the domain. It examined the domain with the purpose of identifying the main enablers, barriers and complexities as well as the most pressing concerns and unaddressed requirements in the field. In terms of the conceptual model, it helped identify the main concepts within the domain which are used (traditionally and currently) in shared conceptual models within research and practice.

3.4.2.2 Review of developments in BIM adoption

The developments in BIM adoption were examined through non-formal methods: The three main methods being:

- Continuous review of UK BIM Task Group updates, review of new standards and publically available specifications, opinions on LinkedIn and blogs
- Attending events and seminars in London

- The expressed requirements of Asite users and the discourse related to BIM within Asite product development meetings

3.4.2.3 Questionnaire survey (*Perspective 1 – Users*)

An online questionnaire survey, sent to Asite users, was used to identify the various requirements, ways of use, challenges/barriers and proposals of BIM collaboration tool users. The survey proved to be efficient in collecting feedback from a relatively big number of respondents from a variety of disciplines. It included both closed-ended and open-ended questions. Nineteen questions were posed which were split into three sections:

- An introductory “You and your organisation” section
- “Section A”: questions on BIM adoption, interoperability and the drivers for BIM.
- “Section B”: lifecycle phase-based questions as well as the perceived benefits on the use of web-based collaboration.

The questionnaire was disseminated to one hundred Asite users from the Asite customer directory as well as to nineteen participants of “Build London Live”, a 48-hour, web-based, multi-disciplinary design competition hosted on the Asite platform (Build London Live, 2012). The survey attained twelve responses from the Asite customer set (12%) and five from the “Build London Live” event participants (26%), yielding seventeen responses overall out of one hundred and nineteen potential respondents (14%).

The research was designed, expecting approximately thirty responses (and a 25-30% response rate). The actual response was approximately half of what was expected. For this reason, the feedback could only be used for half of the expected purposes. i.e. the granularity of some questions and the variability in respondents role and other attributes could not allow for generalisations. The responses, however, particularly from the open-ended questions, were useful in the overall in the development of the research.

3.4.2.4 Interviews and workshops (*Perspective 2 – Vendor*)

A series of semi-structured interviews with Asite personnel were used to understand the view of vendor, particularly in relation to the view of the users and the in relation to the proposed preliminary framework. The main results of the questionnaire survey were presented during interviews. The semi-structured interviews were structured by presentation slides. Other resources were also presented where relevant. Standard questions were asked in order to aid comparison between the two respondent’s views. This stage was characterised by a significantly more open-ended discussion compared to the questionnaire survey. This was useful in capturing feedback on the feasibility, timeliness and business rational of the recommendations proposed.

It should be acknowledged that these interviews were easily facilitated because of the researcher being based in the software vendor’s office. This research stage was designed for three interviews. Due to the open-ended questions and part-exploratory nature of this stage it was considered that the focus should be on the depth of the discussion and allowing for the interviewees to expand on their views and descriptions of their experiences. Therefore, a longer engagement time was chosen over having more participants. Due to other commitments, the third potential interviewee could not attend

the interview so only two interviews were conducted. This did not significantly affect the overall quality of the findings and the utility of this stage.

3.4.2.5 Data fidelity study and scenario-based testing (Perspective 3 – BIM Collaboration Tool)

The next perspective involved a more careful examination of software: mainly the Asite BIM collaboration tool but also its interaction with the widely used BIM design tool, Revit Architecture 2013 (Autodesk, 2014). This method was employed in order to gain a better understanding of the software itself and its interaction with other software as well as the important schemata. Perspective 3 helped identify the main concepts of a BIM collaboration tool and the experience of using it. This would later on help in product gap analysis. Technical aspects were examined as well as aspects relating to user experience, ease of use and organisational role requirements e.g. whether technical experts would be needed from the user's side in order to assure a seamless experience in the use of the set of software. It should be acknowledged that a particular design software was used and a particular collaboration tool. The aim, however, was not to evaluate these software but to bring important issues to the surface. The study's thoroughness and generalisability was improved by using five different BIM models from different sources and by examining different scenarios.

3.4.2.6 Usage data analysis (Perspective 4 – BIM Collaboration Tool Use)

Perspective 4 involved analysis of meta-data from project communication occurring through Asite online workspaces. Specifically, data from (1) Document Listings, (2) Document Distribution Reports and (3) Comment Listings and Forms listings. These were extracted from the Asite online system into Excel spreadsheets to aid interrogation.

The three types of analysis conducted on this data were:

- A statistical analysis of communication meta-data.
- A social/organisation network analysis on the communication meta-data.
- An interpretative analysis of communication data (the content of the messages exchanged)

The analysis of this type of data was employed in order to understand the way users use data, uncover any important patterns and important concepts for the model. Part of the rationale was also the availability of big amounts of data. It should be noted that the volume and variety of the data posed a significant challenges. This perspective elucidated the need for much more sophisticated "Big Data" analyses, backed by collection of data on project context. In this context this study could be used as a proof of concept or pilot study.

3.4.2.6.1 Network Analysis

Of particular interest was the Network Analysis applied to communication meta-data, both due to its availability and the potential of network analysis to uncover previously unidentified patterns. Benefits included the new insight provided by the network graphs which allowed digitally mediated communication to be studied from a different perspective. Graph representations are visually intuitive and allowed for easier recognition of patterns through inspection and then verification by network properties.

One of the major limitations of the application of network graphs in this study was that it did not account for *content* of messages. Additionally there lied some challenges in interpreting observations due to the non-uniform way in which users used the Asite workspaces. For example, often users would post on behalf of others. Furthermore, often some interactions are pure formalities (e.g. having to reply to an action with a “no comment”). This analysis required a good understanding of the context of communication and the specifics of the collaboration tool and there was significant effort in filtering meaningless data. It should also be noted that this analysis did not account for interactions through other media such as email, phone, face to face communication and meetings due to the complex communication patterns between projects and the high level of project specificity. This means that it was only possible to present a partial picture of project communications.

It should be noted that use of data from these five projects was also governed by the limited availability of projects which data could be used from and limited availability of projects which utilized some kind of BIM technology or process. The research helped identify specific ways in which such an analysis could be improved. These are provided in 4.5.3.3.2.

3.4.2.7 Development of Requirements Engineering approach development (Perspective 5 - BIM Collaboration Tool Improvement)

Perspective 5 was concerned with approaches for improving BIM collaboration tools to take advantage of potential offered by technological paradigms. The paradigm of Semantic Technology was used as it is gaining increasing interest and promising significant efficiency improvement but more importantly because it requires some significant change in how collaboration systems are understood and on perceptions on how they can help users.

The approach was developed to best fit the context of Online Collaboration Platforms and be specific to Semantic Technology and was documented. This Requirements Engineering approach included semi-structured interviews with Asite implementation consultants. The documentation of this approach both in text and graphical format allowed for its evaluation.

3.4.2.8 Informal ways of data acquisition

The researcher also gathered data, opinions, and behaviours by non-formal and non-structured ways such as attending client meetings, analysing/interpreting requirements specifications, attending Product Development meetings and attending marketing events and conferences.

3.4.2.9 Formalisation and evaluation of the conceptual model

The aim of the conceptual model developed is the eradication of BIM communication waste through a better understanding of waste, and how it comes in to existence. The basic elements, requirements and principles of this model emerged through the five perspectives studied in chapter 4. The model was then completed and formalised in chapter 5.

In order to introduce some guidance in further developing this model, four desired attributes were selected:

- To provide common reference i.e. describe concepts that are easily understandable and applicable to BIM practitioners.

- To be universal i.e.be applicable across different realms of BIM
- To be robust i.e. withstand the characteristic dynamism of BIM technology development
- To be actionable i.e. provide guidance to product developers and standard authors as well as project-level BIM implementers.

The five steps followed in the development and formalization of WIMBIM were as follows:

1. Definition of basic elements and requirements from WIMBIM (chapter 4)
2. Clarification of purpose and desired characteristics of WIMBIM.
3. Review of relevant literature in search of concepts relevant to basic elements of WIMBIM.
4. Development of WIMBIM in text format (iterative process):
 - Fundamental Assumptions
 - WIMBIM elements and their relationships
5. Development of WIMBIM in visual format (an iterative process).

3.4.2.9.1 Evaluation principles and method

3.4.2.9.1.1 Performance indicators for a conceptual model

The set of desired characteristics for the model, namely to Provide a common reference, Universality, Robustness, Actionability played a major role in developing the evaluation approach. A number of studies relevant to evaluation of conceptual models, frameworks and ontologies were consulted. Namely Bryman & Bell (2011), Scriven (1996) and Clarke and Dawson (1999) who examine and contrast between the two basic types of evaluation, formative evaluation and summative evaluation. Additionally, Akkermans & Gordijn (2006) in "What is This Science Called Requirements Engineering?" identify the six Categories of Validity: Descriptive, Theoretical, Interpretive, Reasoning, Internal and External.

Based on the desired characteristics and the review of relevant literature it was decided to design the evaluation process around the following evaluation categories:

- Need for such a model
- Validity of model
- Utility of model
- Usability of model

Four semi-structured interviews with BIM experts were conducted in order to evaluate the model. The evaluation process included both closed-ended and open-ended questions and was designed to allow for the interviewees to ask for any clarifications during the interviews. The knowledge and experience of the interviewees and the depth of the discussion was the major factor in the design of this research stage. Four responses were considered appropriate for the granularity and scope of the evaluation questionnaire. The interviewees were selected because of their experience with BIM implementation, BIM standards implementation, and involvement in research and development efforts. The variation in roles and experience of the interviewees helped significantly reduce the risk of a biased sample. Indeed, the responses were valuable in terms of giving overall levels of need for, validity, utility and usability of the model and for highlighting specific limitations and areas for improvement.

3.5 Summary

The mixed methodology adopted and the general design of the research were a result of the aim and objectives of the project, the observations from the Literature review, the nature of project context and the project setting and the availability of data. The aim of the project was to develop a conceptual model appropriate for Requirements Engineering for BIM collaboration tools, which made for a complex research project that required an examination of the domain from multiple perspectives.

This study adopted sequential stages: a literature review and review of developments in BIM adoption, five “perspectives” studying different aspects of Requirements Engineering for BIM collaboration tools, model development and finally model evaluation. Between and within these stages a combination of research methods, both qualitative and quantitative were been adopted.

4 DIFFERENT PERSPECTIVES ON BIM-ENABLED ONLINE COLLABORATION PLATFORMS - THE EMERGENCE OF “WIMBIM”

4.1 Introduction

The Literature Review, the Review of Developments in BIM adoption over the course of this study (2011-2015) and the preliminary framework stage have identified:

- The need for a better *conceptual framework* to support BIM research and BIM practice in general, but also specifically the need for an appropriately expressed framework that will support Requirements Engineering for BIM-enabled OCPs.
- The highly *dynamic* and *experimental* nature of the BIM adoption movement in the UK which is characterised by significant uncertainty.
- The *multi-aspect* nature of BIM and the need for proposed solutions to address all aspects (users, technology and process) in order to be effective.
- The *lack of definition* to the exact role of OCPs in the BIM process (partly as a result of the above).

As explained in the Literature Review this study focuses on the software tool development “effort stream” of collaboration requirements (rather than on the softer, human aspects and on process aspects). This does not mean that human and process aspects are disregarded, but that the outcome of this study is mainly addressed towards stakeholders within the domain of Requirements Engineering for BIM collaboration tools.

This chapter builds on the preliminary conceptual framework from the Literature Review (which consists of models of the AEC-FM process and a preliminary framework for OCP roadmaps). Five different perspectives (or approaches) for investigating the role of OCPs in the BIM process and improving the service of OCPs are utilized, as listed in Chapter 3. These perspectives are explored by focusing on different parts of the domain (as illustrated in Figure 4). The first two perspectives complete the scoping study which uncovers context-specific issues further to those identified by the Literature Review:

- Models for representation – Scoping study part A (in Literature Review) Perspective 1: Users (scoping study part B)
- Perspective 2: Software vendors (scoping study part C)
- Perspective 3: Software and schemata
- Perspective 4: Use of software and patterns in digital communication
- Perspective 5: Improving software

Subsequently, issues around the online BIM collaboration tool, Asite cBIM, arising during the course of the study are reported as well as a categorisation of the requirements for BIM-enabled OCPs.

Finally, by synthesising the findings from these perspectives it is possible to define the need for a conceptual model (the “Model for Waste in BIM process Interactions” or “WIMBIM”) as well as to identify its basic elements. This model is then formalised and evaluated in chapter 5.

4.2 Perspective 1 (Scoping study, part B): Understanding AEC-FM practitioners: perspectives, current use and requirements from BIM and OCPs

Having built a preliminary conceptual basis with the “BIM element mappings” and preliminary framework for OCP roadmaps (chapter 2: see Literature Review), the next step was to survey AEC-FM practitioners in order to capture their perspectives on BIM and OCPs, the way they currently use these technologies, their requirements and the relevant barriers. In parallel, the analysis was used to raise issues regarding the effectiveness of the terminology and the assumed models in communicating about Requirements Engineering for BIM and OCPs.

4.2.1 Questionnaire design and responses

A questionnaire survey was designed for these purposes and disseminated to one hundred individuals from the Asite customer directory through email, followed up with telephone calls. Additionally, the questionnaire was sent to nineteen participants of “Build London Live”, a 48-hour, web-based, multi-disciplinary design competition hosted on the Asite platform (Build London Live, 2012). The full body of the questionnaire is presented in Appendix A. The nineteen questions were split into three sections:

- An introductory “You and your organisation” section
- “Section A”: questions on BIM adoption, interoperability and the drivers for BIM.
- “Section B”: lifecycle phase-based questions as well as the perceived benefits on the use of web-based collaboration.

The survey attained twelve responses from the Asite customer set (12%) and five from the “Build London Live” event participants (26%), yielding seventeen responses overall out of one hundred and nineteen potential respondents (14%). The respondents came from a range of companies within the AEC-FM industry and held different roles (Figure 12). As shown, 15 out of 17 (88%) consider that they are currently implementing BIM. This indicates a much more “BIM-advanced” sample compared the general UK AEC industry where, in 2011, 31% claimed to be currently implementing BIM (NBS, 2012).

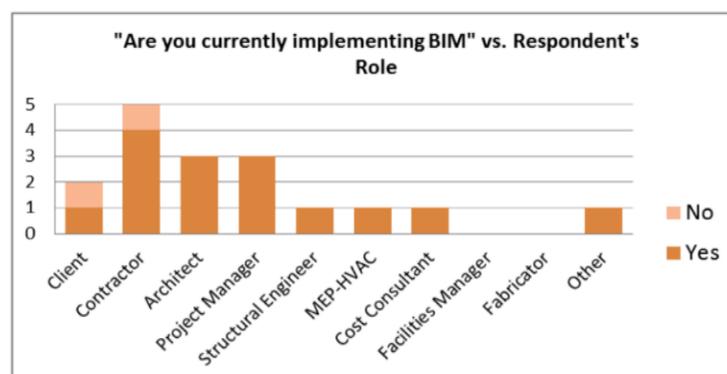


Figure 12 Respondent's roles by BIM implementation

4.2.2 Questionnaire results

The most relevant results from the questionnaire are presented and discussed below:

4.2.2.1 Section A

4.2.2.1.1 Drivers for adopting BIM

No particular option stood out as the primary driver for adopting BIM. Respondent's companies were adopting BIM for a number of reasons at the same time. "Direct business benefit" was identified as a driver in 11 out of the 17 responses while "Information exchange across project teams" and "Government mandate" in 9 out of the 17 responses. "Client requirement" was identified as a driver in 7 out of the 17 responses.

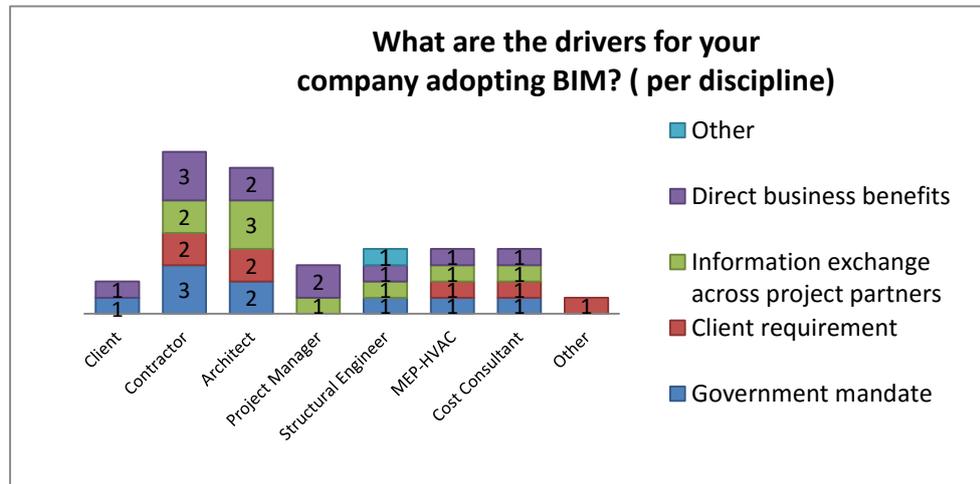


Figure 13 What are the drivers for your company adopting BIM? (per discipline)

4.2.2.2

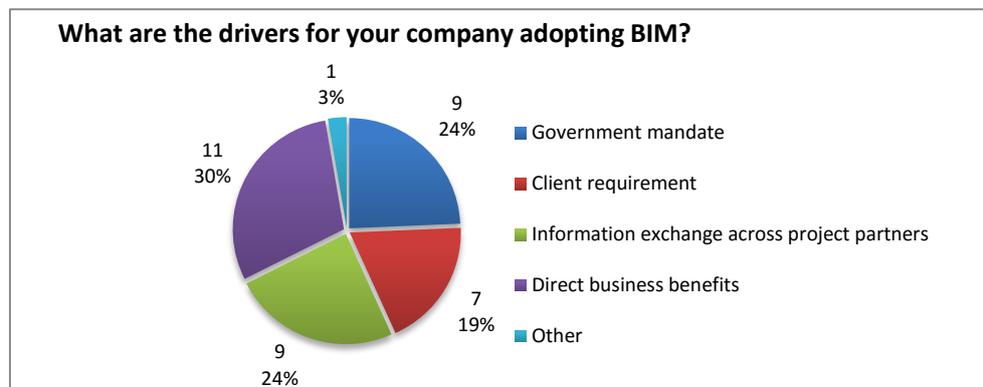


Figure 14 What are the drivers for you company adopting BIM?

4.2.2.2.1 Achieving compatibility (interoperability)

The responses to this question indicated that the IFC-based cBIM module offered by Asite and the IFC data exchange standard in general were not a trusted solution for practitioners. In 9 out of 17 responses, respondent's companies were requiring the use of proprietary products (such as Autodesk Revit) in order to achieve compatibility in either all (3 respondents) or the majority (6 respondents) of their projects. The Asite platform was used as a solution for compatibility for all projects in only 1 case and the majority of projects in only 2 cases. An external standard such as IFC was utilised in all projects in 2 cases and the majority of projects in 5 cases.

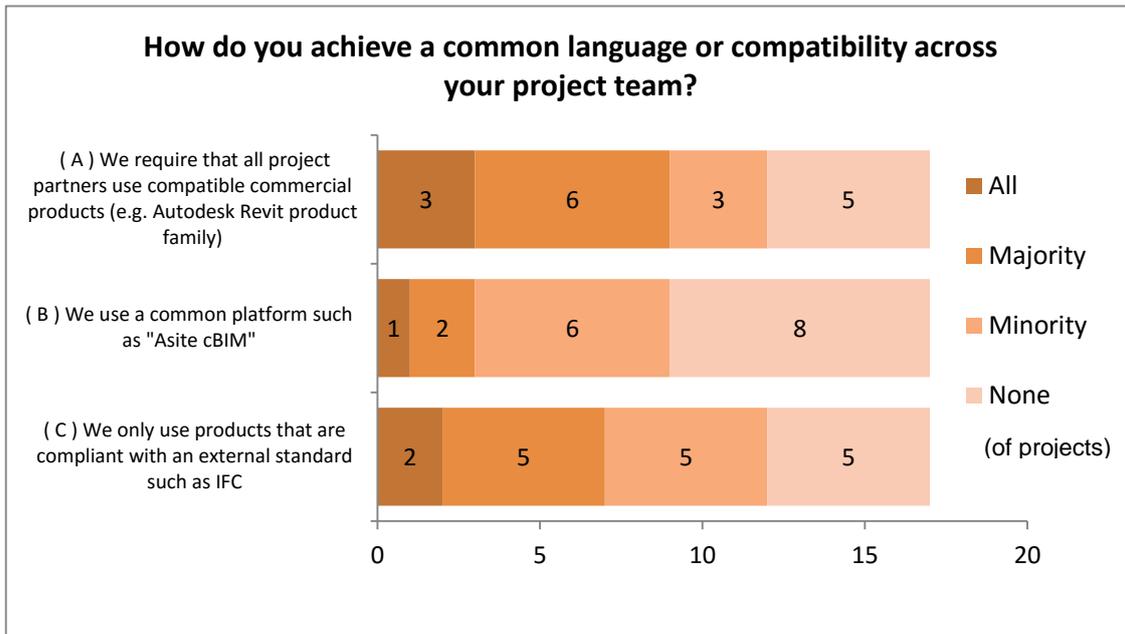


Figure 15 How do you achieve a common language or compatibility across your project team?

4.2.2.3 Section B

4.2.2.3.1 Benefit of BIM and benefit of web-based collaboration around a shared model

This question compared the perception of the benefits of BIM (in general) to the benefits of “web-based collaboration around a shared model” across different areas. The results indicated that BIM and “web-based collaboration around a shared model” were seen as similarly beneficial across different areas. The biggest benefit in web-based collaboration around a shared model” was “Coordination”: 11 responses reported that it was highly beneficial and the rest (6) reported that it was beneficial.

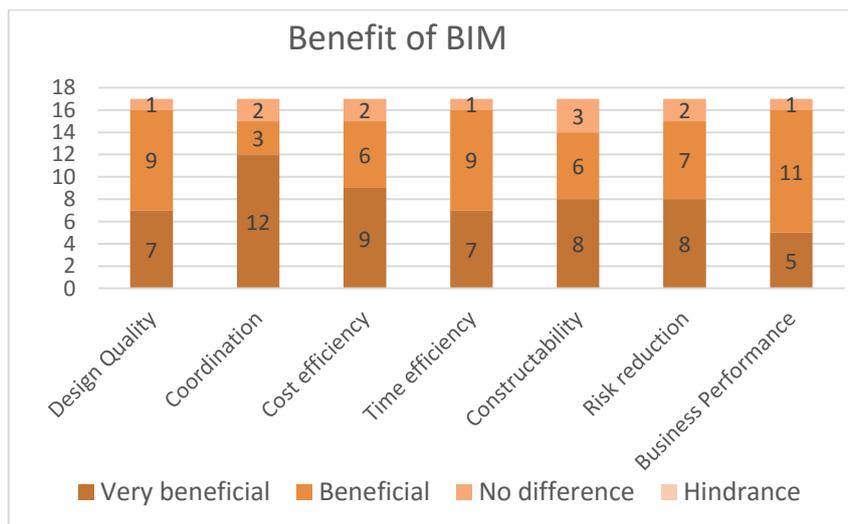


Figure 16 Benefit of BIM across different areas

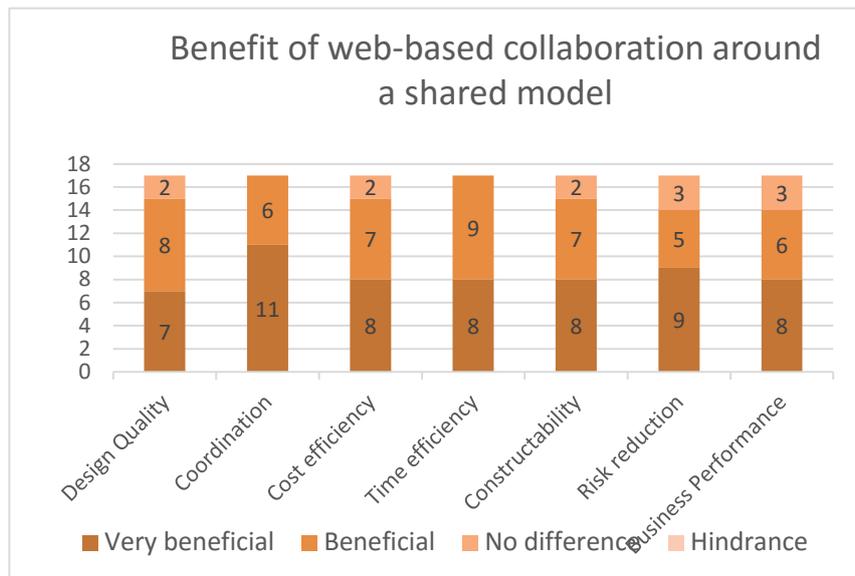


Figure 17 Benefit of web-based collaboration around a shared model

4.2.2.3.2 BIM embeddedness

This question asked how “embedded” BIM is at each phase of the project lifecycle. The responses showed that BIM displayed low levels of embeddedness at the beginning of projects (“Preparation” phase), increased at “Design” phase and peaked at the “Pre-construction” and “Construction” phases. It would then slowly decrease at the “Use” phase. The results agree with the rationale that BIM embeddedness increases with the need to create more detailed specifications as the construction phase approaches. This was also consistent with the responses to the open-ended question on the requirements from BIM at each stage (Section B of the questionnaire).

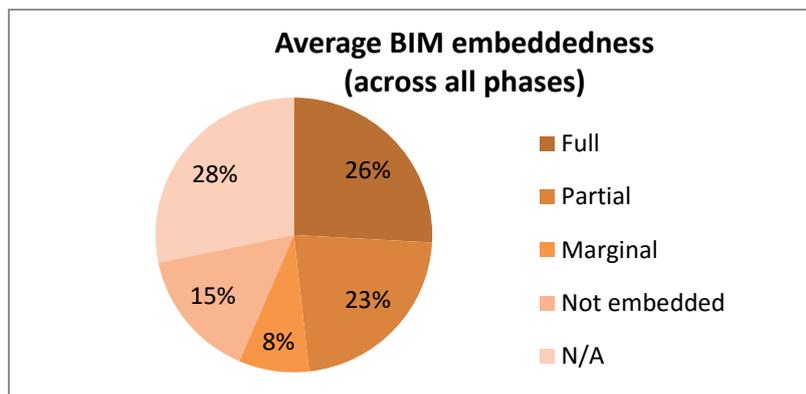


Figure 18 Average BIM embeddedness (across all phases)

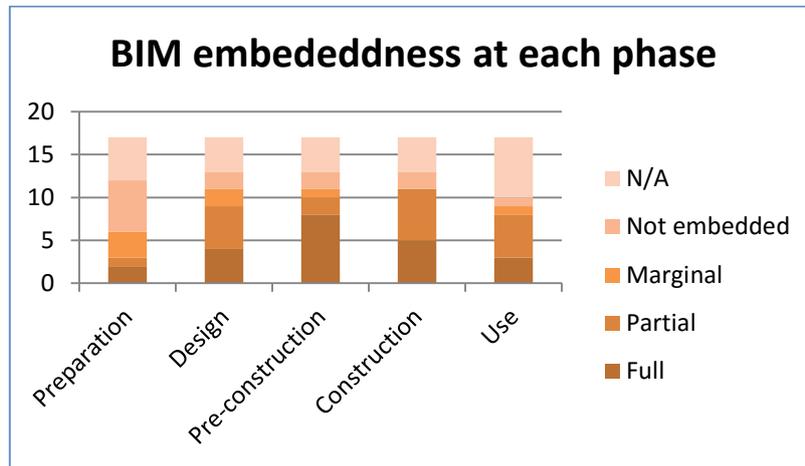


Figure 19 BIM embeddedness at each phase

4.2.2.3.3 Requirements and expectations from BIM at each phase (open-ended question)

The responses were in-line with the responses on BIM embeddedness per phase (presented above). Requirements for early phases were for the availability of tools to support “fluid thought”, “incorporation of hand-drawn sketches” and “preliminary massing” and “exploration of different solutions”. A high level of detail had little importance at this phase. As the project progressed towards Pre-construction and Construction phases the responses concentrated on the requirement for “high level of detail”, “accurate specifications” and “quick extraction of information”. During the Construction phase, the requirement for identifying the implication of design changes was expressed.

4.2.2.3.4 Additional comments (open-ended question)

Respondents were prompted to provide any additional comments based on their own experience. The main themes and opinions in the additional comments were:

- The requirement for digital environments to embrace the “fluidity of early stages”.
- Asite was tailored primarily contractors and that it needs to recognise the different types of work being conducted by different disciplines.
- A different machine-based package was being tested by their company for model review and interrogation
- A respondent reported their view of web-based collaboration and expressed a requirement/wish for Asite in the following comment: “The key for use of web based collaboration system is the **intuitiveness of the graphical user interface** and **lightness of navigation throughout models**. Would be nice to combine the capability to set up automatic checking rules similar to Solibri Model Checker while having a similar navigation & markup interface as Tekla BIMSight...”

4.2.3 Summary of findings from Perspective 1

4.2.3.1 Questionnaire results

The main findings from the questionnaire results were:

- The lack of confidence in IFC data exchanges stands as a critical barrier to web-based BIM collaboration.
- The user interface of Asite cBIM needs closer examination.

- There is a gap hence an opportunity for OCPs to support early stages: preparation and conceptual design. This means that collaboration tools should enable user interactions at the Preparation and Design phase where the seamless flow of *intent* is critical.

4.2.3.2 *Evaluation of utility of terminology and concepts used in questionnaire*

The process of this questionnaire was in many respects part of a Requirements Engineering process. Therefore, observations on the utility of the terminology and shared concepts within the Requirement Engineering process could be made.

It is noted that a meta-analysis revealed that the following terms were used as primary concepts in communicating around Requirements Engineering for BIM collaboration tools: “business benefit”, “government mandate”, “information exchange”, “compatibility”, “interoperability”, “common platform”, “design quality”, “coordination”, “time efficiency”, “cost efficiency”, “constructability”, “risk reduction”, “business performance”, “preparation”, “design”, “pre-construction”, “construction”, “construction”, “use”, “web-based collaboration”, “interoperability”, “time efficiency”, “coordination”, “level of detail”, “fluidity”, “user-interface” and “machine-based”.

- It is evident that both the researcher, the company and the respondents have a vague understanding what they are after but are not able to explicitly express these requirements.
- Even though the stakeholders understand that the requirements from each phase are different, this doesn't enable them to make any generalisable conclusions and built robust models. This poses the question of whether the main reason for separating phases should apply in the development of collaboration tools.
- Regarding the requirement for flow of intent: The terminology was not fully able to support the communication of this concept in the Requirements Engineering process.

4.3 **Perspective 2 (Scoping study, part C): Understanding the software vendor**

The final part of the Scoping Study was a series of semi-structured interviews with Asite personnel. This step aimed to capture the company's perspective and relate it to the perspective of the practitioners and the concepts and proposals in the BIM Element Mappings and Preliminary Framework for OCP development.

4.3.1 ***Semi-structured interview design and delivery***

The most significant findings from the literature review and the questionnaire survey were used to generate a set of two semi-structured interviews with Asite members; a Senior Implementation Consultant with fifteen years' experience in construction IT and the company Professional Services Manager. The purpose of the interviews was to share relevant findings and, more importantly, get feedback on the feasibility, timeliness and business rational of the recommendations proposed.

The slides used to structure and guide the interviews are presented in Appendix B. This consists of the set of standard questions used to generate the discussion and the replies from the interviewees in note form. The interview was divided into two main sections:

- Section 1: The interviewees were presented three graphs resulting from the analysis of the questionnaire results. These were used to introduce the interviewees to the nature and aim of the

research (e.g. by contrasting the number of users which choose to enforce the use a common software package instead of using Asite for interoperability the objective of reducing the first to increase the latter was introduced) as well as to capture the interviewee's reactions to the findings.

- Section 2: The interviewees were presented with recommendations based on the "BIM-element mappings" and the "Preliminary Framework for Development". Relevant questions were asked subsequently. As was intended, in some cases, the interviewees discussed the relationships of the themes in question with previous themes or with the results from the questionnaire.

4.3.2 **Main findings from semi-structured interviews**

4.3.2.1 *Senior Implementation Consultant*

The interviewee held a pragmatic approach throughout the interview explaining that "companies' will focus on the bottom line" and that "we (Asite) need to balance vision and reality". He was confident with breadth of functionality offered by Asite and believed that "technology is in place".

He suggested that business process and culture are currently more important parameters since "we (Asite) have broken enough ground". The implementation consultant argued that the lack of adoption is largely owed to economic conditions, cultures non-conducive to technology-based change, and cost of implementation, marketing and the *user interface of the product*. Additionally he explained that "politics" (e.g. high level agreements between companies and competitor platforms) often play a more significant role than the functionality of the product itself for the selection of a collaboration platform for a project. Additionally, regarding the alignment of construction companies to the BIM-enabled vision, he gave examples of companies sharing and acting upon the vision and companies who do not, demonstrating the disparity.

Regarding interoperability he believed that it is not always central to what Asite offers and depends on the use of the platform (i.e. use as a document management compared to use as an e-procurement solution). He readily stated that the he could clearly see how the three levels of interoperability are connected. Additionally, his experience tells him that *IFC is not currently adequate*.

When discussing the functionality development roadmap, he suggested a "commercial information management" feature. He also examined the idea of producing a separate Knowledge Management (KM) module. Regarding circumstantial developments he envisioned more hardware (e.g. diggers, plant) related automation in construction sites which could be managed on Asite. Finally he explained that Asite can currently coordinate processes in the "2D world" effectively.

4.3.2.2 *Professional Services Manager*

The interviewee recognised the limitations of the current cBIM module. When presented the vision figure the interviewee recognised that "*we lack in providing modelling in the time and cost dimensions*". He explained that Asite cannot currently replace machine based design/planning in native formats but can serve as a client review tool. As he also recognised that I he believed that Asite should "facilitate our customer's tools" (e.g. a Revit plugin to Asite cBIM which was deployed in the following months). The professional services manager agrees the view that some clients share the same vision and some don't.

He expressed the belief that Asite could improve in the provision of business interoperability and also agreed that the levels of Interoperability are connected.

When discussing the functionalities development he suggested the introduction of Facilities Management module. The interviewee believed that Asite, as a technology, is a KM tool to an extent and it depends on how the clients use it. An SRM tool would improve KM as knowledge is lost between projects. He explained that the use of Asite by the Environmental Agency is a good example of KM because they tend to collaborate with the same organisations between projects. Finally, the interviewee also recognised that coordination is key.

4.3.3 Summary of findings from Perspective 2

The main findings from Perspective 2 are outlined below:

- The different in the perspective of vendors to that of the users.
- The (relevant to the above) uncertainty in overall Requirements Engineering area.
- The, resultant, need for robust model for long term development.
- There is significant variation in uses of and requirements from the Asite collaboration tool.
- The importance of politics and high-level agreements within the construction software domain was appreciated.
- The importance of user interface and easiness of use (which was also expressed from users in Perspective 1) was also appreciated.
- The belief from vendor representatives that potential Knowledge management functionality bears significant utility.
- Finally, the lack a robust way to communicate about requirements from BIM-enabled OCP within the Requirements Engineering process was observed (as in Perspective 1).

4.4 Perspective 3: A closer examination of a web-based BIM tool – Asite cBIM

4.4.1 Introduction

Amongst the main findings in the Scoping Study, both in the questionnaire survey and the semi-structured interviews, was that there is lack of confidence in the IFC data exchange standard which stood as a critical barrier to the adoption of the paradigm of web-based working around a shared model (or multiple shared models). There was a general concern that data conversions from native software to IFC omitted information to varying degrees such that organisations actively sought to bypass the use of IFC files. For this reason, a closer examination of Asite cBIM, an IFC-based online tool was conducted.

The purpose of the examination was two-fold: it served as a data fidelity study (Analysis 1) as well as a study on the efficacy of Asite cBIM as a communication and coordination tool (Analysis 2). The author conducted this study under the supervision of the Senior Implementation Consultant at Asite. Seven weekly meetings were held to help guide this process where the Consultant would also give feedback on the expressed requirements of users and potential implications of proposed functionalities under consideration. This process was the basis for the production of three BIM-

specific documents for Asite: a cBIM training agenda and exercises, a (draft) cBIM implementation protocol, and a (draft) general BIM modelling guidelines document.

The following software was used:

- Autodesk Revit 2012 and Autodesk Revit 2013 (the native format being “.rvt”)
- Asite cBIM 2012 (November 2012 version)

The examination aimed to uncover the different problems users could face when using Revit as a native design and/or analysis software and exporting IFC models to Asite cBIM for purposes such as model review, coordination and object-based procurement.

Apart from research findings, Perspective 3 yielded an additional output: the elicitation of five principles for BIM model-based communication.

4.4.2 Analysis 1: Technical (data) interoperability - Testing IFC data fidelity on Asite cBIM

4.4.2.1 Purpose

This part of Perspective 3 examined the fidelity of the building information set of a given BIM model at various points through which users could potentially access and make use of this information.

4.4.2.2 Methods

Four methods were used for examining data fidelity (see figure 10 for illustrative screenshots):

- Within Revit: Comparison of the model Element Properties between .rvt and the corresponding IFC models (i.e. the models exported from the .rvt models).
- Exported from Revit, examined in Excel: Comparison of exported element schedules (in .xls) between .rvt and the corresponding IFC models (see Appendix C).
- Inspection of Object List/Model Tree of the IFC model in Asite cBIM.
- In Revit and Asite cBIM: Visual inspection of exported IFC models.

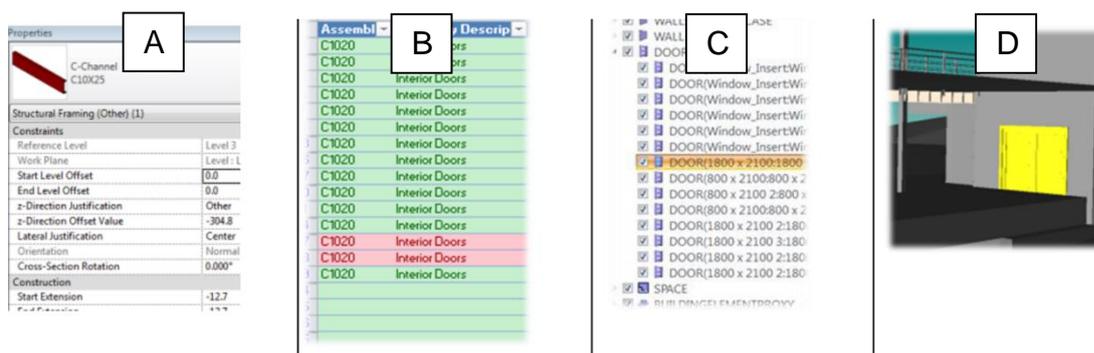


Figure 20. Illustrative screenshots from the four methods used for examining data fidelity

Five different BIM models were used to carry out this study (figure 11):

1. The “Basic Architectural Sample” provided with Autodesk Revit packages.
2. The “Basic Structural Sample” provided with Autodesk Revit packages.
3. The “Basic MEP Sample” provided with Autodesk Revit packages.
4. A high-rise building model produced by an Asite client and used in a real project.
5. A model used by a product supplier from the Asite directory.

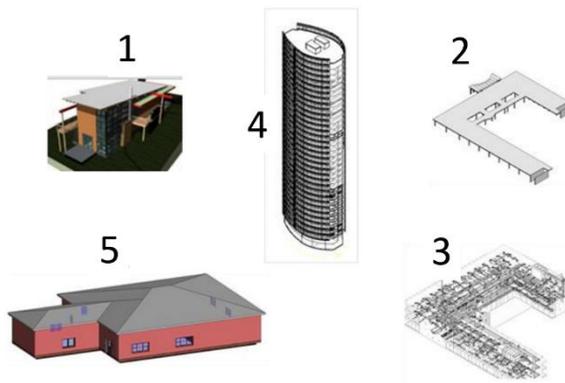


Figure 21. The five BIM models used in this Perspective 3

4.4.2.3 Observations

The observations from the four methods are provided below:

4.4.2.3.1 Method A: Within Revit: Comparison of the model Element Properties between .rvt and the corresponding IFC models.

The object “Properties” tab in Revit was used to determine whether attributes such as “Name” and “Phasing” were maintained. Visual inspection as well as the “Type Properties” determined whether colour was maintained. The “Error/Warning Reports” window (which pops-up when opening the IFC model) gave indications on the loss of geometry and parametric definitions. From the models tested, “2. Revit Structural Sample” was the only one that did not present any problems. This was attributed to its:

- More standard and simple element types.
- Single colour with no visual patterns on surfaces.
- Lower variation in element types.

4.4.2.3.2 Method B: In Excel: Comparison of exported element schedules (in .xls) between .rvt and the corresponding IFC models.

Element schedules were exported from native .rvt models and the corresponding IFC models (both from Revit) and were compared in MS Excel. Discrepancies within the object sets were identified. Appendix C presents the mapping diagrams for the conversions. The most important observations from this method are:

- Not all elements were maintained in the conversion.
- Some Categories were lost and the corresponding elements fell under the category called “Generic Models”.
- Not all elements contained OmniClass information (typically the minority did). Any OmniClass information was not maintained in the IFC schedules (this was critical in case users wanted to perform object-based procurement from cBIM since this would be based on OmniClass information).

4.4.2.3.3 Method C: Inspection of Object List/Model Tree of the IFC model in Asite cBIM

The interface of Asite cBIM contains a Model Tree of the IFC model objects on the side of the model visualisation area. From this inspection, the main observations were:

- Compared to IFC-Revit schedules (Method B) no elements were lost.
- Some elements are added.
- Element categories have changed.

4.4.2.3.4 Method D: In Revit and Asite cBIM: Visual inspection of models

Some, often very salient, discrepancies were detected from visual inspection. Examples from model 1: Revit “Basic Architectural Sample” are provided:

- Floors are out of position in IFC models (both Revit and Asite cBIM) (Figure 22)

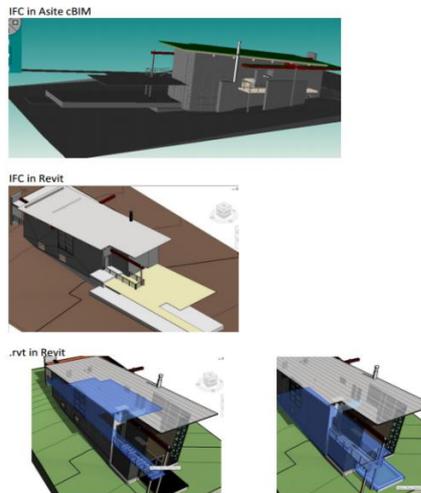


Figure 22 Visual inspection: comparing original .rvt model with IFC exports in Revit and Asite cBIM

- The window elements in the model were not transferred properly in the conversion (see Figure 23)

	.rvt in Revit	IFC in Revit	IFC in Asite
Left side		<ul style="list-style-type: none"> • The 2 windows exist but are opaque 	<ul style="list-style-type: none"> • The 2 windows exist but are opaque • Can be added to object list
Front side		<ul style="list-style-type: none"> • Gaps 	<ul style="list-style-type: none"> • Gaps
Back side		<ul style="list-style-type: none"> • Gaps 	<ul style="list-style-type: none"> • Gaps

Figure 23 Issues with windows elements in Revit to IFC conversions

4.4.2.3.5 Summary of export results from different IFC export configurations

Autodesk Revit 2013 offered the ability to customise the IFC export settings (certain IFC versions based on Model View Definitions e.g. IFC GSA are provided). These settings affect the IFC exports and the warnings from these exports. Figure 24 summarises the export results from the different export configurations.

		Export configurations							
		2x3	2x3	2x2	2x2 BCA	2x3 GSA	2x3 CV2.0	2x3	2x3
		IFC	IFC	IFC	IFC	IFC	IFC	IFC	IFC
Parameters	File Version	f	f	f	t	t	t	t	t
	File Type	f	f	f	t	t	t	t	t
	Split walls and columns	f	f	f	t	t	t	t	t
	Include base quantities	f	f	f	f	t	F	t	t
	Space boundaries	1st level	1st level	1st level	1st level	2nd level	None	1st level	None
	Visible elements of current view	f	f	f	f	f	f	t	t
	Export plan view elements	f	t	f	f	t	f	t	t
	Export Revit property sets	f	t	t	t	t	f	t	t
	Export IFC common property sets	t	t	t	t	t	t	t	t
	Use 2D room boundaries for room volume	f	f	f	f	f	f	t	t
	Use family and type name for references	f	f	f	f	f	f	t	t
	Exports parts as building elements	f	f	f	f	f	f	f	t
	Export surface styles	f	t	t	t	t	f	t	t
Results	Conflicts	4	4	4	4	3	3	3	3
	Enclosed region	1	1	1	0	1	0	0	0
	Not cutting host	0	0	0	1	1	1	1	1
	Separation lines overlap	0	0	0	0	0	37	0	0
	Σ	5	5	5	5	5	41	4	4

Figure 24 Warnings from different IFC export settings (f=parameter/option disabled, t=parameter/option enabled)

4.4.2.4 Introduction

This part of Perspective 3 tested Asite cBIM as a tool for communication, coordination and workflow support.

4.4.2.5 Methods

Asite cBIM was tested under typical use-case scenarios such as model import, model export, communicating issues and instructions about models and/or objects and looking for information within a model. Observations relating to user experience, communication efficiency, coordination efficiency and functionality were made as part of the production of the three Asite BIM-specific document (cBIM training agenda and exercises, draft cBIM protocols document, and draft general BIM guidelines document).

4.4.2.6 Observations

Particular attention had to be drawn to modelling consistency: Lack of proper specification in the original file can cause apparent or non-apparent discrepancies despite the original model appearing consistent.

The other three principles forming the basis of the BIM guidelines were categorisation, level of detail and appropriateness/purposefulness. Additionally, users were encouraged to carry preliminary interoperability tests before use of the software for real project purposes.

The guidelines and protocol were also informed by the set of eleven “principles for the through-life management of engineering information” put forward by the Knowledge and Information Management (KIM) Project (McMahon et al. 2009). These were: parsimony, granularity, identity, usability, reusability, evaluation, portability, robustness, discovery and design.

4.4.2.7 Proposals

The examination helped identify some areas which required additional functionality or further consideration:

4.4.2.7.1 New functionalities proposed

- Model management/coordination:
 - Linking models on “web-app”: There was no mechanism for linking BIM models via the browser-based version of Asite (or “web-app”).
 - Integrating cross-discipline folders.
- Search and interrogation
 - Object-based search tool (this would aid procurement, model review, mark-up).
 - Customisable model tree (sorting by containment, object type or sort according to native software sorting).
- User interface
 - Customisable centre of rotation – This would make orbiting the model more comfortable.

4.4.2.7.2 Areas requiring further consideration

- BIM governance:
 - Folder structure and access rights.
 - Inviting a User to collaborate on cBIM.
- Model-based Workflows: better integration with tasks performed on the web-based document management and more clarity in the relationship of access rights to model-based workflows.
- User Experience, easiness and required level of proficiency of users
 - It would be challenging for individual, non-expert users to overcome these technical challenges without any guidance.
 - User Experience of exporting/converting: Direct conversion from .rvt to IFC in Asite cBIM was not possible. The native .rvt had to be converted to IFC in Revit first.

4.4.3 Summary of findings from Perspective 3

The main findings from Perspective 3 are summarised below:

- It has been verified through examples that is IFC not producing adequate data transfers and that this stands as a critical barrier for utilising web-based collaboration tools such as Asite cBIM.
- The building information conversion and exchange process is not simple enough to be conducted by non-specialist user effectively. There is a need for specialised knowledge and/or strict conversion protocols.
- There is a need for rigid protocols to guide export and coordination process.
- Apart from data fidelity, which is key, the importance of User Experience, User Interface, easiness of exports and model management are also important barriers.
i.e. it's not only BIM model data that is lost: Time in BIM workflows is lost, communication of intent is lost. Furthermore, there are also less easily identifiable wastes through information overload.
- Asite cBIM should focus on the intuitiveness and efficiency of BIM model-based communication in order to provide a more useful solution.

4.4.3.1 Findings regarding the assumed conceptual models and terminologies

- There are various ways in which users can access and exchange data, however, there is no standardised way of referring to them. Furthermore, there is no standardised way of referring to the data and type of data required for them to be effective.

4.4.4 **Outcome of Perspective 3: Elicitation of principles for the requirements from BIM model-based communication**

Perspective 3 revealed that particular attention had to be drawn to the BIM model-based communication aspect of Asite cBIM. Additionally, the study by Liu et al. (2011) on the “marketed functionalities” of OCPs in the UK revealed that communication features are markedly the least satisfied category (the other three categories being System Administration, Document Management and Workflow Management).

It became apparent that solutions such as Asite, through cBIM as well of the rest of its service offering, could become the catalyst for change in the transition from the document-based paradigm to the model/object-based paradigm as analysed by Cerovsek (2011). For this reason a set of principles (or heuristics) for BIM-model based communication were produced. These aimed to express the new paradigm and communicate what is essentially different in what is envisioned in a format appropriate for further action by a product development team such as that of Asite.

4.4.4.1 Method

The elicitation of these principles was achieved through a context-specific literature review and a review (focused on model-based communication) of other BIM communication software as well as flagship Product Lifecycle Management software, Siemens Teamcentre (Siemens, 2013) used in the manufacturing and automotive industries. The author also attended a week-long intensive module on “Product Information Systems – Product Lifecycle Management” offered as part of Advanced Manufacturing Engineering courses at Loughborough University where Siemens Teamcentre was used for the module exercises for practicing/simulating collaboration in a product design process.

4.4.4.2 The five principles

The principles are presented below:

Principle 1: The model should be placed at the centre of communication. In other words it should act as the focal point of project communication.

Typically, project communication refers to some aspect of the building information model, hence any communication event should be facilitated through easy reference to that relevant aspect of the model. A number of studies have called upon the need for collaboration to depart from the document-based paradigm and place the structured model as the focal unit of communication. Aouad et al. (2005) have critically described project information as “unstructured and document based”. Yeomans (2006) revealed that the “single build model” was the least adopted out of eight collaborative working techniques. In their ICT Vision mapping, Rezgui and Zarli (2006) suggest that document-centric information exchange should be replaced by model-based ICT. Succar (2009) describes progression in BIM maturity by replacing document-based workflows; Isikdag and Underwood (2010) claim that

“the traditional nature of the industry is extremely ‘document-centric’” while Shafiq et. al (2012) note that “drawing is the currency”.

Principle 2: The model should be as integrated with associated documents and processes as possible.

Integration between the building information model with the associated documents, the collaborating actors and supporting communication tools should always be sought after. A spectrum of integration can be understood which ranges from (1) environments of complete lack of integration; where there is inter-relatedness between objects in reality but it’s not facilitated by the software platform to (2) partial integration where linkages like tags facilitate the associations to (3) real integration, where information can flow automatically. Integration is significant both from an information management/data fidelity perspective and a user-experience perspective. Real integration will enable what (Rezgui and Zarli, 2006) describe as the transition from “file-based exchange” to “flexible interoperability”

Principle 3: OCPs should provide informal communication channels and foster user familiarity.

Communication tools should enable the flow of intent and the association of events in face to face communication.

Product Lifecycle Management (“PLM”)/Product Data Management (“PDM”) software offers improved communication experiences where users connect and chat through social network-style profiles, disclosing their experience and expertise. The, inherently more standardised, manufacturing industry is exploring benefits of higher interoperability such as Knowledge Management.

Principle 4: Communication and coordination for effective collaboration cannot be performed distinctly.

Asite has tools for project information coordination and project responsibility coordination such as role-based access tools and configurable attributes. These have the potential to “naturalise” and improve project communication.

BS ISO 29481-2:2012, the Information Delivery Manual, Part 2: Interaction Framework (BSI, 2012) states that “coordination is dependent on communication, which should be well structured, unambiguous, explicit, and prompt.” It is argued that coordination and communication tasks within a collaborative BIM process can never be understood as entirely distinct since every effective coordination task requires communication to take effect and every effective communication task requires coordination.

Principle 5: Information exchange at the human-to-human communication level should benefit from further standardisation.

BIM can be understood as the “language of construction”: Coates et al. (2010) expressed BIM as the language of construction. It is proposed that this provides a useful metaphor as it portrays BIM as the primary communication medium for construction, hence highlighting the need for all communication processes within BIM to be as integrated as possible. El Diraby (2012) notes that construction informatics are by nature “tied to linguistics and human communication”. Succar (2009) creates a concept-rich ontology, providing a language principally for BIM research and adoption but less so for BIM practice. This idea can be extended to an international level; NIBS (NIST, 2007) describes the

evolution of terminology-related standards across countries while Mondrup (2012) maps Danish and Swedish BIM standards, illustrating that BIM should be an international language. It is not suggested that an adequate universal terminology of objects would deliver a comprehensive “language of construction”. Rather, it represents one of many communication dimensions in this “language”.

The need for structure: protocols and standards: Continuing the metaphor, just like a written language needs grammar, a set of structural rules, to be an effective and universal medium for communication, the collaborative BIM process requires structure through protocols and standards to be an effective medium of communication. The need for interoperability, which can be thought of as a measure of communication effectiveness in BIM, spans from technology to culture (Cerovsek, 2011). While on the technological level, structure and standardisation are clearly important, on the human communication level, especially in inter-organisational collaboration, they are often unacknowledged and difficult or unnatural to adhere to. Aouad and Lee (2005) criticise the traditionally unstructured information in construction projects. Yeomans (2005) illustrates the importance of protocols, especially for multi-disciplinary collaboration. Shelbourn et al. (2005) explain that “it is vital to lay down ground rules for communication so that mechanisms and the need for communication are understood by project participants, and that the communication occurs in a structured and consistent manner.”

Note: Principle 5 relates closely to the BIM Collaboration Format, BCF which, a few months after this part of the study, became a “pre-release” schema under development for becoming an official Building Smart specification (Building Smart, 2014).

4.5 Perspective 4: Use of software and patterns in digital communication: Analysis of communication data and meta-data from Asite workspaces

4.5.1 Introduction

Perspective 3 elaborated on the opportunity for OCPs to become the catalyst for the transition from the document-based communication paradigm to the model/object-based communication paradigm. The outcome of Perspective 3 was the articulation of five principles which are to be used as heuristics for BIM model-based communication. In Perspective 4, communication data and meta-data from projects utilising the Asite collaboration platform were collected and analysed in order to:

- Test the **manifestation** of these five principles and their implications on communication effectiveness.
- Explore any relevant **patterns** in project communication (as an exploratory analysis) and relate them to concepts such as communication efficiency and BIM maturity.
- Lay the ground for meaningful **metric-based analysis** on data and meta-data from project communication through OCPs.
- In parallel, identify **concepts which should be included in the conceptual model** to be developed which would support the Requirements Engineering discourse.

Three types of analysis were conducted:

- Analysis 1: A statistical analysis of communication meta-data.
- Analysis 2: A social/organisation network analysis on the communication meta-data.

- Analysis 3: An interpretative analysis of communication data (the content of the messages exchanged).

4.5.2 Context of the data collected: Asite workspaces

The data analysed was extracted from online “Workspaces” in Asite. The specific sources of data were (1) Document Listings: listing all the documents, drawings and models hosted within the workspace and the associated fields, (2) Document Distribution Reports: listing all the Actions distributed (i.e. delegated or disseminated) by users to other users with reference to a specific document, drawing or model, (3) Comment Listings: listing all the comments made upon uploaded documents, drawings and models and Form listings (Request For Information (RFI) forms:used to facilitate more structured communication often in reference to uploaded documents, drawings and models.

All four sources of data were extracted from Asite directly into Excel spreadsheets. These reports-spreadsheets captured fields such as Document name, Folder, Date Uploaded, Purpose of Issue, Author organisation, Recipient organisation, Action Status, Action type. Indicative screenshots are provided in Figure 25:

Full Filepath	folder	File Name	Doc Ref	Comment	Doc Title	Private	Iss No	Rev	Publisher	Publisher Org	Published	Doc.	Pr
IPS-AST 44(01).pdf	IPS-AST 44(01).pdf	IPS-AST 44(01).pdf	IPS-AST 44(01)		GENERAL ARRANGEMENT-GF-1	No			ronaldjammens van	Astudio	01-Feb-2013 09:25 VET	Yes	For

Purpose of Issue	Status	Comment Creator	Author Org	Comment Id	Comment Date	Comment Title	Comment Content	Assoc Docs
For Construction	A - Accepted	John.N.Cowie	Balfour Beatty Construction Limited	DOC-COMW11	04-Feb-2013 12:36 VET	Document Status Change	Document Status was changed from --- to A - Accepted by Gary Ewenright, Balfour Beatty Construction Limited on behalf of John N	
For Construction	A - Accepted	John.N.Cowie	Balfour Beatty Construction Limited	DOC-COMW11	04-Feb-2013 12:36 VET	Document Status Change	Document Status was changed from --- to A - Accepted by Gary Ewenright, Balfour Beatty Construction Limited on behalf of John N	

Assoc Docs	Assoc Form	Attributes	Attach.Files	Markup	Private
					No
					No

Figure 25. Screenshots showing the fields captured in the extracted reports-spreadsheets

It should be acknowledged that only the actions, documents and communication performed through the three data source types were analysed. Other forms of communication such as e-mails, physical meetings, and telephone communication have not been captured and analysed. Additionally, the content of documents, drawings and models was not examined.

The five projects

Data from five projects have been used. Those five projects were selected based on their varying degrees to which BIM was utilised and the availability of the data (i.e. mix of convenience and stratified sampling). The identity of the projects is not disclosed and ethical research protocols of the industry and academic research partners were followed.

Table 8 summarises the basic contextual data about the five projects. All projects were delivered through “Design and Build” contracts. The number of collaborating organisations ranged from 10 to 30 and the number of collaborating individuals ranged from 30 to 80. The projects are ordered and numbered according to how the basic information about their software configuration indicates their “BIM advancement” i.e. Project 1 is the most “BIM advanced” and Project 5 the least “BIM advanced”.

Table 8. Summary of Project Workspace Data: Project Context and Usage Statistics

	Project 1	Project 2	Project 3	Project 4	Project 5
Contract type	Design and Build	Design and Build	Design and Build	Design and Build	Design and Build
Level of project completion	Construction 80% complete	Complete	Complete	Complete	Detail Design
Collaborating organisations (approx.)	30	40	30	30	10
Collaborating individuals (approx.)	70	80	80	60	30
Software Configuration: Model coordination method, BIM applied?	Separate software for BIM model coordination. Email for communicating model coordination	Design coordinated through physical meetings. Partly paper-based.	Design coordinated through physical meetings. Partly paper-based.	No 3D models used	No 3D models used

The unit of analysis: The transmission

The most central concepts examined in the analysis are explained below:

- User: any project stakeholder who is able to participate in digital project collaboration through an Asite account.
- A container (or resource): anything that could hold information that is relevant to the project. This information could be building information, specifications, requirements, meeting minutes, building regulations etc. A container (or resource) could be in the form of document, a 2D drawing or a 3D model.
- A transmission: Any exchange of information from one user to another. This could be the transmission of project information and/or instructions or opinions in reference to project information or other containers.
 - *Purpose of transmission:* it should be noted that every transmission had a purpose. This was often (not always) explicitly identified within project communication

Figure 26 illustrates the concepts described above.

Project Workspace Metadata from Asite

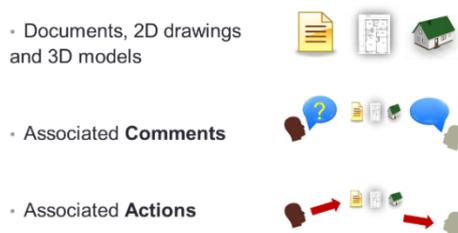


Figure 26. Illustration of the type of data collected. Comments and Actions were in reference (associated) to documents, 2D drawings and 3D models which were uploaded to Asite project Workspaces

Analysis 1: Statistical (metric-based) analysis of communication meta-data

Data from the reports-spreadsheets was used to generate graphs which illustrated relevant patterns through communication meta-data and related to the five principles proposed in Perspective 3.

Table 9 presents the basic contextual information from the five projects and statistics on Commenting and the use and interaction around 2D containers in comparison to 3D containers. It is evident that the highest activity in commenting in all projects is from contractors followed by the main architect and main engineer (table 2).

Table 9. Statistics on Asite-based communication and use of containers

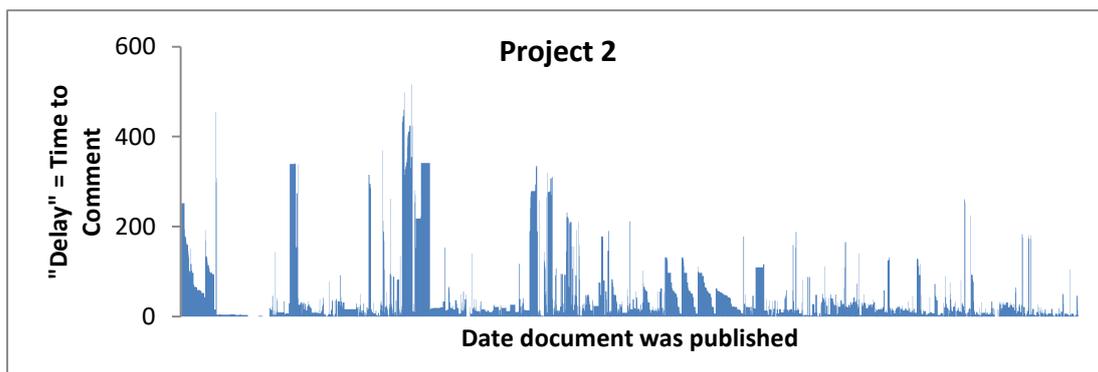
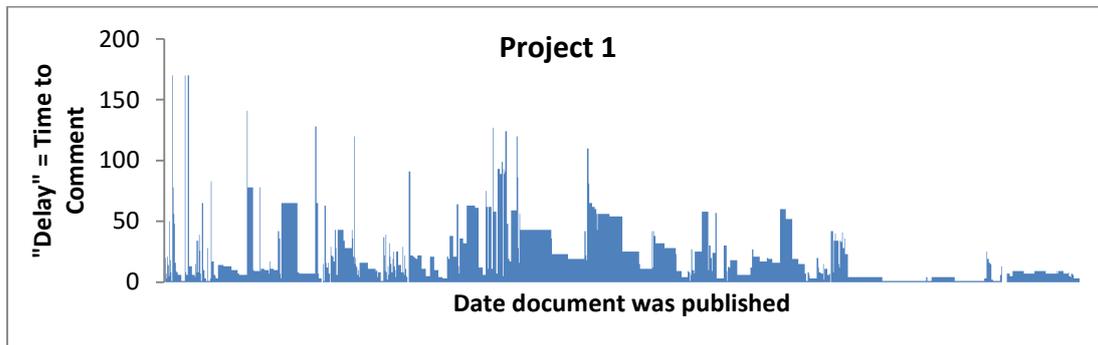
		Project 1	Project 2	Project 3	Project 4	Project 5
Contract type		Design and Build	Design and Build	Design and Build	Design and Build	Design and Build
Level of project completion		Construction 80% complete	Complete	Complete	Complete	Detail Design
Collaborating organisations (approx.)		30	40	30	30	10
Collaborating individuals (approx.)		70	80	80	60	30
Software Configuration: Model coordination method, BIM applied?		Separate software for BIM model coordination. Email for communicating model coordination	Design coordinated through physical meetings. Partly paper-based.	Design coordinated through physical meetings. Partly paper-based.	No 3D models used	No 3D models used
No. file formats	Total	8	16	16	11	2
	2D drawing	1	1	1	1	1
	3D (including IFC?)	3 (yes)	3 (yes)	5 (no)	0 (-)	0 (-)
No. Comments (approx.)		1300	5700	2300	1300	170
Contractor comment share (or Land Developer for project 4)		71%	57%	34%	85% (developer)	83%
Architect comments share		19%	8%	21%	4%	16%
Engineer comments share		8%	6%	24%	2%	1%
Comments per 2D drawing or document (total 2D docs(approx.))		0.88 (1470)	0.87 (6230)	1.28 (2030)	0.20 (6240)	0.54 (510)

Comments per 3D model (total 3D models)	0.1 (20)	0.39 (23)	0 (15)	- (0)	- (0)
Revisions per 2D drawing or document	2.20	2.25	1.88	1.88	1.44
Revisions per 3D model	4.50	1.96	1.80	-	-
Average commenting “lag”** in days (standard deviation)	21 (23)	45 (77)	45 (71)	14 (34)	4 (11)

The main observations from Analysis 1 are outlined below:

4.5.2.1 Comment “lag” (project timeline)

Commenting “lag” is the time, in days, between when a container is published and when the first comment is made in reference to it. The average commenting lag is 21 days, 45 days, 45 days, 14 days and 4 days for projects 1 to 5 respectively (Figure 27). This indicates that there is a considerable lag between when a user creates a set of information and when a collaborator makes use of it. This “lag” in responses observed in the data analysis is consistent with the concept of “response latency” as defined by Koskela (2013) and (Chachere & al. 2009) who try to understand the “wastes” inherent to the AEC design phase in order to ultimately apply approaches like Lean methodologies in order to reduce those wastes.



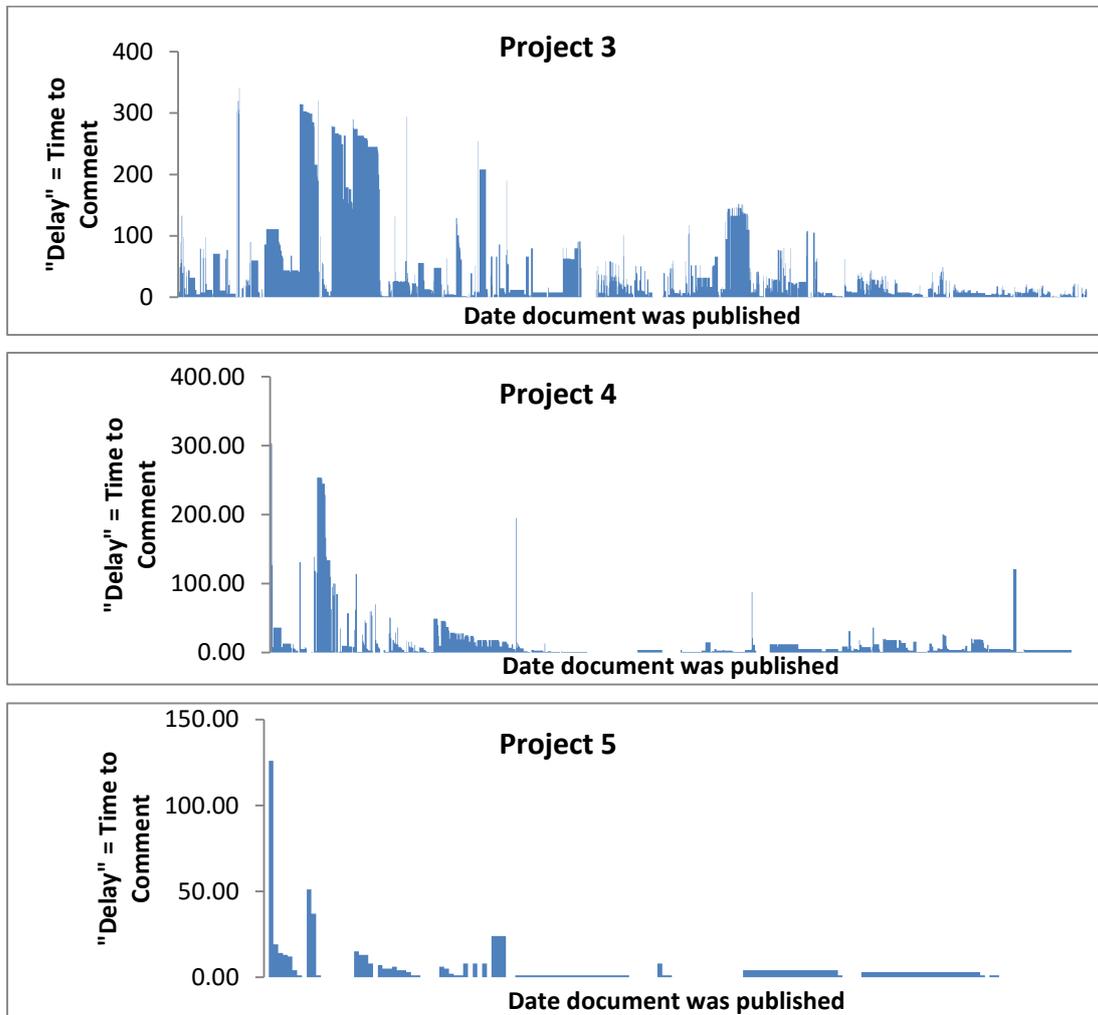


Figure 27 Comment Lag (project timeline) - Projects 1 to 5

4.5.2.2 Comment count and comment author per document publisher – Project 1

The dominance of contractors as commenters is also shown in Figure 28. It is also evident that only three companies; the main contractor, the architect and the mechanical engineer participate in 98% of commenting despite many documents having been uploaded by many other collaborators.

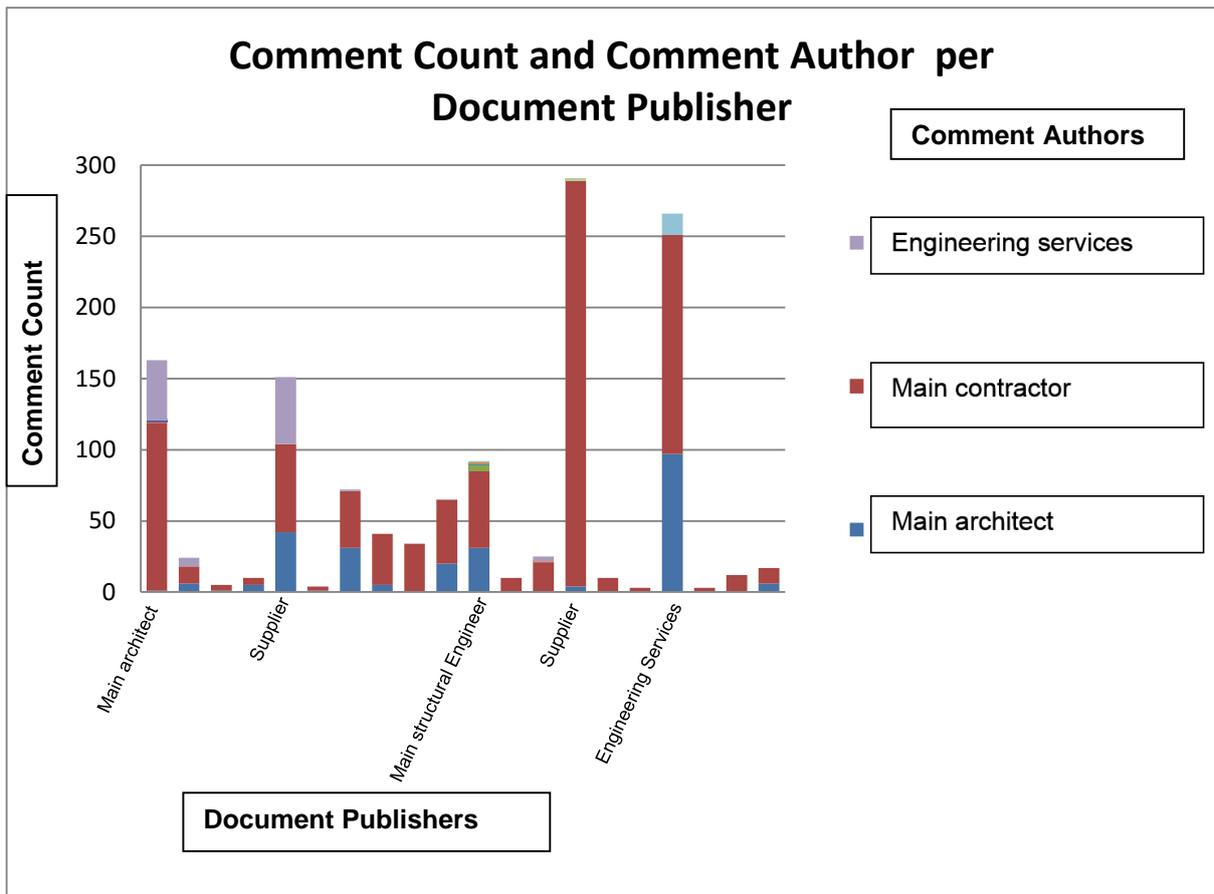


Figure 28 Comment Count and Comment Author per Document Publisher - Project 1

4.5.2.3 Action count and “on-timeness” per recipient company (project 1 only)

There were approximately 25000 actions assigned in project 1 (Figure 29). The contractor was the main recipient in Actions, followed by the Architect and the Mechanical Engineer.

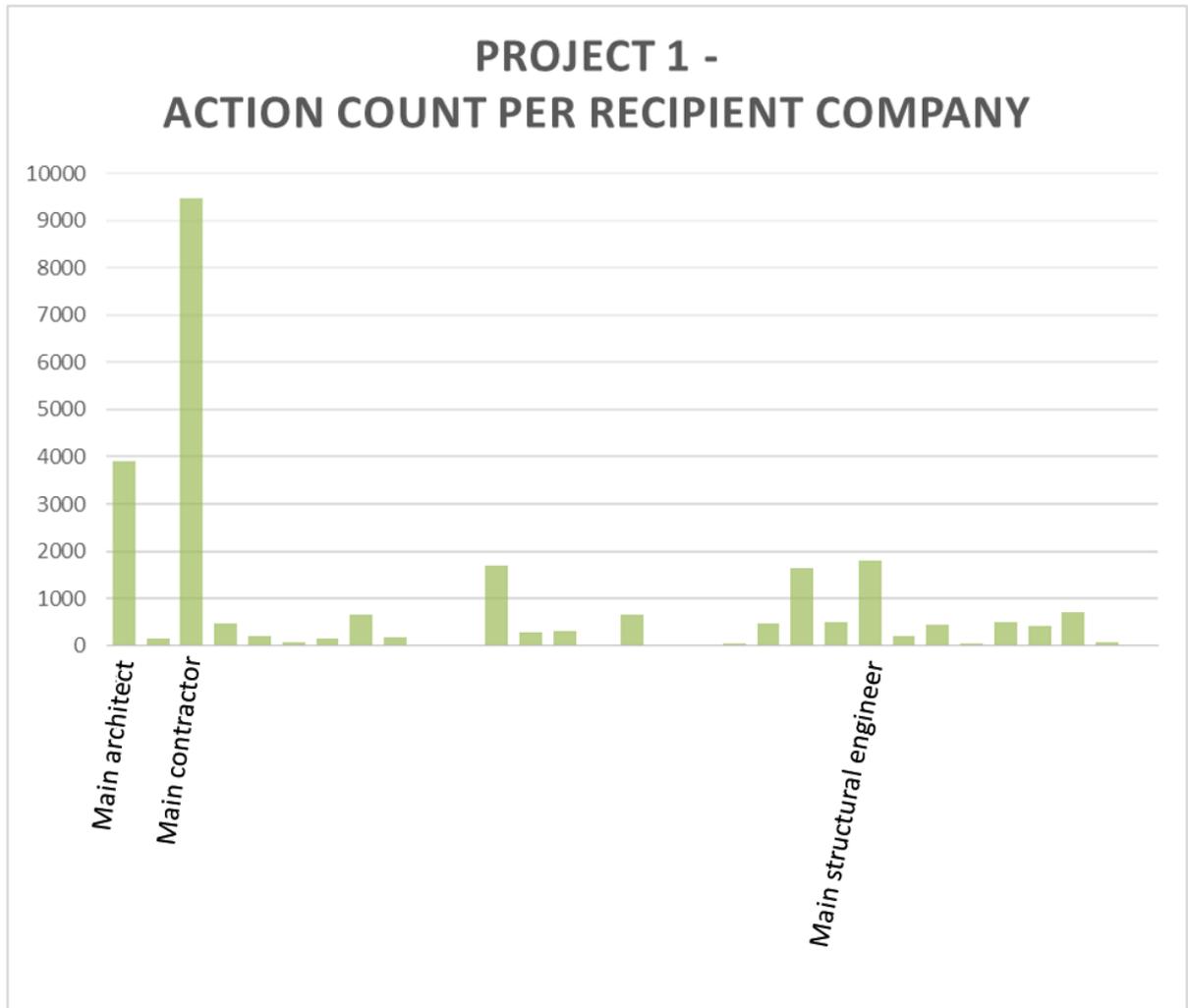


Figure 29 Action count per recipient company - Project 1

4.5.2.4 Action count and action status per comment count (project 1 only)

Figure 30 separates containers according to how many comments have been made in reference to them and then counts the number of Actions assigned in reference to them and whether these Actions were Cleared, Complete or Incomplete e.g. for containers which received one comment, more than 4000 actions were cleared. Containers with 0 comments have the highest proportion of

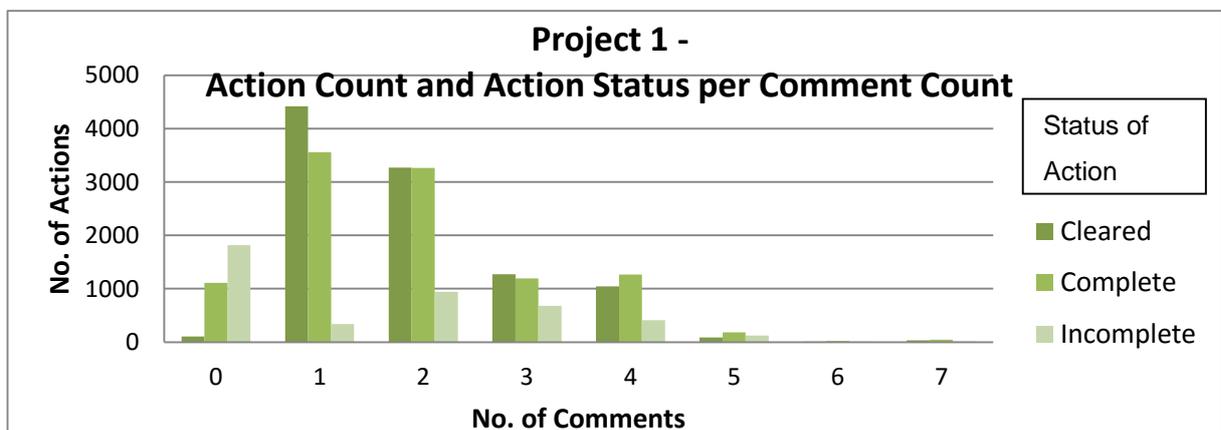


Figure 30 Action Count and Action Status per Comment Count

incomplete actions. This supports the assumption that some form of commenting is required before completing an action.

4.5.2.5 Action count and action status per purpose of issue (project 1 only)

As shown in Figure 31, “For Comment” and “For Construction” are the most common purpose of issue of a container by far. Their Cleared-Complete-Incomplete ratio is similar, yet Cleared Actions outweigh Complete Actions where “For Construction” was the Purpose of Issue of a container.

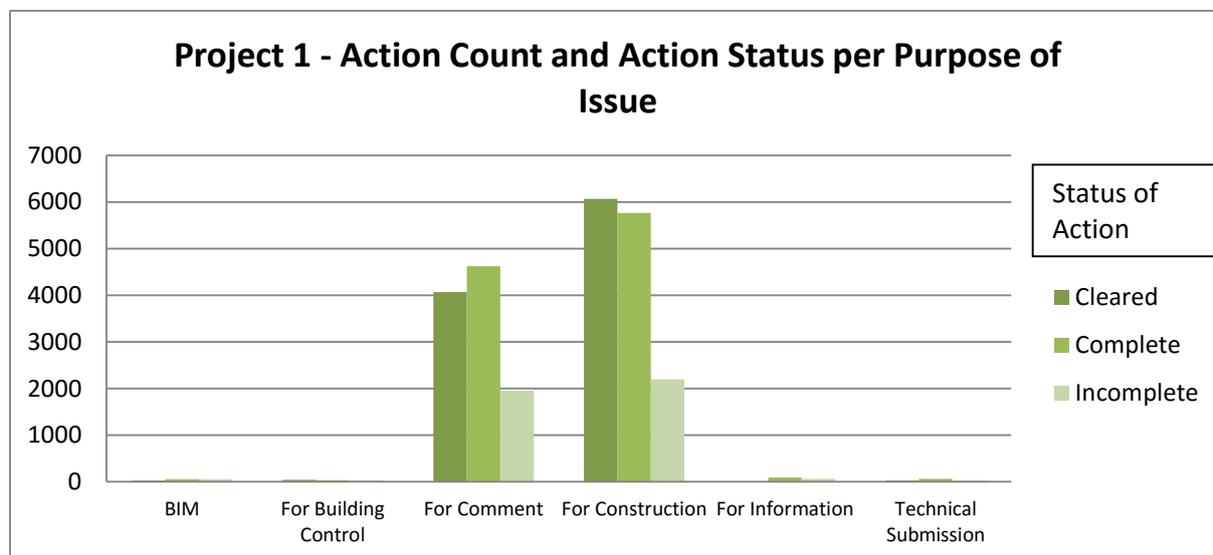


Figure 31 Action Count and Action Status per Purpose of Issue - Project 1

4.5.2.6 Comments per 2D drawing vs. comments per 3D model

As shown in table 9 as well as in figure 22 below, significantly more comments are made on 2D drawings than on 3D models. This is a sign of the dominance of the paradigm of document-based communication (as opposed to model-based communication). This type of interaction makes locating comments and issues (and useful information in those comments) more difficult if the identity of the container in question is not known. Figure 32 below shows that in most projects drawings (.dwg) and Adobe Portable Document Format (.pdf) were the focus of commenting.

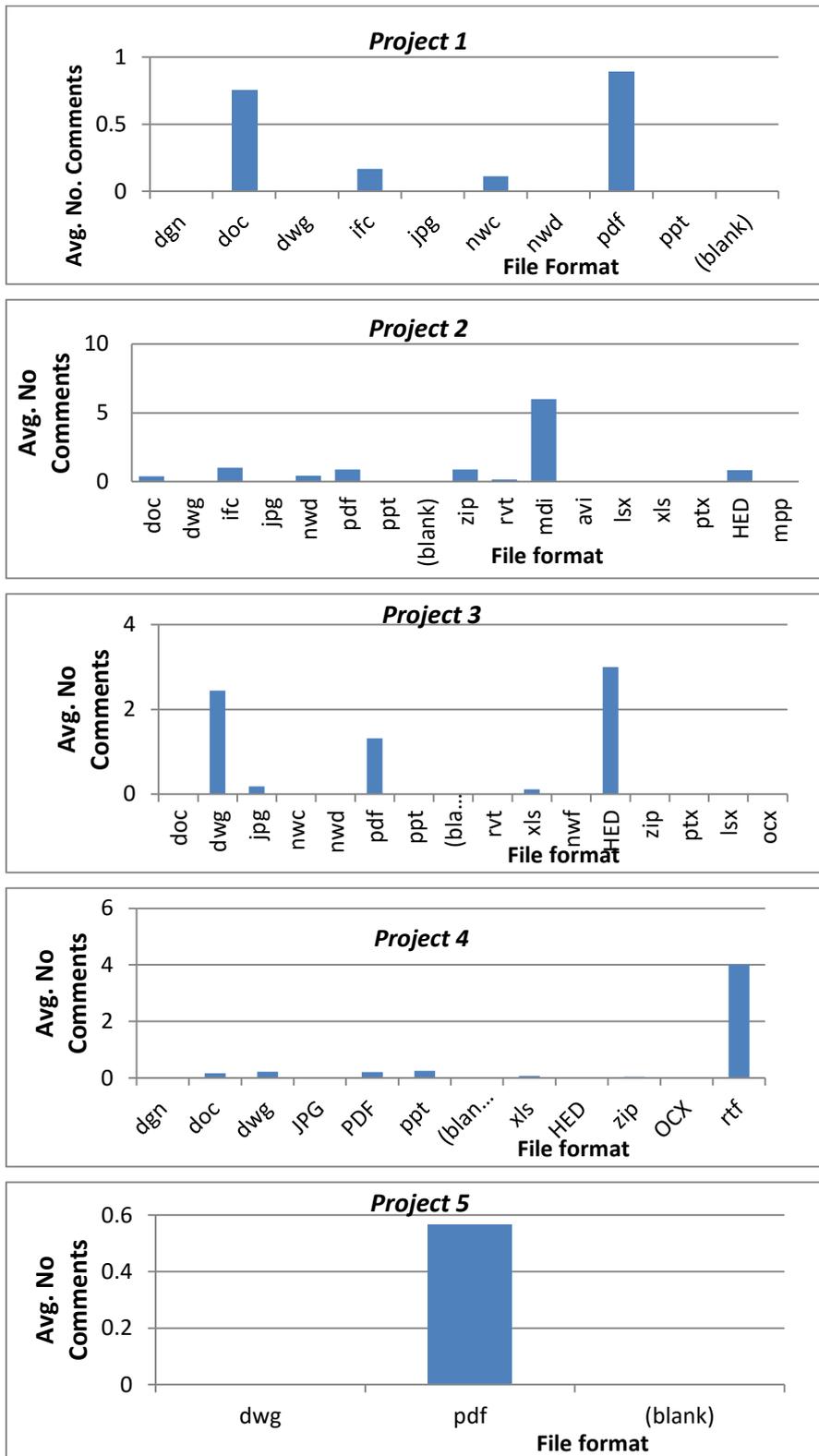


Figure 32 Average number of comments per 2D drawing vs. comments per 3D model

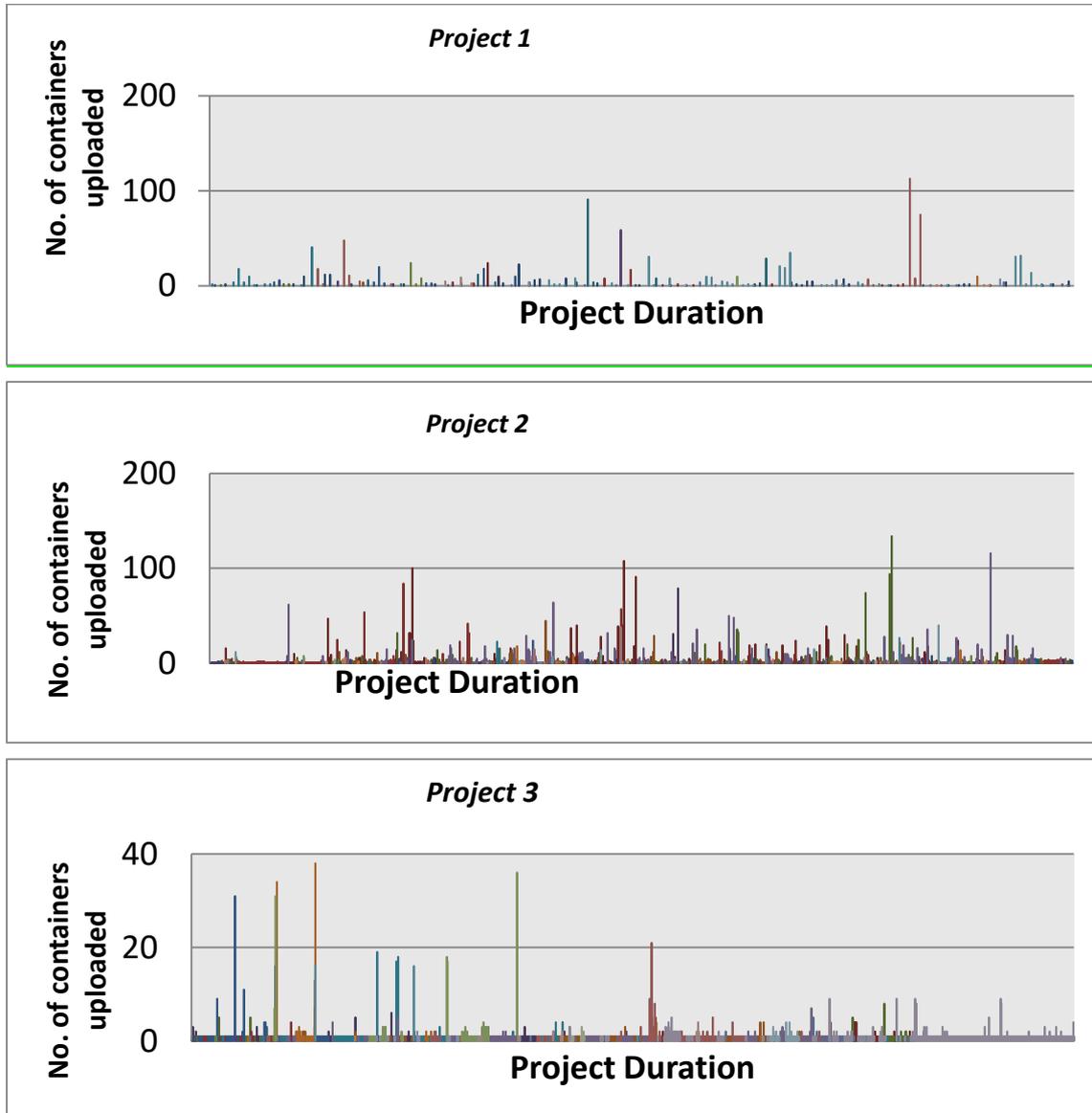
*MDI: Microsoft Document Imaging format , **HED: Document (HighEdit), *** RTF: Rich Text Format

4.5.2.7 Revisions per 2D drawing vs. revisions per 3D model

As shown in table 9, despite communication being around 2D containers, 3D models are revised in similar levels. This is a form of process waste as users would typically first refer to 3D models, then communicate based on 2D containers and then revise the 3D model. In other words, this indicates a lack of immediacy in communication.

4.5.2.8 Publishing per organisation (project timeline)

Figure 23 shows that each company mainly publishes in some specific phase during the project. Different organisations publish at different times. This is a sign of sequential collaborative process.



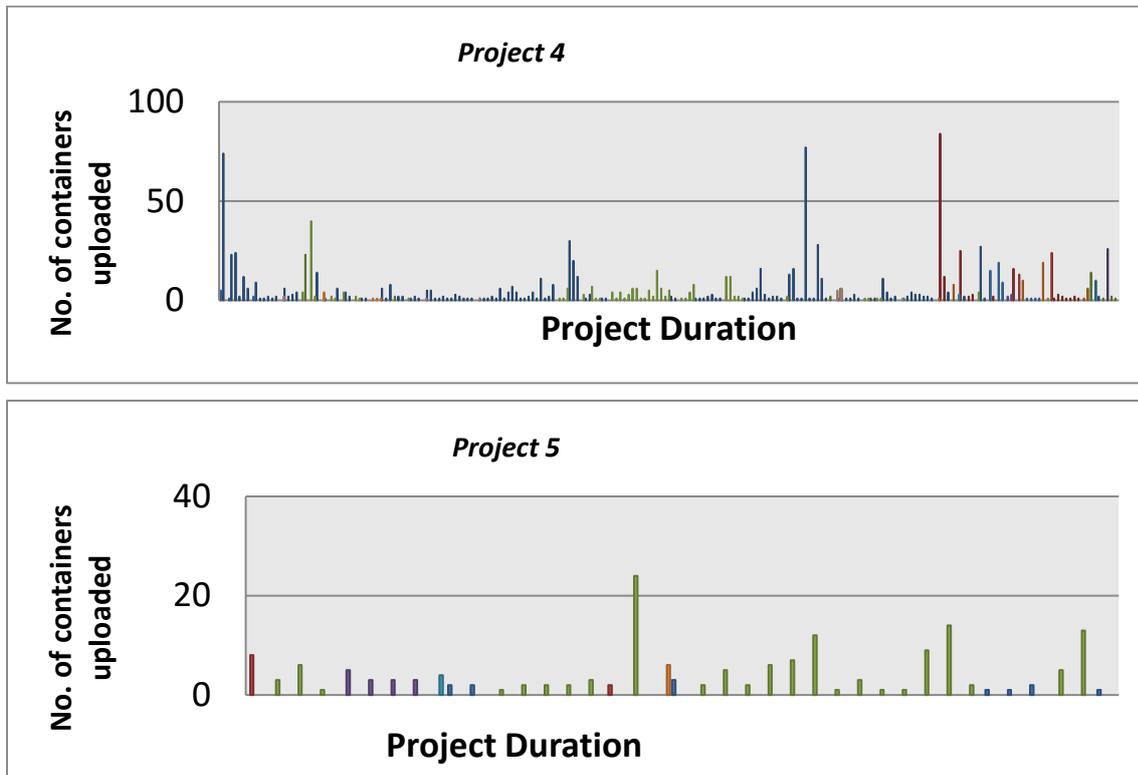


Figure 33. Publishing per organisation (project timeline) Note: company disciplines are not identified because of haphazardness of contribution

4.5.3 Analysis 2: Project network analysis

Analysis 2 utilises the network properties of the data from the spreadsheets-reports extracted from Asite Workspaces (in every transmission there is a sender and a receiver). In Action Distribution, (sender) users assign an Action in reference to a container to specific users (receivers) while in Commenting (sender) users direct their comments in reference to containers to other users (receivers).

The data captured was used to produce network graphs using Social Network Analysis software Gephi (Bastian et al., 2009). Users are represented by the nodes in the network and the interaction between them, the transmissions, are represented by the edges (or ties) in the network. Visual and network metric-based analysis of the networks is used to elucidate patterns in project communication that was facilitated by Asite Workspaces.

4.5.3.1 What type of networks are we dealing with?

The most significant characteristics of the networks presented in Analysis 2 are outlined below:

- Even though the nodes in the network represent people, the networks are *not entirely "Social"* (as would be expected by the term "Social Network Analysis"). The behaviour in the project network was defined partly by pre-defined processes, protocols and contracts.
- Networks are *directed*: there is an Action/Comment Sender and an Action/Comment Receiver.
- Networks are *weighted*: each node is weighted according to the number of actions/comments between the two users it joins.

Additionally, the following characteristics are acknowledged but are not captured in the network graphs in Analysis 2:

- Networks and in reality *dynamic*: the actions/comments occur throughout project duration. The static depictions represent an overlay of the accumulated actions through project time. Any sequence between serially dependent actions is not depicted.
- Behaviour in the network is typically *sequential*: Actions often come as a result of previous actions.
- The networks are characterised by “*referring*” *communication*: Actions were in reference to containers (documents/drawings/models). The graphs presented do not provide any reference to the documents, drawings or models which the actions refer to or the decisions made to modify them. Arguably, “bi-modal” networks (where one mode of nodes are users a second are containers) would have served as more appropriate representations for many purposes.

In relation to general network analysis metrics (or network properties) some metrics were readily fitting in this context (e.g. density, modularity) while others were more difficult to interpret (e.g. closeness) or possibly even trivial.

Finally, it should be noted that that the networks plotted are only two types of many networks that can be conceptualised. For some networks the data are recorded and for other, possibly meaningful ones, data is not recorded. The networks in Analysis 2 were prescribed by the purpose of the examination and by the nature of data collection context.

4.5.3.2 Network Graphs

4.5.3.2.1 Action Distribution: Comparison of overall action distribution across the five projects

Figure 24 presents the “Action Distribution Graphs” for the five projects.

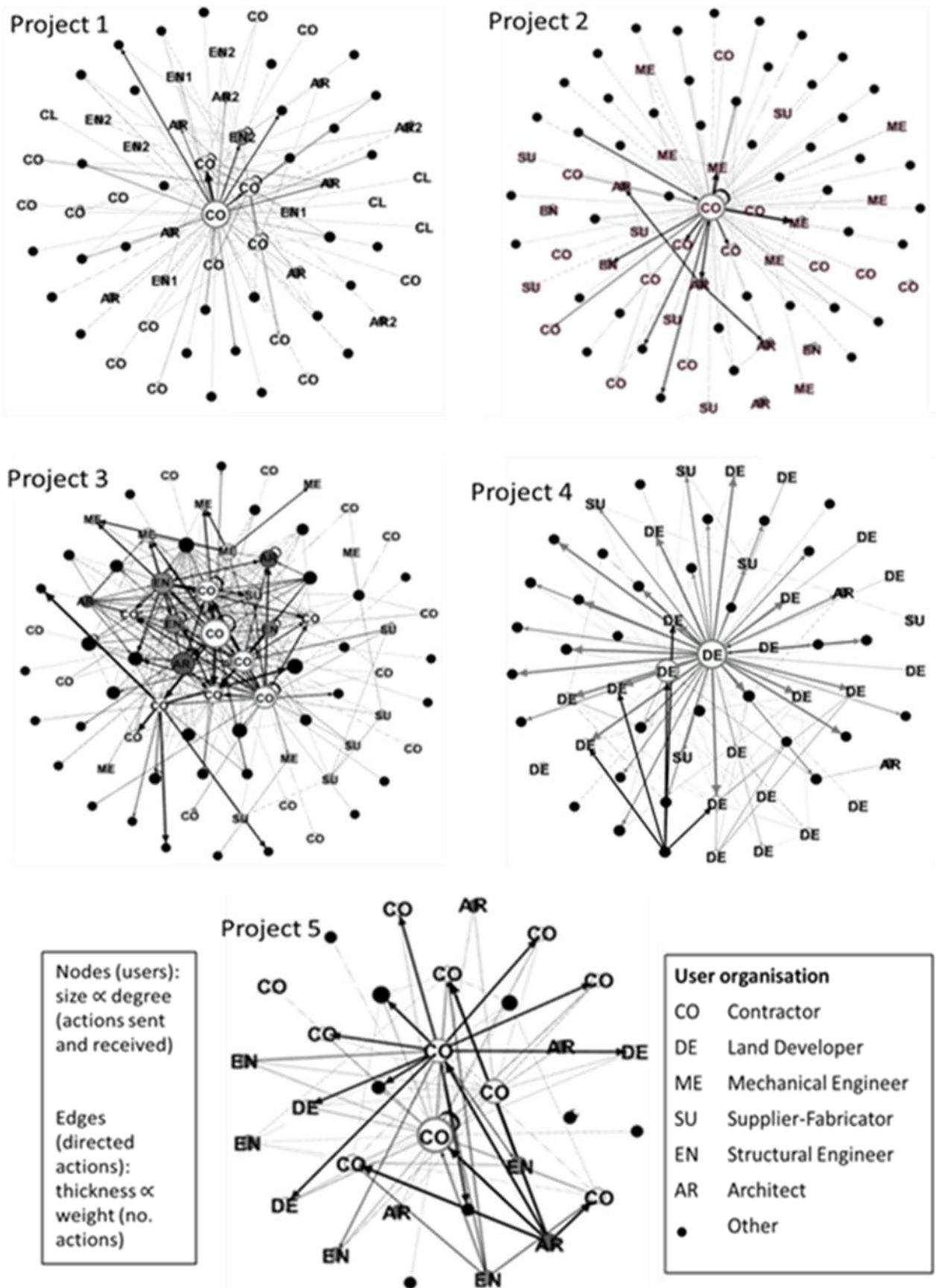


Figure 34 Action Distribution Graphs from the five projects

Adaptation-interpretation of generic metrics for network characteristics to the context of Action Distribution in project collaboration

The domain of Social/Organisational Network Analysis utilises a wide range of metrics to describe the characteristics of networks. From these, a set of metrics was chosen and proposals for their interpretation in the context of Action Distribution were made. These are presented in table 10.

Table 10. Network graph statistics and suggested interpretations

Measure	General definition of measure	Suggested interpretation within context of Action Distribution	(rank in parenthesis)				
			Proj. 1	Proj. 2	Proj. 3	Proj. 4	Proj. 5
Graph Density	Total number of observed edges divided by the total number of possible edges.	The spread of Action Distribution.	0.03 (4)	0.02 (5)	0.07 (2)	0.04 (3)	0.10 (1)
Average Degree	The average number of users a user has had at least one interaction with.	The degree of user interaction.	2.06 (4)	1.12 (5)	4.99 (1)	2.23 (3)	2.87 (2)
Average Weighted Degree	Average of sum of weights of the edges of nodes.	The intensity of Action Distribution.	369 (1)	130 (3)	130 (3)	161 (2)	117 (5)
Modularity	A measure of the definition of the communities within the network.	A measure of the definition of the communities within the network.	0.00 (5)	0.26 (3)	0.36 (1)	0.18 (4)	0.36 (1)
Connected Components	No. sub-graphs in which any two nodes are connected to each other, and which are connected to no additional nodes in the network.	A measure of isolated practice between groups of users.	0 (5)	1 (3)	1 (3)	3 (1)	2 (2)

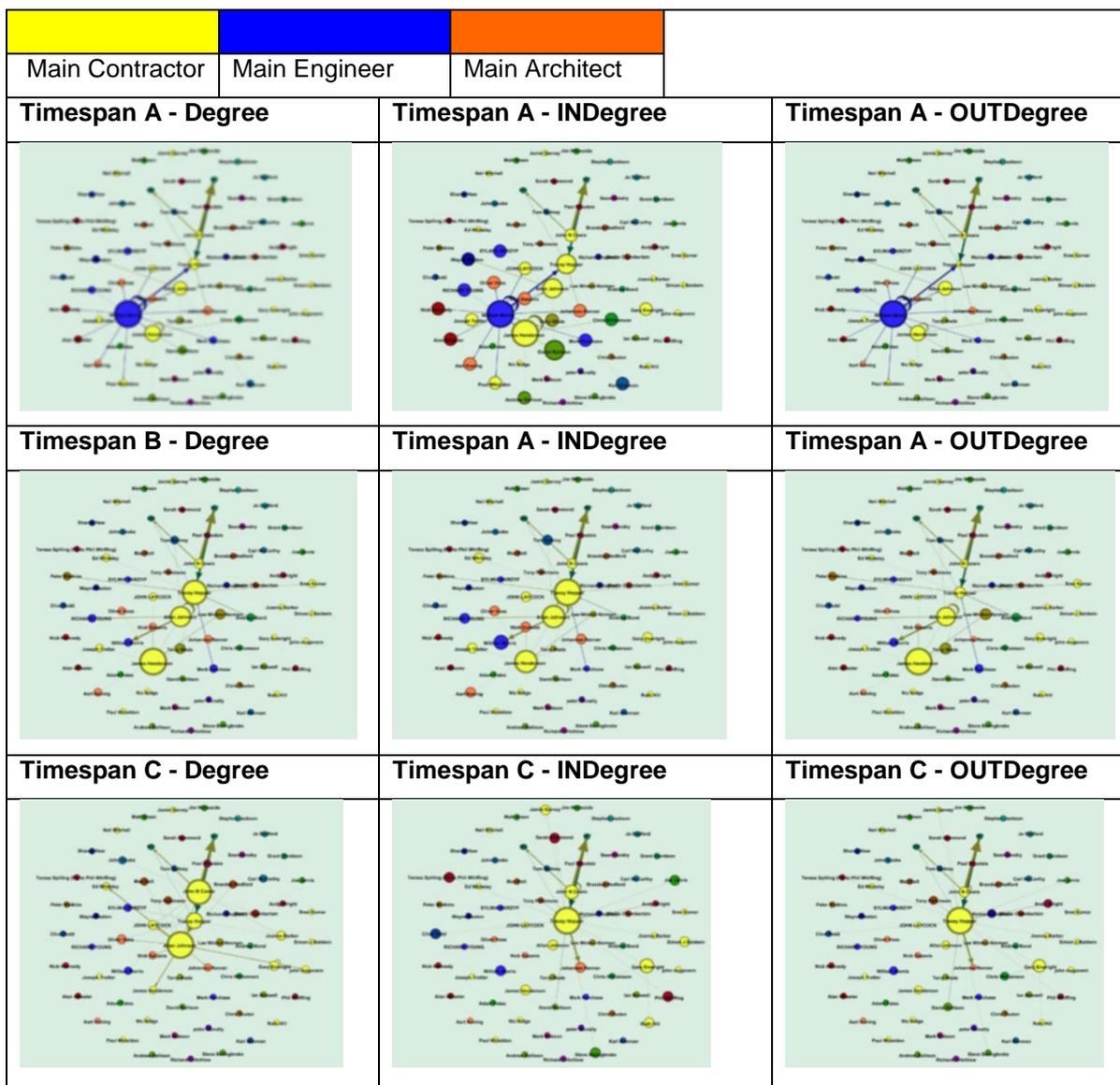
Observations from Action Distribution Graphs (figure 24) and captured network metrics in table 10

- Degree and weighted degree do not agree (in terms of project ranking).
- Users from the contractor organisation (or land developer in project 4) display the highest degree in all networks.
- The most central user in all networks is the document controller.
- Project 4 displays a very star-like network graph suggesting central control by the developer. This is in agreement with the high comment share of developer.

- Project 3 displays some particularities; It has the highest average degree, the second highest graph density, the highest modularity, visually the most discipline inclusive network with the densest network core, the most even comments share and the highest commenting lag.
- Project 3 and 5 both visually display the least uniform, least star-like networks as well as jointly having the highest modularity.
- The projects, going from 1 to 5, are decreasingly BIM-advanced (Table 9). The only observed correlation is with “Connected Components”. The relatively small absolute number of these connected components as the existence of other project-specific factors which couldn’t be examined in combination with the relatively small sample of projects does not allow for any inferences from this correlation i.e. these connected components in the network could have arisen from a number of different reasons irrelevant to BIM advancement and software configuration.

Action Distribution: A closer look at action distribution on Project 1

Figure 25 presents a more analytical view on the Action Distribution Network of Project 1. The project duration is split into five equal time spans (A to E). Additionally, apart from the (general) degree of each node, the INDegree (size of node analogous to number of incoming actions) and OUTDegree (size of node analogous to number of outgoing actions) are presented in different graphs.



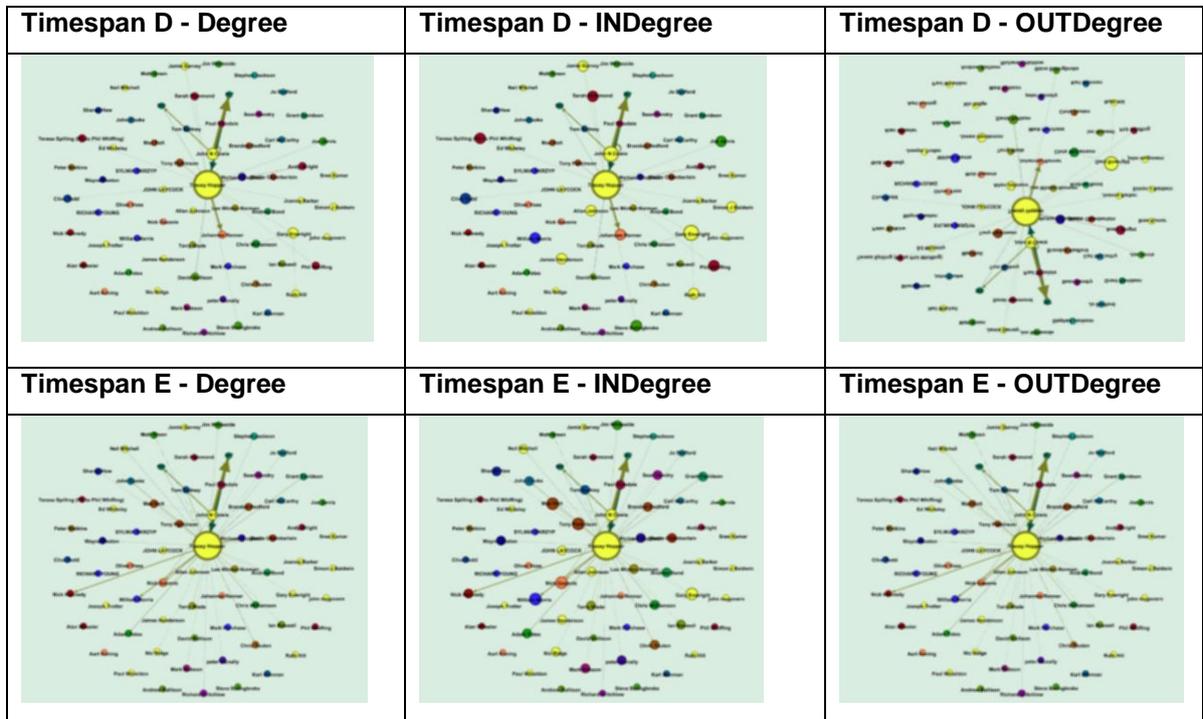


Figure 35 Action Distribution in Project 1: IN/OUT degrees at different timespans

Observations:

- Users from the Main Engineer are more active at the beginning. Gradually, most activity falls with the document controller who represents the Main Contractor.
- In terms of OUTDegree (assigning actions) one particular member from the Main Engineer and the Main Contractor's document controller are by far the most active.
- Actions are assigned to users from many companies, as is shown more clearly in the INDegree graphs.

Commenting: A closer look on commenting in Project 1

The graphs in Figure 26 present "inter-company commenting". Each node represents one company and the edges are formed when users from different companies commenting on documents published from users from other companies. The INDegree graph shows that the receivers of Comments are predominantly the Main Architect, the furniture provider and the Engineering Services Consultant. The OUTDegree graph shows that, by far, the biggest Commenter is the Main Contractor.

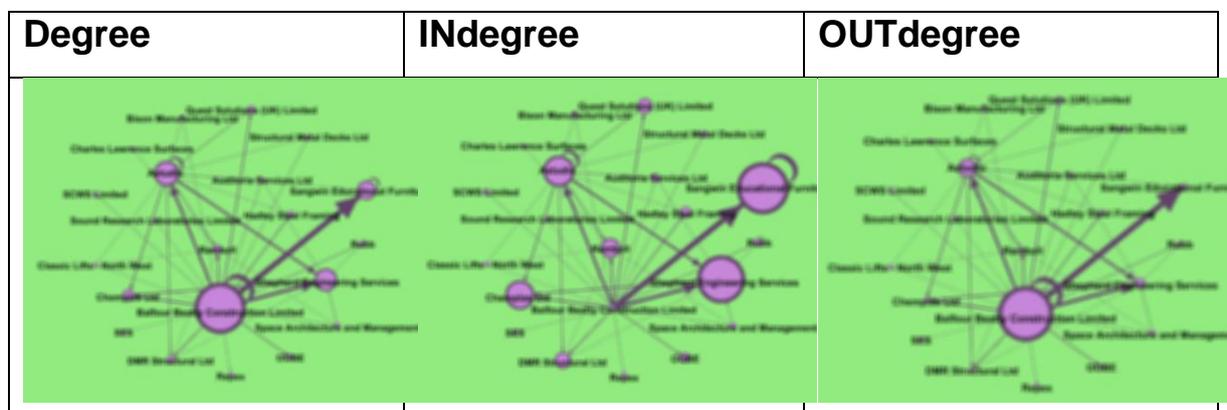


Figure 36 Commenting in Project 1: IN and OUT degree

4.5.3.3 Discussion on the utility and implications of analysis and evaluation

4.5.3.3.1 Utility of Analysis

The analysis carried out reveals some correlations between the selected measures as well as providing some indications on what methodology improvements would yield more meaningful results. The presented analysis is not adequate to support the five principles in Perspective 3 since the sample of five projects is not sufficient to respond to the high granularity resulting from the number of selected measures. In addition, underlying variables such as project type, contracting company and process protocols make comparison even harder. The measure most relevant to the reviewed themes is Software Configuration which includes indications of BIM-advancement.

4.5.3.3.2 Improving the analysis

A more meaningful analysis would result from (1) a bigger sample of projects, (2) keeping variables such as project type and contracting company identical, (3) accounting for underlying contextual factors such as process protocols, (4) including success indicators such as time and cost efficiency rather than just interaction pattern indicators, (5) refining or further breaking down the measures (this could lead to the development of indicators of “Model-centricity” or “Model-integration” and their correlation with the success indicators), (6) including projects where a BIM model-server was utilised, (7) accounting for the time element, i.e. plotting different network graphs for each project phase) and (8) capturing the communication that occurred outside the online workspace environment.

4.5.3.3.3 Emerging questions

A number of questions arising from this analysis regarding the potential of network representations in providing meaningful insights. What could the project network graphs produced tell us about:

- Model-centricity vs. document centricity
- Collaboration: Interdisciplinary/inter-organisational collaboration
- Time efficiency: e.g. revealing any patterns in time lags associated with roles and/or phases.
- Project phases and their particular characteristics
- Types of interactions such as model-based, document-based, non-content-based etc.
- The opportunity for additional automation of communication tools through analysis of communication content.

Analysis 3: Interpretive analysis of communication data

The two predominant ways in which Asite users were able to communicate in reference to uploaded resources (containers) were:

- The Commenting Functionality: users would comment in reference to a specific resource (container) but had the ability to associate other resources (containers) already uploaded on Asite or attach a new resource. Therefore, the comment receiver could access the associated or attached resource by clicking on a link that would appear in message screen.
- The, more structured and formal, Form Functionality: forms of predefined structure, typically standardised for the purposes of each project, were used for more structured communication. The

form was created independently of any resource (container) but, like in Comments, the user had the option to associate and/or attach a resource (container).

The content of the messages within these comments and forms as well as the existence and identity of associated and attached resources (containers) were examined. The intent of comments was deduced and the comments were deconstructed into elements in order to examine the predominant categories (or streams) of communication. The intended effect and “easiness” of effective transmission of the message was compared to the actual effect and easiness in order to deduce communication efficiency.

Analysis of content of Comments

Term frequency statistics

The most frequent words or phrases were identified through observation. The frequency of these words and phrases in each of the five projects is presented in Figure 27.

total comments	occurrences	percentage	
1298	335	26%	no comment
1298	139	11%	see
1298	21	2%	associated
1298	67	5%	attached
1298	32	2%	as discussed
1298	36	3%	discussed
1298	7	1%	e-mail or email
1298	65	5%	refer
1298	397	31%	drawings
1298	70	5%	drawings ok
1298	177	14%	please

total comments	occurrences	percentage	
5701	2331	41%	no comment
5701	139	2%	see
5701	21	0%	associated
5701	167	3%	attached
5701	36	1%	as discussed
5701	32	1%	discussed
5701	7	0%	e-mail or email
5701	304	5%	refer
5701	397	7%	drawings
5701	70	1%	drawings ok
5701	488	9%	please

total comments	occurrences	percentage	
2590	1368	53%	no comment
2590	148	6%	see
2590	1	0%	associated
2590	62	2%	attached
2590	1	0%	as discussed
2590	2	0%	discussed
2590	40	2%	e-mail or email
2590	103	4%	refer
2590	78	3%	drawings
2590	0	0%	drawings ok
2590	168	6%	please

total comments	occurrences	percentage	
1270	1031	81%	no comment
1270	9	1%	see
1270	0	0%	associated
1270	12	1%	attached
1270	0	0%	as discussed
1270	0	0%	discussed
1270	0	0%	e-mail or email
1270	14	1%	refer
1270	12	1%	drawings
1270	0	0%	drawings ok
1270	39	3%	please

total comments	occurrences	percentage	
279	13	5%	no comment
279	2	1%	see
279	0	0%	associated
279	2	1%	attached
279	0	0%	as discussed
279	0	0%	discussed
279	0	0%	e-mail or email
279	0	0%	refer
279	2	1%	drawings
279	0	0%	drawings ok
279	3	1%	please

Figure 37 Term Frequency Statistics from Comment content. The “Occurrences” column shows the number of comments where a particular word or phrase appears. Projects 1 (top) to 5(bottom)

The analysis showed that within project communication there is a significant amount of reference to other files-containers which are hard to access from the point of view of the receiving user. This is a sign of need for further integration of content.

Analysis of content of “Request for Information” Forms

Form listings from Projects 2,v3 and 4 were used to examine the intent, associated containers and content (if any) of the messages within the forms. It was found that these also indicate a similar forms of waste in the effective transmission of the intended messages e.g. in intent for action to be taken, in

referencing the relevant resource or event (e.g. a previous discussion between the sender and receiver that occurred on-site).

Conclusions from Analysis 3

The examination of comment content and RFI form content has helped identify the main categories of message elements (can be otherwise expressed as message streams or message flows). These are:

- Building information: to be modified (including attributes like the state of acceptance of a object or model) , to be incorporated, to be consulted
- Project requirements and specifications
- Industry codes and regulations
- Instructions
- Reference to project event (including other communication events and project actors/ software users)
- Intent (the communication layers necessary for turning project requirements into results).

4.5.4 Findings from Perspective 4

Perspective 4 has analysed a data set in three significantly different ways. The findings are grouped into the following themes.

4.5.4.1 BIM transmission (or “BIM message”) and its efficiency

It is evident that within a project there exists a vast number of digital transmissions. Additionally there seems to be considerable amount of waste in terms of communication efficiency and effectiveness. This highlights the potential in eliminating some of the waste in them. This is a matter of whether a transmission should take place as well as how can a required transmission be as efficient as possible.

Waste in transmissions manifests itself as:

- Lag in comments: The “lag” in responses relates to the “response latency” as presented by *Koskela* (2013) and (Chachere & al. 2009).
- Sending information and instructions to too many receivers
- Information overload
- Lack of immediacy in accessing relevant containers
- Lack of immediacy in referencing parts (e.g. objects) in containers

The interpretation of Comment Content and Form message content revealed the different elements/flows in a transmission:

- Building information: to be modified (including attributes like the state of acceptance of an object or model), to be incorporated, to be consulted
- Project requirements and specifications
- Industry codes and regulations
- Instructions
- Reference to project event (including other communication events and project actors/ software users)

- Intent (the communication layers necessary for turning project requirements into results).

4.5.4.2 Document-centric vs. model-centric communication paradigm

If the projects studied represent (e.g. number of comments on documents etc.) typical communication settings in construction projects then the challenge for BIM collaboration tool vendors is to create an effective model-based environment which would more efficiently satisfy the collaboration requirements described by the principles expressed in Perspective 3 and ideally eliminate any unnecessary, non-value adding steps within communication.

As a critical evaluation of the approach taken, it should be acknowledged that many of these 2D documents were generated from a 3D model as it is typically easier for users to approve 2D drawings. It should be noted that it is not proposed that 2D should be eliminated. Rather, more efficient ways of interacting with information should be sought. Additionally, this analysis provides no solid, quantitative evidence that the document-centric paradigm is inefficient and BIM would be more efficient. This assumption is based on a general perception and appreciation of the benefits of BIM.

4.5.4.3 Shared concepts and terminologies – Requirements from and elements for Conceptual Model

This Perspective-Phase has showed that there is significant variation in project software configuration across projects. The existence of multiple software and the resultant need for varied project software configurations has steered the attention away from the fundamentals of communication and contributed to some unintended consequences: poor overall user experience, poor information management and poor knowledge management.

It is evident that currently communication tools do not satisfy all communication dimensions: Formal and Informal communications channels, Model/object-based communication, fostering familiarity, supporting immediacy in communication exchange and supporting transparency in collaborative project information management.

Additionally, the analysis has showed that human-human model-based interaction will benefit from further formalisation.

4.5.4.3.1 Levels of representation/analysis of communication networks

The Network Analysis illustrated how project communication can be represented by networks. The networks studied are only two out of many different networks that can be conceptualised.

Alternatively, they can be understood as “layers” (e.g. the action distribution layer) of project-level interaction.

4.5.4.4 Utility of approach and broader implications

It was particularly challenging to compare overall communication efficiency between projects due to project-specificity (variables such as scale of project, size of project team, competency level of participants, companies involved, delivery method, phases examined, software configuration, and purpose of each software).

4.5.4.4.1 Broader implications: Is a Big data analytics-type approach applicable to Cloud BIM?

The use of technology through which usage data is recorded is rising dramatically. The increasing amounts of this data might pave the way to the introduction of approaches equivalent to Big Data analytics within construction practice. This would reveal previously unexplored patterns of interaction and their correlations to project success indicators. Network analysis offers a valuable perspective both for developers and researchers project team interaction patterns as well as for visually reporting project interaction patterns to decision makers in the actual project. The analysis presented in this paper serves as a crude attempt for exploring these patterns. Apart from the presented metric-based and network graph-based analysis, approaches such as content analysis could reveal patterns in human communication (e.g. interpreting comment content and capturing “folksonomies”) and provide a basis for codifying and automating communication (including communication intent) within virtual environments.

4.5.4.5 Semantic technology - expressing the above differently

It is acknowledged that one important type of network yet not analysed is that of user-container-user networks. In addition there are object-object networks formed by the relationships between model objects. The project can be represented as a “knowledge graph”. This provides the link to the utility of semantic technology as it has the power to leverage the semantics within these networks in order improve the efficiency of interacting with project information. In other words, using the project data as a knowledgebase (given that it is adequately structured).

4.6 Perspective 5: Mechanisms for improving OCPs - An approach for identifying and evaluating opportunities offered from Semantic Technology to BIM-enabled OCPs

4.6.1 Introduction

The importance of semantic interoperability has been acknowledged, mostly implicitly, in previous perspectives presented in this chapter as well as in chapter 2: Literature Review.

- In Perspective 1 the need for alternative, context-specific categorisations of IFC objects was identified.
- In Perspective 3 the utility for software design, interoperability and user experience of mapping concepts between Revit files (rvt), IFCs and Asite was illustrated
- Also in Perspective 3 the need for discipline-specific views of information and generally, the utility in collaboration tools capturing the semantics of industry.
- Perspective 4 illustrated the need for improved user experience through better container integration and intuitiveness in model-based communication.

Perspective 5 uses Semantic Technology as an example of a new technological paradigm in order to build a Requirements Engineering approach that is specific both to BIM-enabled OCPs and Semantic Technology.

Problem and context-specific issues (identified in Perspectives 2 and 4)

It is evident that current practice across AEC-FM does not utilise the potential demonstrated within research initiatives. Furthermore, and what is the premise of Perspective 5, the opportunities arising from semantic technology specifically for OCPs can come closer to realisation if a more formal, hence more communicable and more improvable approach for their identification and evaluation is adopted.

As identified in previous Perspectives (particularly 2 and 4), two issues which emerge as a result of natural traits of AECFM (project specificity and project-led nature, inadequate standardisation, discipline fragmentation, life-cycle phase fragmentation) and the emergence of cloud-based solutions are:

1. Cross-project variation in both high-level software configuration (what combination of software to use) and low-level software configuration (which part of each software to use). The vague distinction between the roles of software calls for an approach supporting flexibility (from the perspective of project set-up) and prioritisation (from the perspective of software development).
2. Requirements Engineering for cloud-based solutions tends to be a combination of moving existing functionality to the cloud as well as devising novel, “fit-for-cloud” functionality.

4.6.2 Purpose, approach and method [could move to literature review]

There is evidence of infrastructure for (Beetz et al. 2011) and applications of (Vanlande et al. 2008) semantic technology within some forms of collaboration software. However, framework-setting studies (Singh et al., 2011) and studies focusing on requirements from commercial, browser-based Online

Collaboration Platforms (Liu et al., 2011; and Shafiqet al., 2013) do not address semantic technology. Therefore, in Perspective 5, the research sets out to devise a formal requirements engineering approach which accounts for the, often changing, role of OCPs within the BIM process as well as the natural traits of semantic technology and AECFM. The aim is to provide a mechanism for bridging the gap between promised opportunity and realisation.

Through a demonstrated attempt to identify and evaluate opportunities offered to OCPs by semantic technology, a context-specific requirements engineering process is developed and documented. The focus is not on technical issues (e.g. developing or extending ontologies or schemata) but rather on technology and domain literature mapping. “Solving a problem simply means representing it so as to make the solution transparent” (Simon, 1981). Following this notion, the research in Perspective 5 attempts to solve the technology implementation problem by providing suitable representations of different aspects of the problem. The steps followed are outlined as:

1. Deduce the pre-requisites for an effective semantic functionality and the stakeholder context
2. Understand the nature of opportunities offered by Semantic Technology in AECFM
3. Identify a suitable representation of the role of OCPs in BIM process,
4. Identify a number of illustrative, OCP-specific functionalities
5. Devise a method for evaluating these functionalities.

4.6.3 Step 1: Pre-requisites for an effective semantic solution

An effective semantic solution is defined as a solution provided by a software system which is enabled by a computer interpretable knowledge representation (ontology) and **provides value** to the software user. Based on a review of relevant literature (Berners-Lee et al., 2001; & Allemang and Hendler, 2011), a simplified model of the pre-requisites for an effective semantic solution was developed for the purposes of this research (Figure 33).

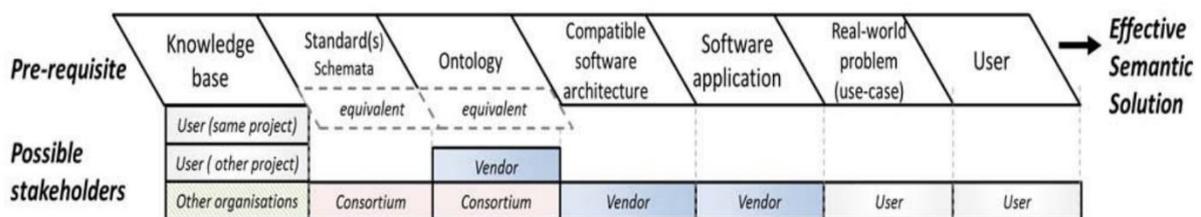


Figure 33 Model for pre-requisites for effective semantic solution

The model demonstrates that typically: (1) an effective semantic solution results from the contribution of a diversity of parties whose effort and benefit is not necessarily aligned and (2) within the “Standards” and “Ontologies” domains; there doesn’t exist exclusivity amongst possible instances for a given solution. This highlights the need for harmonisation in this joint effort if effective semantic solutions are to become more widespread.

4.6.4 Step 2: What is the nature of the benefit offered from Semantic Technology to OCPs?

Acting as the hub for project information which is typically diverse, unstructured and is continuously updated to satisfy varied information exchange needs, OCPs could benefit considerably from semantic technology. The diversity of applications and benefits found within AECFM research is demonstrated by Abanda et al. (2013). A number of studies address issues relating to online collaboration by developing capabilities such as model-document integration (Caldas et al., 2004), conformance requirements organisation (Yurchyshyna et al. 2009), document indexing (Elghamrawy and Boukamp, 2010) and configurable model exchanges (Venugopal et al., 2013). A general framework for semantic web-based information management (Anumba et al., 2008) aims to “enhance collaboration, avoid information loss, overload and misunderstanding”. Through this diversity of applications, a universal pattern is that once the benefit is realised a “new” type of waste, a waste of semantics (meaning), is eliminated and becomes observable through its absence. Therefore, Perspective 5 attempts to utilise this effect in demonstrating the potential of semantic technology for OCPs.

4.6.5 Step 3: The OCP and its role in the BIM Process

4.6.5.1 OCP and their core “BIM Use Purposes”

In order to facilitate a rational approach for deriving semantic technology-enabled functionalities for OCPs, the role of OCPs in the BIM process is expressed in terms of the “BIM Use Purposes” developed by Kreider and Messner (2013) (Figure 34). The guiding criterion for developing these was “which Use Purposes require the sharing of information between collaborating parties”.

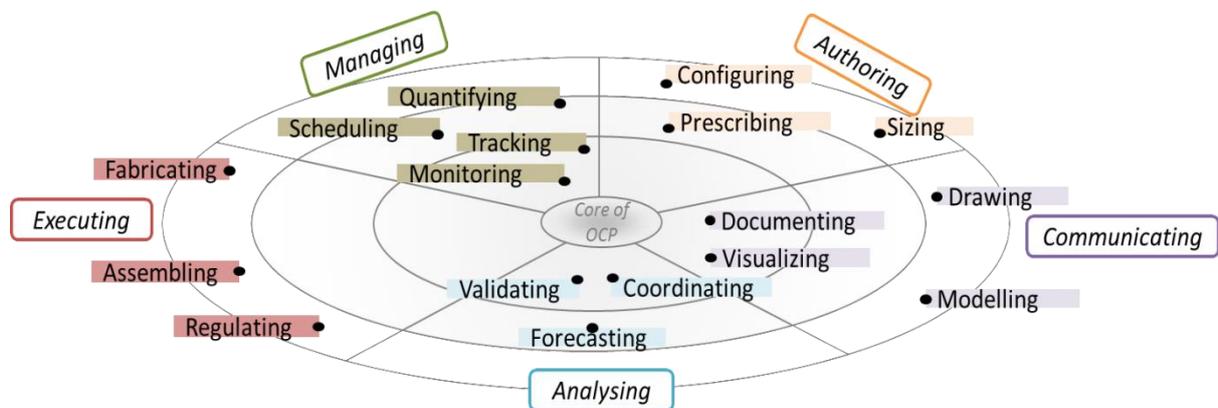


Figure 349 The role of OCPs in the BIM Process in terms of "BIM Use Purposes"

4.6.5.2 Heuristics for enhancing OCPs

Subsequently, a set of heuristics were developed for evaluating and improving the service of OCPs. These arose from previous Perspectives in this study as well as by capturing and formalising the product development and marketing material of the sponsor company (Asite, 2014). The heuristics are:

1. Integration of content, e.g. model- document integration, tagging.
2. Integration of features, e.g. BIM-based procurement,

3. Controlled workflow, e.g. content distribution process automation, controlled revisions of content),
4. Role-based configuration
5. Flexible workflow
6. Intuitive experience/environment
7. Visibility/transparency
8. Easy access to relevant information
9. Knowledge management: intra-project
10. Knowledge management: inter-project
11. Mobility.

4.6.6 **Step 4: Identifying opportunities offered to OCPs by semantic technology**

4.6.6.1 *Identifying opportunities: some illustrative use-cases/functionalities*

The Core OCP BIM Uses Purposes (Tracking, Monitoring, Documenting, Visualising, Coordinating, Visualising) were coupled with the Heuristics for enhancing OCPs to devise seven illustrative applications of semantic-web technology inspired from the capabilities demonstrated in literature (also presented in Appendix D, columns: “Functionalities” and “Supported BIM Uses and Heuristics followed”). These illustrative functionalities are:

1. Semantic search with search recommendations, e.g.:
 - role-based recommendations
 - project phase-based recommendations
2. Recommended or automatic associations of content, e.g. based on:
 - tag meta-data
 - ontology meta-data
 - content
3. Notification of relevant content in other project workspace
4. User/role-based recommendation for recently uploaded documents
5. Recommend individual in project team based on model/document content or meta-data
6. Recommend standard, guideline or regulation based on model/document content or meta-data
7. Recommend listed supplier for object within model.

These functionalities were used for demonstrating the utility of the following steps in the approach.

4.6.6.2 *A fitting representation of opportunity: value as waste elimination*

As identified in Step 2, value to the user can be represented as waste elimination and, in this case, elimination of “waste in meaning “or “cost of inadequate semantic interoperability”. Elucidation and evaluation of this waste can be achieved by comparing current technology and process to counterfactual scenarios where semantic interoperability is present. The “Cost Analysis of Inadequate Interoperability in the U.S. Capital Facilities Industry” (NIST, 2004) provides a useful tool for this approach. Specifically “Table 4-1: Summary of Technical and Economic Metrics” shown in part in Figure was used as a basis for evaluating the seven illustrative functionalities identified in Step 4. The adapted evaluation table is presented in Appendix D.

Table 4-1. Summary of Technical and Economic Impact Metrics

Source of Cost	Impact	Technical Metric	Economic Metric
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Figure 40 The main titles from "Table 4-1: Summary of Technical and Economic Metrics" from the NIST Interoperability cost analysis study (NIST, 2004)

4.6.7 **Step 5: Evaluating opportunities offered to OCPs by semantic technology – semi-structured interviews for gathering expert opinions**

Separate semi-structured interviews with three Asite Implementation Consultants were conducted to inform the evaluation table (Appendix D). The consultant's experience on software configuration and consultancy to users was used to assess the functionalities in terms of three categories:

1. The perceived level of demand from users
2. The potential value (in the consultants' view)
3. The level of disruption to existing processes from the implementation of the seven proposed functionalities.

Interviewees were given a 40 minute presentation covering the basics of semantic technology and simple mock-ups illustrating the seven functionalities (screenshots from the presentation are presented in Appendix E). The latter part included discussion with clarifications, and feedback and recommendations for refinement. At the end, the interviewees were asked to complete a response sheet (Appendix F) where they ranked the seven functionalities in terms of the three categories and provided additional comments.

4.6.8 **Results from semi-structured interviews**

The main results and indications arising from the interviews were:

- The most valued and demanded from the illustrative functionalities, according to the implementation consultants, relate to searching and content associations. These represent enhancements of existing features.
- Cross project/workspace data access was considered disruptive.
- Amongst comments and discussion the biggest barriers were data privacy and the openness/availability of data for the knowledge base. The former highlights a chronic barrier to BIM and knowledge management while the latter highlights the utility of the IFC data model and its subset, COBie in "unlocking" the data in the knowledge base.
- The need for controlled workflows is not accounted for in the proposed recommendation style use-cases.
- The concept of waste, and in this case, waste in semantics, despite at first requiring some clarification was effective for explaining and discussing the capabilities and benefits of a new technological paradigm such as semantic technology.

4.6.9 Discussion

4.6.9.1 The approach and its utility

The approach that was followed in this Perspective is captured in a flow chart form in Figure 31. BIM Use Purposes were selected as a language for scoping the role of OCPs in BIM and combined with OCP-specific heuristics to devise illustrative use-cases. Their value can be represented as semantic waste elimination and quantified by adapting the NIST (2004) framework. Their relative importance can be identified by surveying experts (and users in future work).

The approach allows for the incorporation of any BIM Use, a likely revision given the dynamic nature of the BIM software industry. Additionally, it explicates the waste elimination potential of proposed functionalities in a way in which the impact on different users/collaborators at different phases can be assessed. The approach can be further developed to map waste on a project phase-user group-activity category framework, as in the “Cost Analysis of Inadequate Interoperability” by NIST (2004) (specifically “Figure ES-1, 3D framework”, presented in Figure 41). As a result, this can help characterise the natural contribution of semantic technology to OCPs.

Figure ES-1. 3-D Representation of Estimation Approach of Inadequate Interoperability Costs

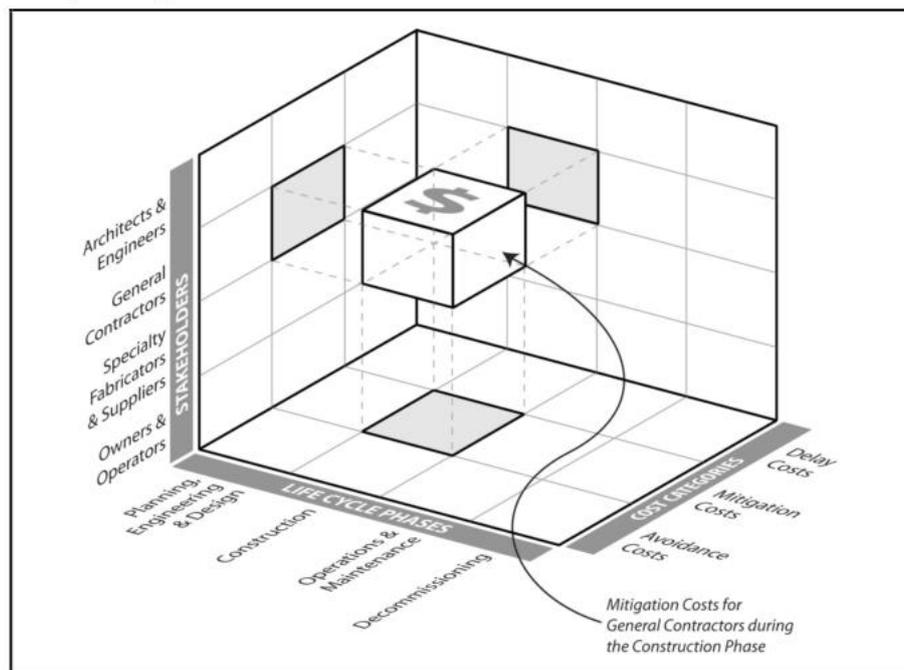


Figure 41 3D framework from the NIST interoperability cost analysis study (NIST, 2004)

The captured process can help communicate the approach, track decisions and revise the approach. Within the OCP vendor, it helps compare current ways of working to a semantic technology-enabled state and characterise the natural contribution of semantic technology. Additionally it can serve as a mechanism for communicating gaps and aligning pre-requisites within the industry. Ultimately, the approach can form the basis for an automated requirements elicitation system, given the availability of repositories and codification of resources.

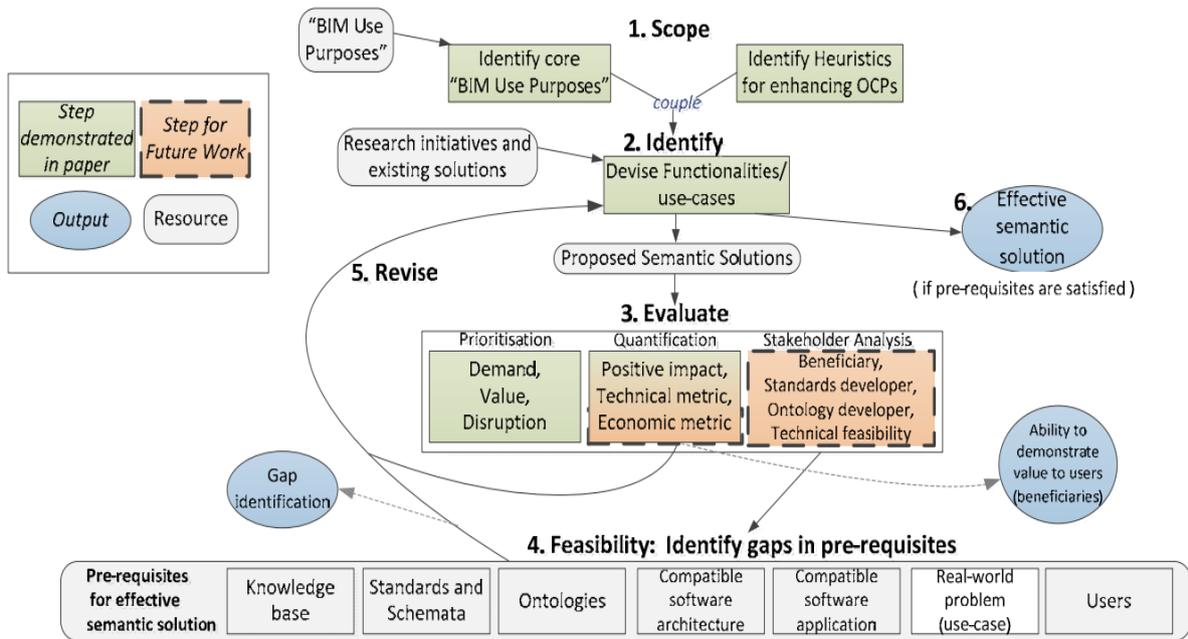


Figure 42 Outline of Requirements Engineering approach followed

4.6.9.2 Main limitations of approach and execution

The main limitations of the approach in Perspective 5 and its execution are as follows:

- The illustrative functionalities were neither exhaustive nor representative of the diversity of potential opportunities.
- OCP users were not engaged at this stage of the research.
- The technical feasibility was not assessed thereby omitting some of the basic pre-requisites identified in Step 1 (Figure).

4.6.10 Contributions of Perspective 5 to the conceptual model

The work in Perspective 5 leads to two main conclusions which contribute to the conceptual model developed in this study:

- Waste provides an appropriate reference concept for an inclusive Requirements Engineering process and especially for the purpose of introducing new technological paradigms.
- The capabilities of a container of project information (e.g. semantic richness or the ability to “understand” the “explain” the meaning of its content to collaboration systems) significantly impact the efficiency of BIM interactions.

4.7 Issues around Asite cBIM adoption during the course of the study

This section of chapter 4 briefly summarises data and opinions collected informally over the course of the study through the Asite product development discourse.

The three main categories of issues around Asite cBIM were identified as:

- Data fidelity
- User-interface and user-experience
- Speed

The 6 areas of cBIM capabilities were identified as:

- Communicating
- Interrogating and searching
- Associating and merging
- Procuring
- Tracking
- COBie capabilities
- Lists and views

4.7.1 *The three main categories of Requirements for BIM enabled-OCPs were identified as:*

- Explicitly expressed user requirements
- Standards/codes-imposed
- Not explicitly expressed requirements which satisfy general user requirements

4.8 Conclusion - The need for WIMBIM and the emergence of a preliminary WIMBIM

In chapter 2, the review of literature and the review of developments in BIM adoption in the UK during the course of the study (2011-2014), it was identified that there was a significant disparity of BIM definitions as well as non-harmonised research and development streams. For example, the government construction strategy understands BIM mainly as structured information about assets while other researchers might focus on intuitive design or parametric design. This meant that the lack of definition on BIM is still the source of fundamental problems. This research focused on BIM-enabled collaboration systems and the need for a conceptual model to support Requirements Engineering discourse within this multi-disciplinary, dynamic domain.

The purpose of the research presented in chapter 4 was to identify the exact requirements from the conceptual model for use in Requirements Engineering for BIM collaboration systems (i.e. what it should be used for) as well as to identify its basic elements. The model is called the “Model for Waste in BIM process Interactions” or “WIMBIM”. These requirements and elements, as they have arisen from the Perspectives-Stages in chapter 4 are outlined below:

1. The language (in the form of shared terms-concepts and metrics) commonly used within practice is not powerful, universal and robust to support the discourse of Requirements Engineering for BIM collaboration tools effectively (Perspective 1). Currently, there is no standard or guideline to support this effort i.e. provide common terms-concepts.
2. There is a gap hence an opportunity for OCPs to support BIM communication in early project stages: preparation and conceptual design. This will can only be achieved if collaboration tools better enable the flow of intent in interactions at the Preparation and conceptual design phases (Perspective 1).
3. Uncertainty in the domain of BIM collaboration tools is a significantly hinders confidence in making decisions for tool development (Perspective 2).

4. OCPs should provide informal communication channels and foster user familiarity. This also relates closely to the requirement for the flow of intent as well as to the association/linking of events that have occurred through face to face communication to content in BIM collaboration tools (Perspective 3: Principle C)
5. There is a need to analyse and provide a formal, universal and robust description of a BIM transmission (or “BIM message” or “BIM interaction”) (Perspective 4).
Discourse within the domain Requirements Engineering for BIM collaboration tools should be concerned primarily with this question: How can you work towards enabling the User to make the most of a BIM process transmission?
6. The different types and levels of representation, including the representations of the various networks in a project have the power to elucidate efficiency (and waste) in different ways (Perspective 4: Analysis 2).
7. Despite the recognition that different project phases require predominantly different types of collaboration environments, project phases should not be a fundamental concept-element for the purposes of the conceptual model developed in this study (Perspective 4). Division according to project phases goes against the principle phase-less workflow, the endurance of information and seamless flow of information.
8. The primary data has also validated the there is significant variability on software configuration across projects (this was an observation in the review of development in BIM adoption during the period of this study as well as in Perspective 4). This stands as a barrier towards the development of a universal “language” to support Requirements Engineering for BIM collaboration tools. The inability to evaluate a collaboration environment constructively using universal terms lead to effects like non-intuitive environments characterised by lack of integration and lack of immediacy in communication.
9. Waste provides an appropriate reference concept for an inclusive Requirements Engineering process and especially for the purpose of introducing new technological paradigms (Perspective 5).
10. The capabilities of a container (e.g. semantic richness or the ability to “understand” the “explain” the meaning of its content to collaboration systems) significantly impact the efficiency of BIM interactions (Perspective 5).

4.8.1 *The emergence of the basic elements and principles of WIMBIM*

Table 11 presents the elements in WIMBIM and how they have arisen through this research. These elements are explained further in Chapter 5 where they are synthesised to produce the WIMBIM. The WIMBIM is then put into an appropriate, communicable form and evaluated through interviews with three BIM experts.

Table 11 Elements and principles of WIMBIM as they have come out of the Perspective-phases in this chapter.

Element or principle of WIMBIM	Perspective-phase	Explanation (in brief)
Flows	Perspective 4: use of software: patterns Analysis 3: Communication content analysis	The elements of a “BIM message” were preliminarily identified as: <ul style="list-style-type: none"> • Building information: to be modified, to be incorporated, to be consulted • Project requirements and specifications • Industry codes and regulations • Instructions • Reference to project event • Intent
Transmission (and purpose of transmission)	Perspective 4: use of software: patterns <ul style="list-style-type: none"> • Analysis 1: Statistical analysis of meta-data • Analysis 2: Network graph analysis of meta-data • Analysis 3: Interpretive analysis of content 	The sheer amount of transmissions during a project and the value in improving the efficiency of transmissions as well as the effectiveness of the collective interaction (e.g. eliminating useless transmissions) was acknowledged. The variation in purpose of transmissions was recognised.
Required Transmission, Executed Transmission	Perspective 4: use of software	Each interaction had a purpose which defined data in what flows was required. This was supported at different degrees by the collaboration tool.
	Perspective 5: improving software	The difference is what is described by waste
Waste	Perspective 5: improving software	Waste used as a suitable representation of the problem for communicating within the Requirements Engineering discourse.
Types of waste	Perspective 3 <ul style="list-style-type: none"> • Analysis 1: Technical interoperability Perspective 4	Waste manifested itself in various forms such as: <ul style="list-style-type: none"> • Too much, too little or wrong BIM data • Lack of immediacy in communication • Lack of integration of communication to BIM data
Data Container (and its capabilities)	Perspective 3 <ul style="list-style-type: none"> • Analysis 1: Technical interoperability Perspective 5	The structure, granularity and semantic richness of a type of BIM data container considerably affect transmission/interaction efficiency
Transmission Medium (and capabilities)	Perspective 2 <ul style="list-style-type: none"> • Analysis: Perspective 5	The transmission medium (i.e. the collaboration tool or set of design and collaboration tools) considerably affect transmission/interaction efficiency

Note: Elements/principles are in the order in which they are presented in WIMBIM in chapter 5

Coordination Tool (and its capabilities)	Chapter 4 (not specific to any Perspectives)	Inferred from the set of other elements
Interaction between data containers, transmission media and coordination tools	Perspective 5: improving software	New paradigms such as semantic technology promise more effective interaction
Capabilities of Data Containers, Transmission Media and Coordination Tools as a descriptor of BIM maturity	Literature Review and Scoping Study	In response to: Identification of the need to understand BIM maturity better and express it in an appropriate way
Waste as a descriptor of BIM maturity	Lit Review and Scoping Study	In response to: Identification of the need to understand BIM maturity better and express it in an appropriate way
Representation type: Network Graph	Perspective 4: Use of software: use patterns <ul style="list-style-type: none"> • Network graph analysis 	Ability of network graphs to represent project communication and interactions differently
Representation lens: Scale	Perspective 4: Use of software: use patterns <ul style="list-style-type: none"> • Discussion 	Inferred from the set of other elements
Representation lens: Complexity	Perspective 4: Use of software: use patterns <ul style="list-style-type: none"> • Discussion 	Inferred from the set of other elements

5 FORMALISING AND EVALUATING THE “WIMBIM”

5.1 Overview

In Chapter 4 the need for WIMBIM was identified and its basic elements were derived. In Chapter 5 this concept for a model is formalised and evaluated. After a more detailed explanation of the aim of WIMBIM is articulated, these elements are synthesised and supplemented in order to meet the aim and desired attributes thus forming the model. Subsequently the WIMBIM model is evaluated through semi-structured interviews with four BIM experts.

5.2 Aim and desired characteristics of WIMBIM

The primary aim of the WIMBIM is the eradication or minimisation of BIM communication waste through a better understanding (to be held by all relevant stakeholders) of this waste and how it comes about (i.e. its relationship with the WIMBIM elements).

It is anticipated that by introducing, new, helpful notions of efficiency in Requirements Engineering for BIM Collaboration Tools, a BIM collaboration tool vendor will more effectively work towards enabling a user to achieve the most from BIM process interaction. Therefore, WIMBIM does not aim to impose a way of working (as a code of practice does for example) in order to eliminate waste but rather aims to make the different kinds of communication waste observable so that BIM collaboration tools can be improved and configured in order to reduce waste.

5.2.1 *Desired attributes*

To achieve this aim, the WIMBIM needs to introduce waste as a more identifiable concept within a robust framework (i.e. a framework that is not constrained to specific technology paradigms and specific tools).

It follows that it is critical that WIMBIM should effectively **provide a common reference** i.e. relate software constructs with research constructs through an ontology (in a similar with which Succar (2009) aims to “bridge the chasm” between BIM academia and BIM practice). The WIMBIM, therefore, should be concerned with concepts that are **universal**. These reference concepts also need to be **robust** i.e. be able to accommodate a shift to new technological paradigms such as Semantic Technology by providing a common reference point which is agnostic of technological paradigms itself (a “common denominator”). This will mean that it should provide a framework to explain the characteristics of future technological paradigms to non-experts on technology. Finally the WIMBIM needs to be **actionable** i.e. lead its user to practical advice on how to develop a tool, a guideline, protocol, standard without confusion.

5.3 Developing and formalising the model

5.3.1 *Method used for developing and formalising the WIMBIM*

The following outlines the main steps taken in the development and formalisation of WIMBIM. Steps 4 and 5 of this process were highly iterative.

1. Definition of basic elements and requirements from WIMBIM (chapter 4)
2. Clarification of purpose and desired characteristics of WIMBIM.

3. Review of relevant literature in search of concepts relevant to basic elements of WIMBIM.
4. Development of WIMBIM in text format (iterative process):
 - Fundamental Assumptions
 - WIMBIM elements and their relationships
5. Development of WIMBIM in visual format (iterative process).

5.3.2 ***Relevant literature: Foundations for and context of the model (step 3)***

The WIMBIM relates to a number of research studies and existing or developing standards by drawing from them and/or complementing them and/or inter-relating them. The most significant examples are:

- Cerovsek (2011): A review and outlook for a “Building Information Model” (BIM): A multi-standpoint framework for technological development.
- Succar (2009): Building information modelling framework: A research and delivery foundation for industry stakeholders.
- Abdlemohsen(2013) – Genres of Communication Interfaces in BIM-enabled architectural practice.
- BS ISO(2012) – IDM-2: Information Delivery Manual, Part 2: Interaction Framework.

Once the basic WIMBIM elements were defined a specific review of these resources was carried out which aimed to understand how these resources understood these elements. This review is summarised in Appendix G.

The relevance of WIMBIM to other work is presented in Appendix H. This helps place WIMBIM in context and aids understanding of WIMBIM.

5.3.3 ***Fundamental assumptions and underlying principles (step 4)***

The fundamental assumptions and principles underlying WIMBIM were divided into the main categories as follows:

5.3.3.1 *Flow, transmissions and interactions*

- The principle of **flow** is central to WIMBIM. The flow of various parameters (money, ideas, requirements, material, information, knowledge) can be used to describe the AEC-FM process. Flow manifests itself from the project level down to the individual transmission level.
 - Bertelsen et al. 2006 and 2007 build the ideas of “Critical Flow” “and Construction Physics” on the principle that the Construction process involves 7 FLOWS: Information, equipment, material, crew, space, external conditions, connecting previous works.
 - Ballard and Howell (1998) express the “3 type model”: Resources, Prerequisites, and Directives.

In both models, all flows are strongly interdependent but can be studied separately depending on the purpose of the examination.

- The BIM process is a sub-process of the AEC-FM process which runs in parallel and interacts with the other sub-processes. Hence the BIM process involves only a subset of the AEC-FM process flows.

- The AEC-FM process can be expressed as a series of interactions. These occur through different media, involve different roles, have different purposes, use or amend different containers, can be logged (hence offer the ability to trace) or not logged etc.
- The modelling, simulation and decision support tools involved in BIM are not perfect, i.e. processes cannot be fully automated, and need to work in conjunction with humans. This happens through User-Data Container-User interactions e.g. a clash can be automatically detected but in order for it to be resolved the relevant issues need to be communicated. The WIMBIM is involved with how effective that type of communication can be.
- Part 2 of the Information Delivery Manual, the Interaction Framework (ISO, 2012) provides *the “basic principles of business communication”*: “Once a client or customer has asked to deliver a product or provide a service, there will be a chain of activities in operation, whose combined effect is to provide the product or service. Such a chain of activities is called a business process...” “...the communication that relates to the delivery of an outcome (performative communication). The initiation and execution of a request is through communicative actions. In a communicative action, two parties are always involved: the person who performed the action and the person to whom the action is directed. The handling of a request appears to occur in a particular pattern called the transaction.” The WIMBIM builds on the concept of performative communication.

5.3.3.2 Basics of Communication Waste

It is assumed that:

- An idea or instruction is never fully communicated.
- Data and information are usually not fully communicated.
- Knowledge is rarely adequately communicated.
- Communication waste in one form (or type) is translated into other forms, e.g. lack of the required BIM data causes time delays in finding it and/or sub-optimal design. This sub-optimal design might in turn cause waste in material and so on. Similarly, with the incorrect communication of the required intent or instruction. The immediate focus of a BIM collaboration tool provider should be to eliminate communication waste.
- The premise in WIMBIM is: If communication waste can be identified then it could be tracked and reduced (and possibly measured).

5.3.3.2.1 Why talk about Waste?

It is anticipated that a focus on Communication Waste will help achieve a “*cognitive shift*” within the domain of Requirements Engineering for BIM collaborations tools.

- Waste vs. Efficiency: Efficiency assumes that there is a theoretical 100% efficiency in a defined dimension and focuses attention on reaching it. This study, with WIMBIM, does not aim to quantify waste but to understand it better and accommodate for the continuously developing technological states/ecosystems (which offer increasing efficiency potentials).
- Waste, if described appropriately, can be independent of software family, phase, discipline etc.
- The concept of waste can be used to *supplement* or *re-express* the existing BIM framework (Maturity Model, BIM deliverables, information exchange and coordination concepts) being developed by government BIM task group-led activities, add a layer to the BIM Maturity Model and use communication waste as a “common denominator”.

5.3.3.3 *Collaboration, Communication and Coordination*

- Collaboration is dependent of Communication and Coordination. Communication and Coordination are strongly interdependent. Communication cannot always be completely “free” or “open” in a BIM process: project team members shouldn’t simply say what they want. Good communication depends on:
 - Roles and responsibilities
 - Exposure to information
 - Trust, openness, respect
 - Contracts etc.

These issues are accounted for through **Coordination Tools** such as: Model Production and Delivery Tables, Access Rights Matrix, Governance Models and Information Delivery Manuals etc.

5.3.3.4 *Coverage of the concepts in WIMBIM from Standards, Guidelines and Research work*

It is assumed that every Standard, Guideline and/or piece of research work

- aims (either explicitly or implicitly) to eliminate primarily a particular Type or Types of communication Waste.
- is based on an assumed model of Communication Waste.
- is concerned with or assumes only a number of the elements of this model.

5.4 The WIMBIM

WIMBIM is a set of interrelated concepts which can be used to better describe communication waste within BIM process interactions. The model has the single BIM transmission as the focal unit of analysis and is then built up in a logical way.

5.4.1 **BIM Flows**

“Information” is one of the seven flows in construction that Koskela et.al (2000) identify (Information, Material, Crew, Equipment, External Conditions, Space, and Connecting Previous Works). Ballard et. al (2002) defines a 3 Type Model which consists of Directives, Pre-requisites (including design information) and Resources.

The flows of Information/Pre-requisites and Directives are broken down to form what WIMBIM calls “BIM Flows”. These are:

- BIM data, to be:
 - modified
 - incorporated
 - consulted
- Project specific data.
- Non project-specific data. E.g. building regulations
- Context of issue communicated

- Instruction or Response
- Intent

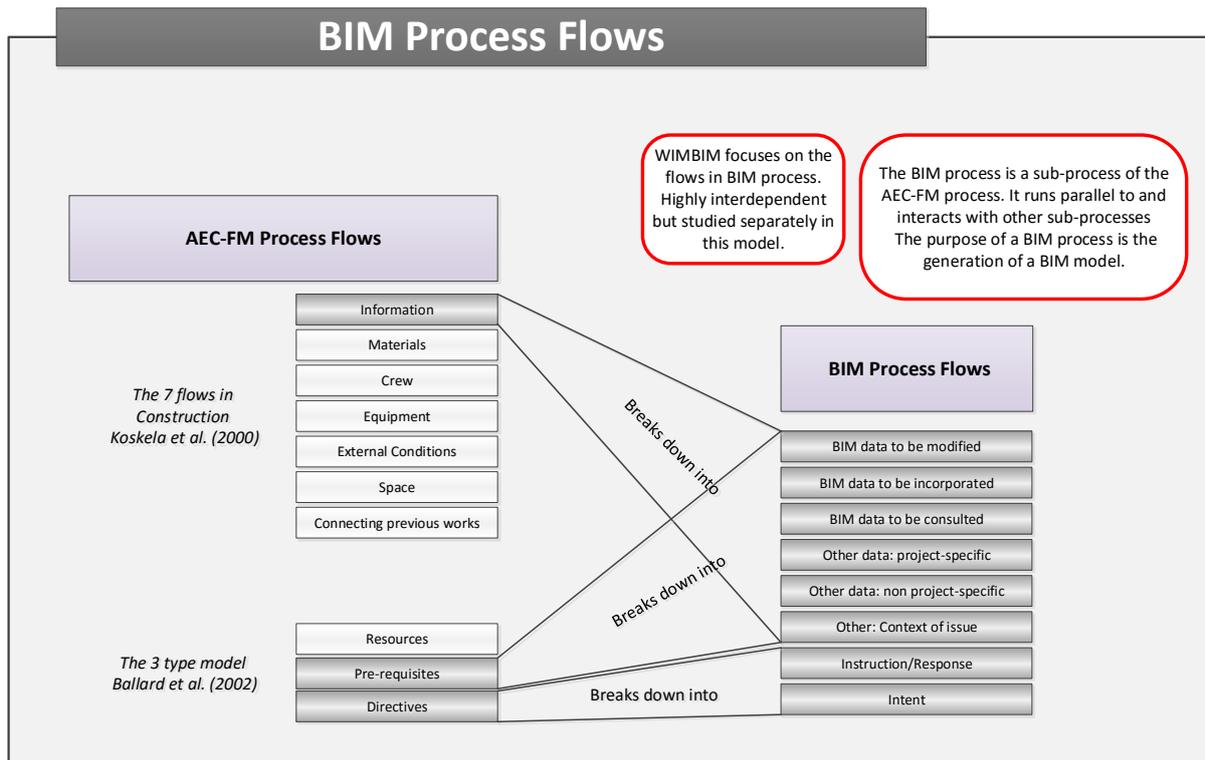


Figure 353 AEC-FM Process Flows and BIM Process Flows

5.4.2 BIM Transmissions

A BIM Transmission is the transmission of data relating to one or more BIM flows from a User to another User or from a User to a Data Container. The collective effect of BIM Transmissions is called BIM Interactions.

5.4.2.1 Main categories of BIM Transmissions

As illustrated in Figure 37, transmissions can be grouped into:

- User-Data Container-User transmissions.
- User-Data Container transmissions.

Note: User-User transmissions are a false concept since a BIM process is defined as the series of interactions whose collective purpose is to generate a BIM model.

5.4.2.2 BIM transmission purpose

Every BIM transmission has a purpose. The purpose defines the required flows and the required subsets of data within these flows.

The transmission purpose always contributes to the ultimate purpose of the BIM process; to generate a BIM model. These purposes relate closely to:

- The “BIM Use Purposes” (Kreider and Messner, 2013)

- Collaboration information flow concepts such as “For Information”, “For Acknowledgement”, “For Comment” etc. which are used by collaboration tools such as Asite (2014).
- “Collect, Create, Correct, Connect” (Coates et al.,2010)
- Modelling, Derivation, Composition (Rezgui, 2013)

5.4.2.3 Required and Executed Transmission

The purpose of a Transmission defines the Required Transmission. In practice, this is typically never the same as the Executed Transmission.

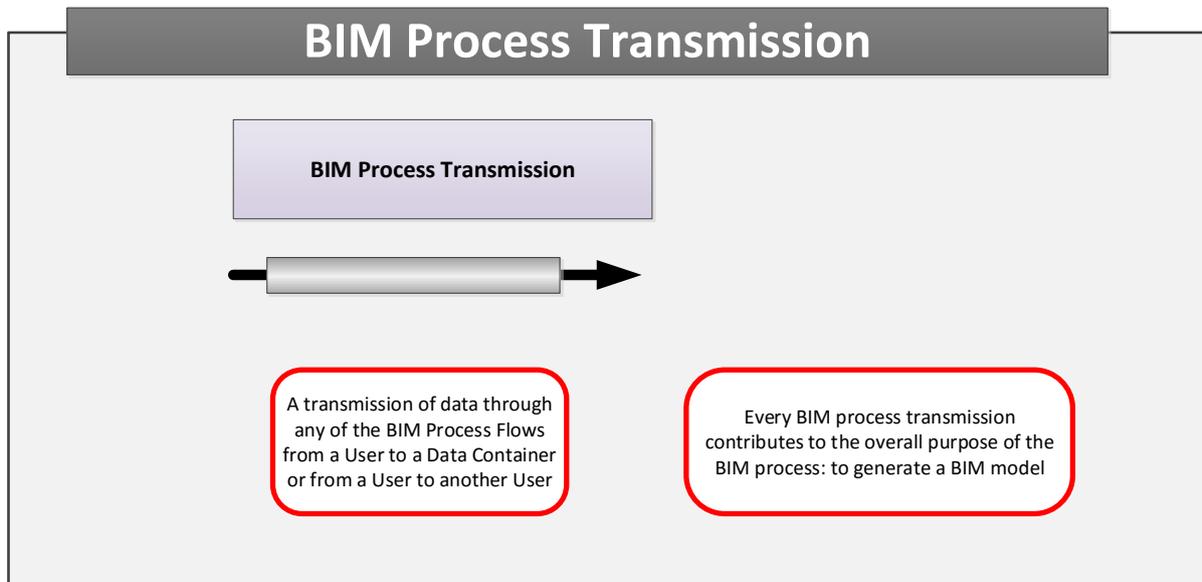


Figure 36 The BIM Process Transmission: The focal unit of analysis of WIMBIM

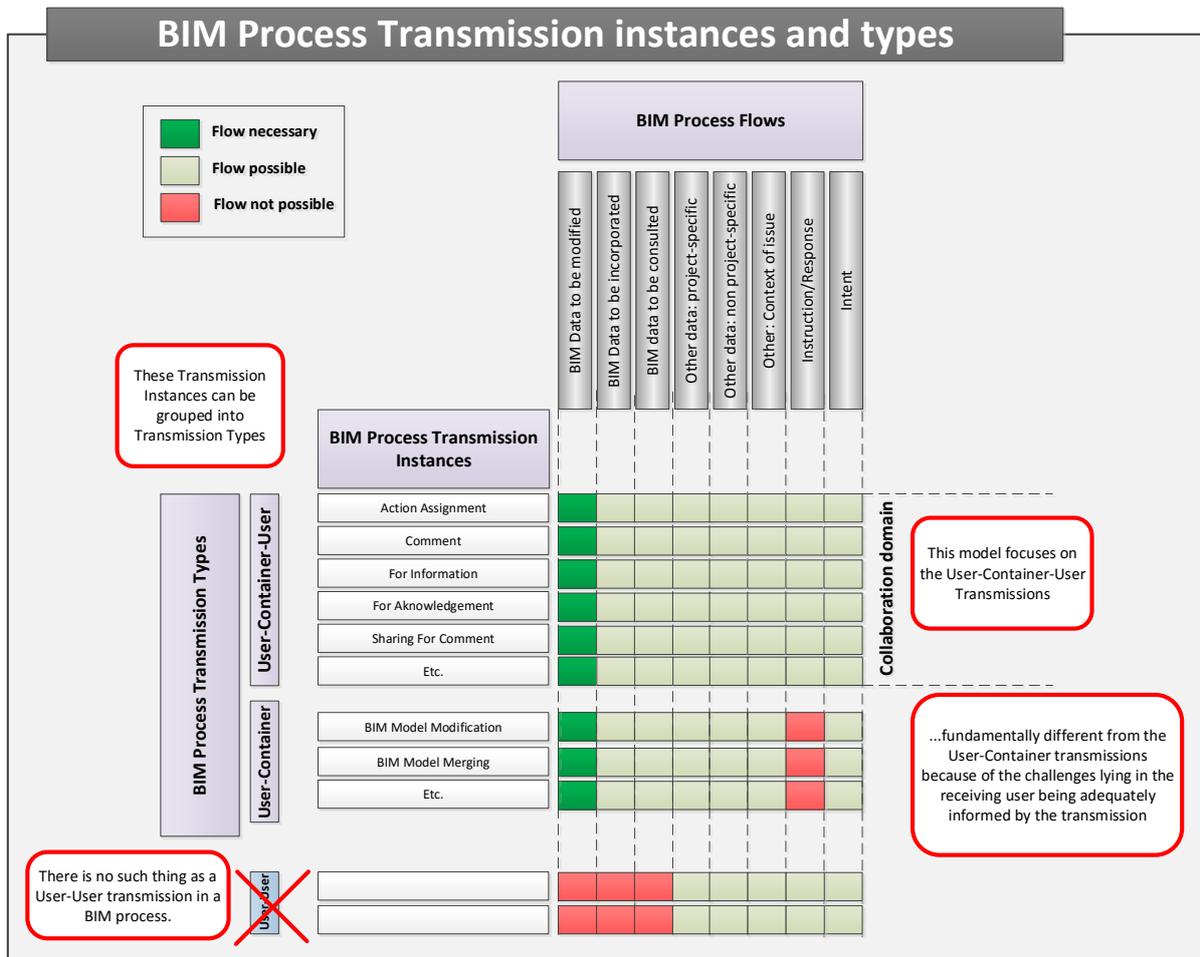


Figure 37 BIM Process Transmissions: Main categories and relation to BIM Process Flows.

5.4.3 BIM Transmission Wastes

BIM Transmission Waste is any discrepancy between the Required Transmission and the Executed Transmission (

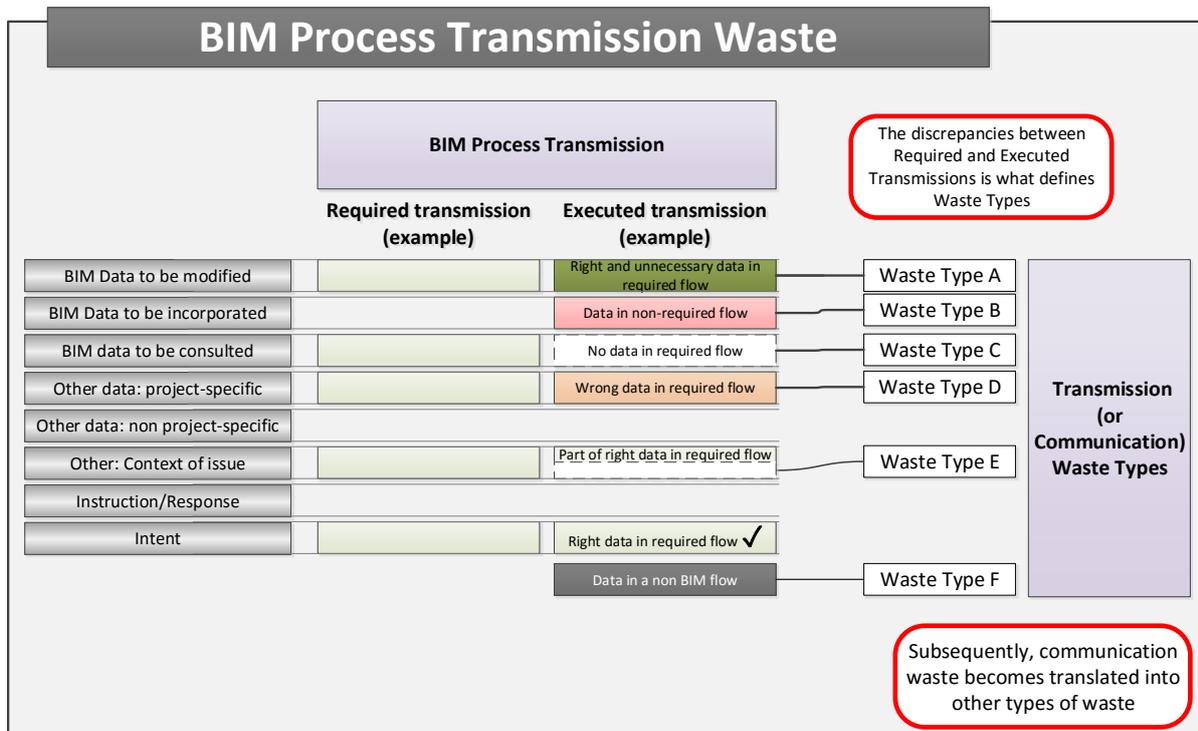


Figure and Figure 5040).

There are 6 different types of discrepancies (an example is provided in Figure 38):

- Right and unnecessary data in the required flow
- Data in non-required flow
- No data in required flow
- Wrong data in required flow
- Part of right data in required flow
- Data in a non-BIM flow

Note: A required transmission can never be fully understood or executed. I.e. there will always be a level of Communication Waste in practice.

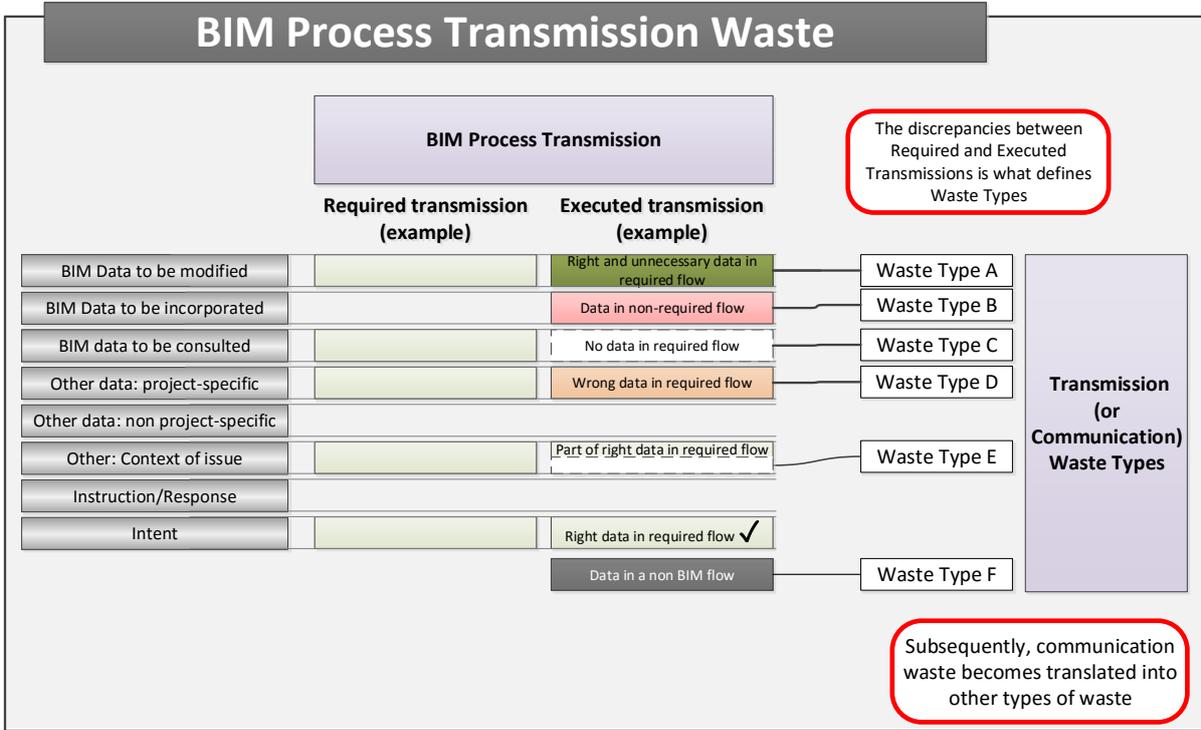


Figure 46 BIM Process Transmission Waste: The 6 different types (A-E)

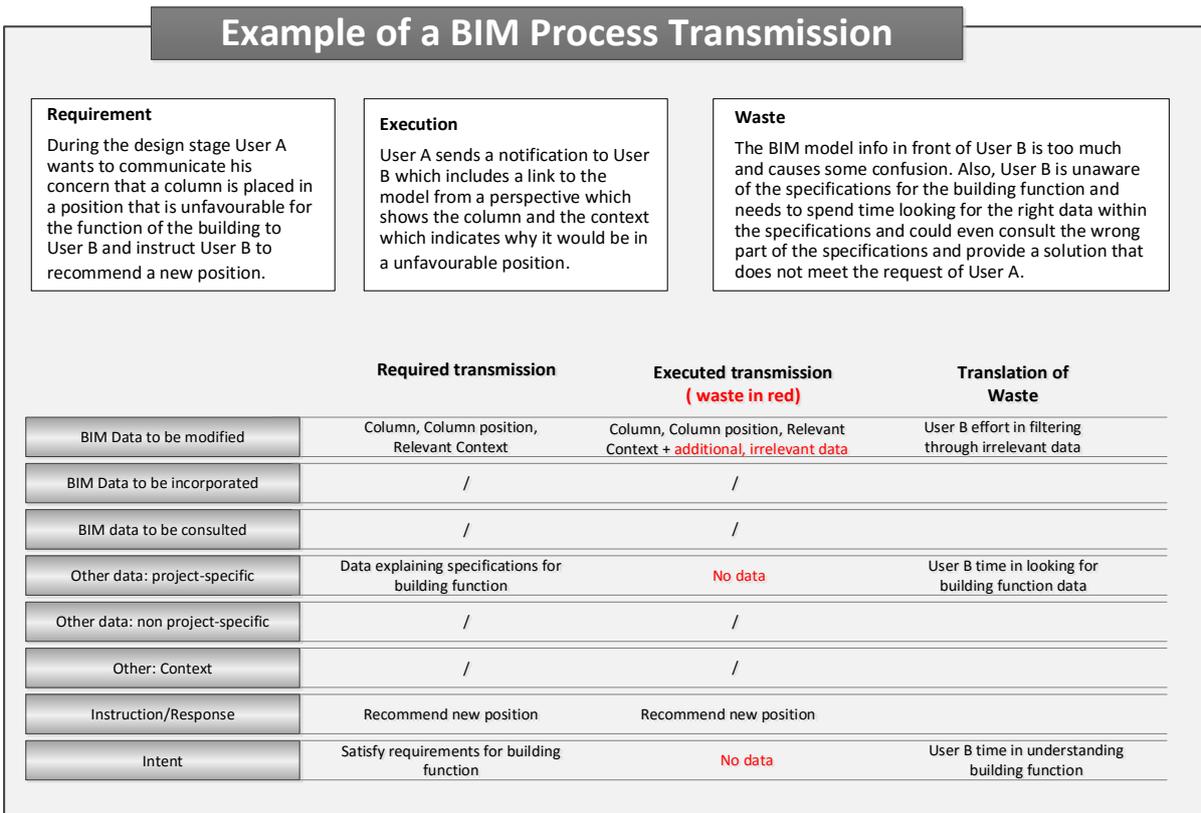


Figure 38 An example of a BIM process transmission with Transmission Waste

5.4.4 ***BIM Data Containers***

A container (term also used in BS1192:2007) of data that corresponds to BIM Flows. Each Efficiency State (explained later on) offers improved BIM Data Containers. Examples are PDF document, IFC model, IFC object, Revit model, COBie spreadsheet etc.

Container types have attributes such as:

- Structure
- Semantics
- Granularity
- Interoperability
- Openness/accessibility

These attributes give rise to: “spectra of fitness” of Containers: spectra which denote the suitability of instances of Containers to specific uses of BIM Collaboration Tools.

5.4.5 ***BIM Transmission media***

The media through which the transmissions/interactions take place. Each efficiency state offers improved BIM Transmission Media. These relate closely to:

- BIM software: design, check, coordination, collaboration etc.
- E-mail, telephone.

A BIM transmission can be either a:

- Single medium transmission, or
- Multiple medium transmission

This is examined in detail in the Abdelmohsen (2013) study on Genres of Communication Interface.

5.4.6 ***BIM Coordination Tools***

The goal of a Coordination Tool is to capture the purpose of any given transmission and allow the transmission of the right data in the right flows. Each Efficiency State offers improved Coordination Tools.

Examples of Coordination Tools in practice are:

- Model Production and Delivery Table (MPDT)
- Information Delivery Manuals and Model View Definitions
- Semantic Exchange Modules (Eastman and Venugopal, 2013)

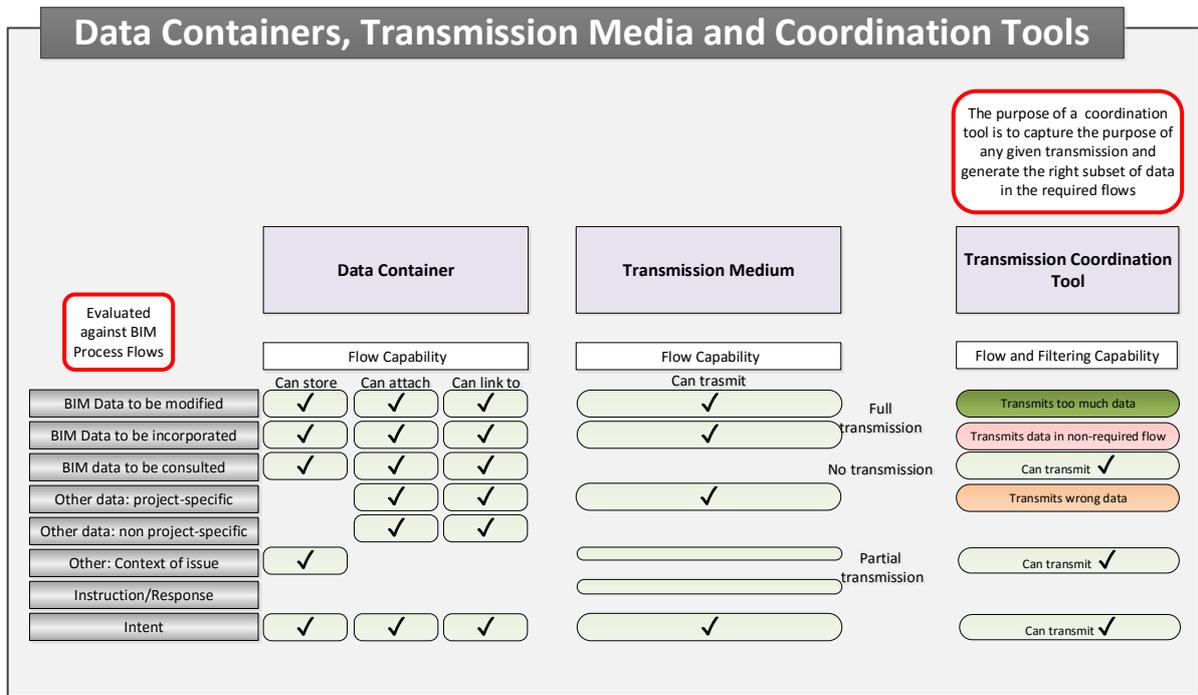


Figure 48 BIM Data Containers, Transmission Media and Coordination Tools

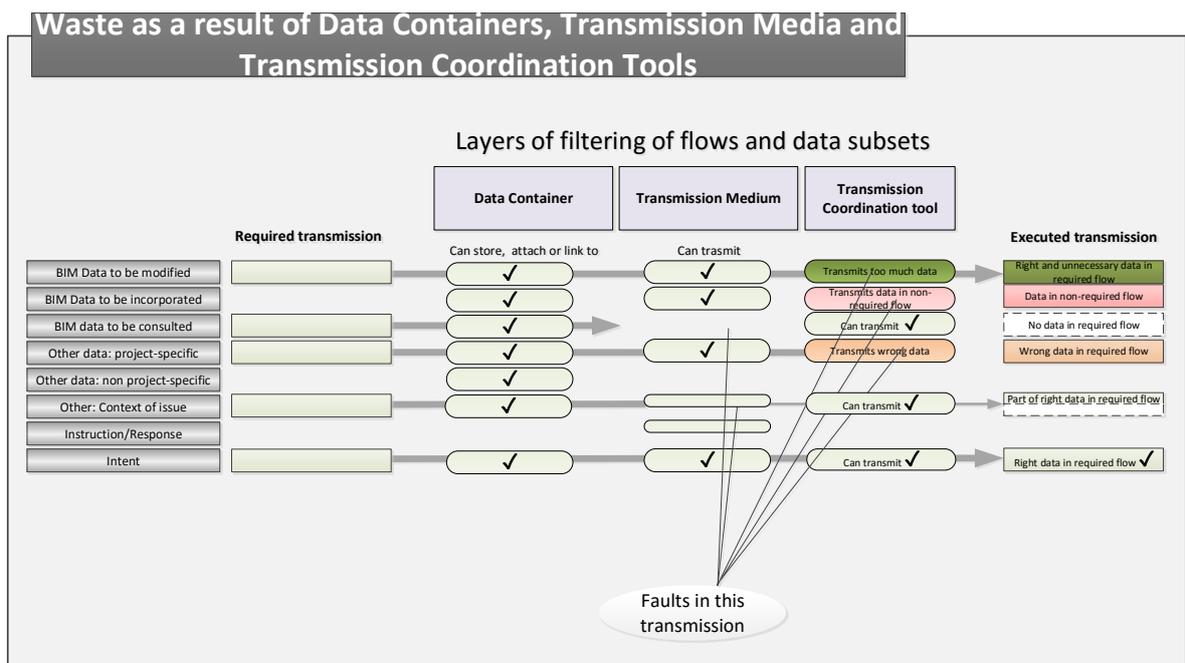


Figure 39 BIM Transmission Waste as a result of BIM Data Containers, Transmission Media and Coordination Tools

5.4.7 Note on Dimensions and Waste

Figure 5040 illustrates how Waste can occur in two basic ways.

- Flow type dimension: Required data missing or partially missing from a flow
- Data subset dimension: All the types of Waste can occur as a Data subset dimension

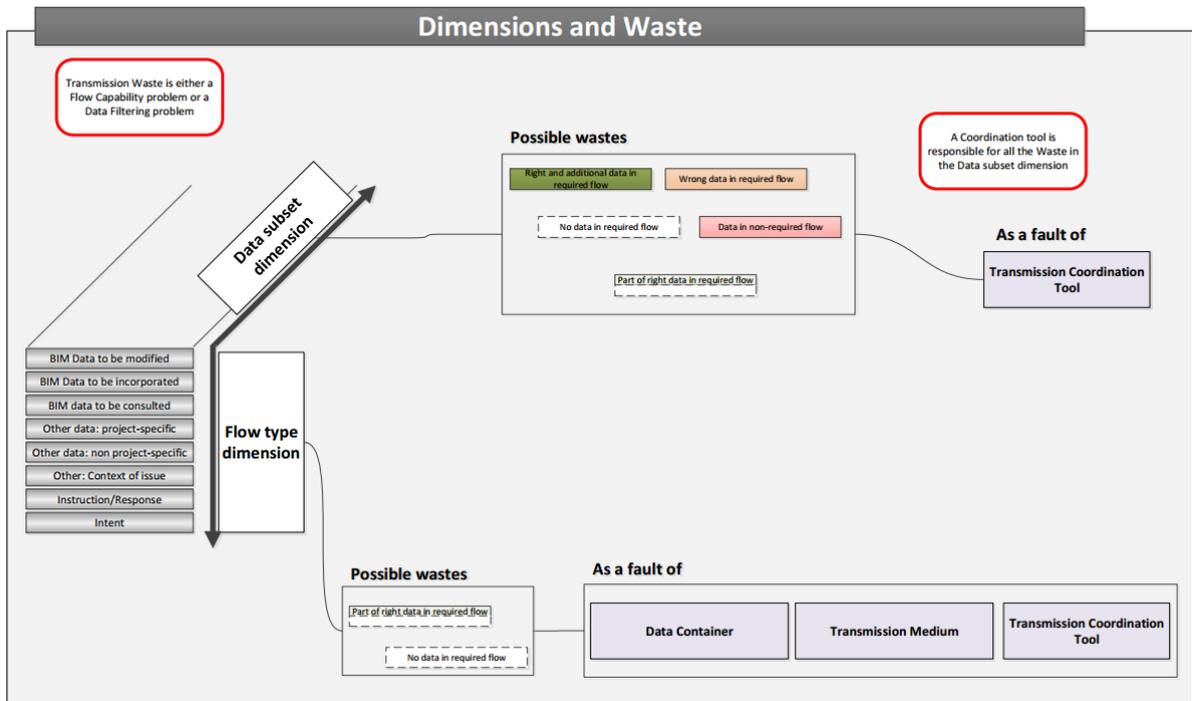


Figure 5040 Dimensions and Waste: The two dimensions of Waste are the Flow Type Dimension and the Data Subset Dimension

5.4.8 Note on Interaction between Container, Medium and Coordination Tool

Interaction between Containers, Medium Coordination Tool is important for eliminating Waste. A good container type enables the coordination tool to capture the semantics of the data in order to filter the data for the transmission accordingly.

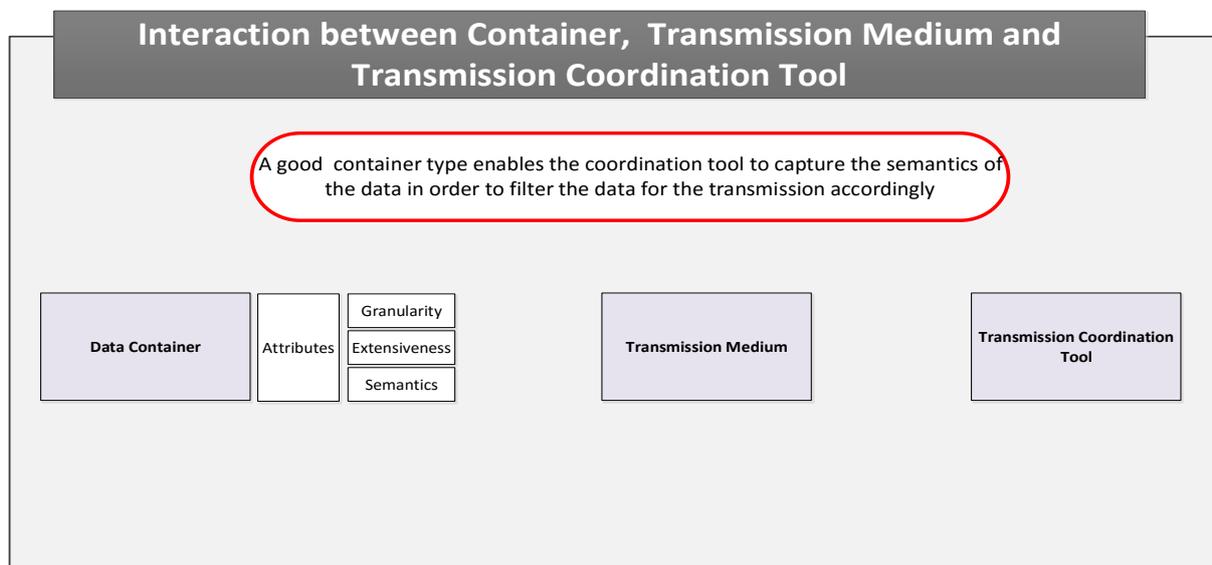


Figure 5141 Interaction between BIM Data Container, Transmission Medium and Transmission Coordination Tool

5.4.9 BIM Efficiency States

BIM Efficiency States are defined by the capabilities and attributes of available BIM data containers, BIM Transmission Media and BIM Coordination Tools.

Each state has a higher maximum efficiency. Each state offers the opportunity to eliminate significantly more of a new type (or types) of waste. States also relate closely to the “counterfactual

scenario” concept defined in NIST (2004) were by a state of improved data interoperability was conceptualised and the relative costs of the then current practices were estimated. As noted above and as Figure 40 illustrates, a required transmission can never be fully understood or executed. i.e. there will always be communication waste in practice. The critical level of development of a Container type: The level of development which allows a project to transition to the next state, e.g IFC being good enough for implementation.

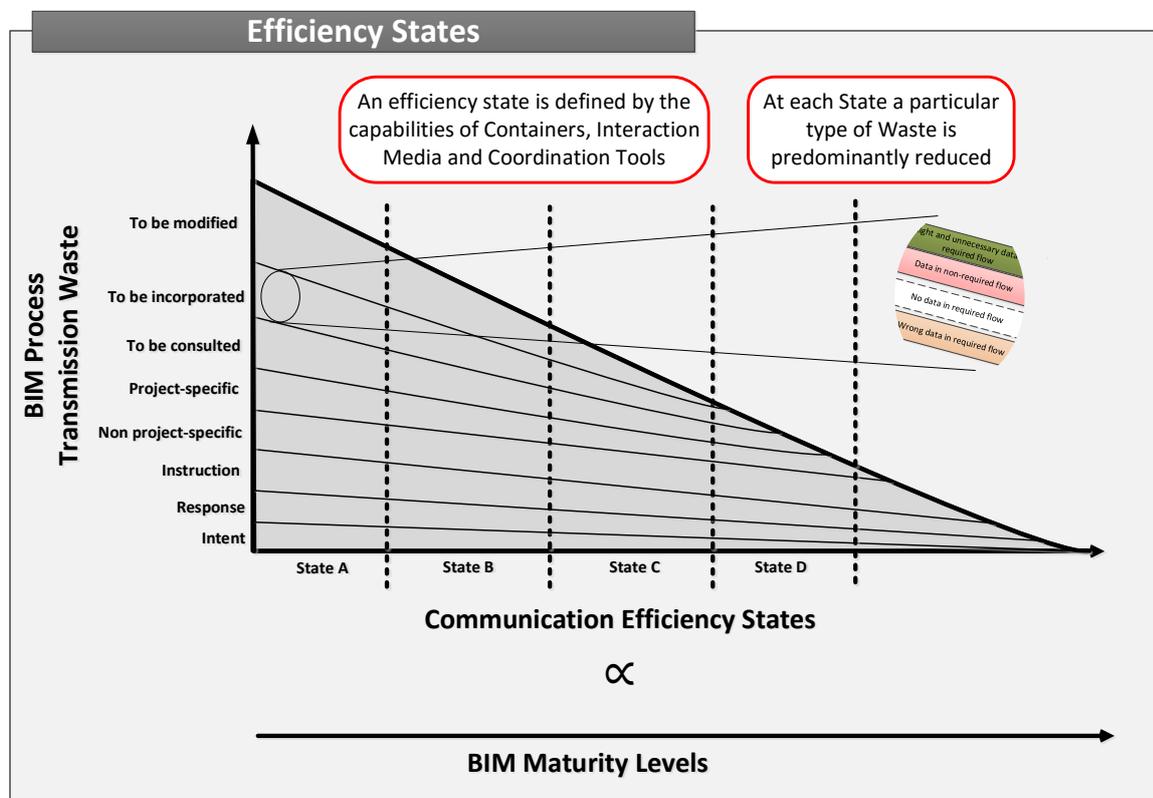


Figure 5242 BIM Efficiency States

5.4.10 BIM Transmission/Interaction Representations

BIM Transmission Representations are methods through which transmissions and interactions can be represented. Examples include:

- Process Maps (e.g. Critical Path Method)
- River Model (Bertelsen et al., 2007)
- True Process Model (Bertelsen et al., 2007), or
- User-Container-User Interaction Network Graphs , or
- User-User Network Graphs.

Each representation types elucidates different Types of Waste. Properties of these representations can be used to describe differences between States.

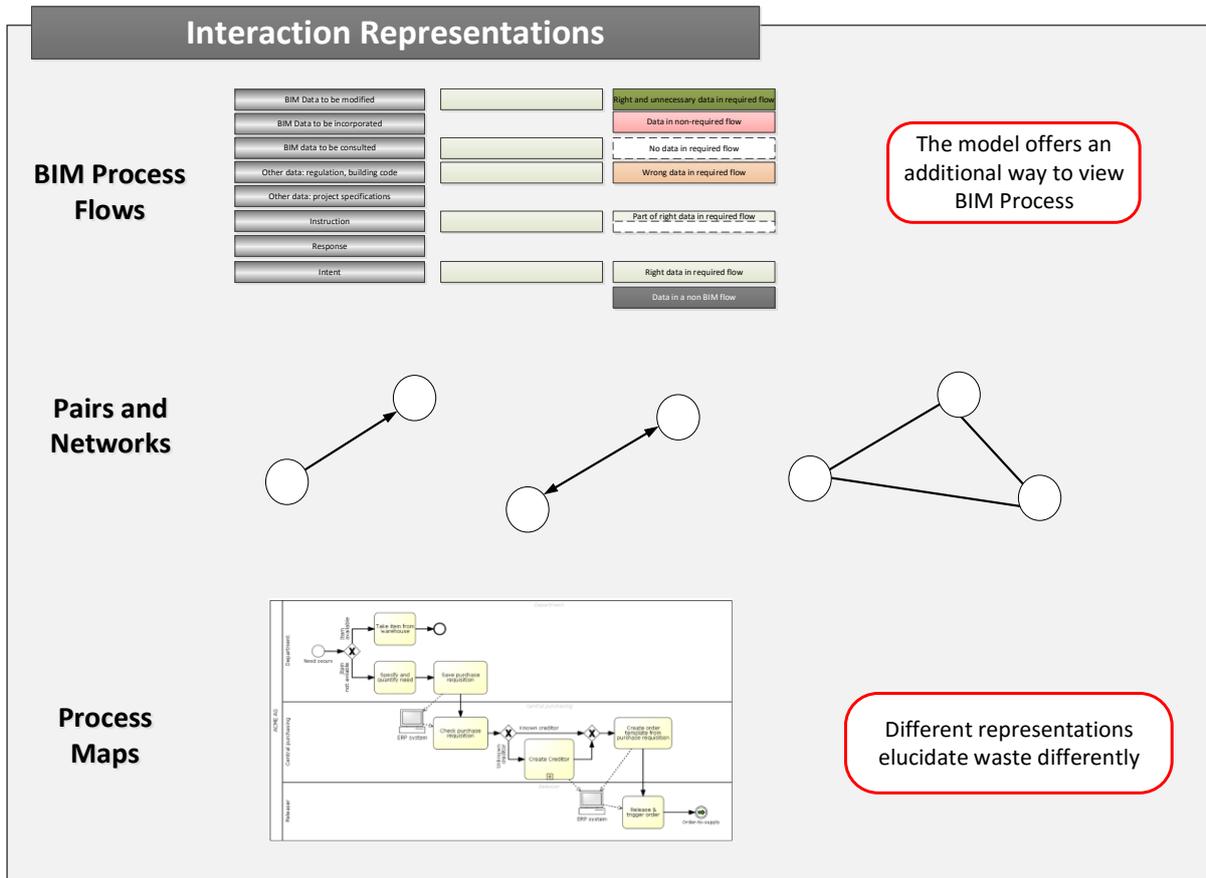


Figure 53. BIM Transmission/Interaction Representations

5.4.11 BIM Transmission/Interaction Representation Examination lenses: Scale and Complexity

5.4.11.1 Scale

Progressive levels of magnification at which BIM transmissions/interactions can be examined. At different levels, Waste becomes apparent differently.

5.4.11.2 Complexity

Whether the interaction and conversion between different components of flow is accounted for.

By examining increasing Scale and Complexity the observer's attention is shifted away from Transmission Efficiency and towards Project Effectiveness (Figure 42).

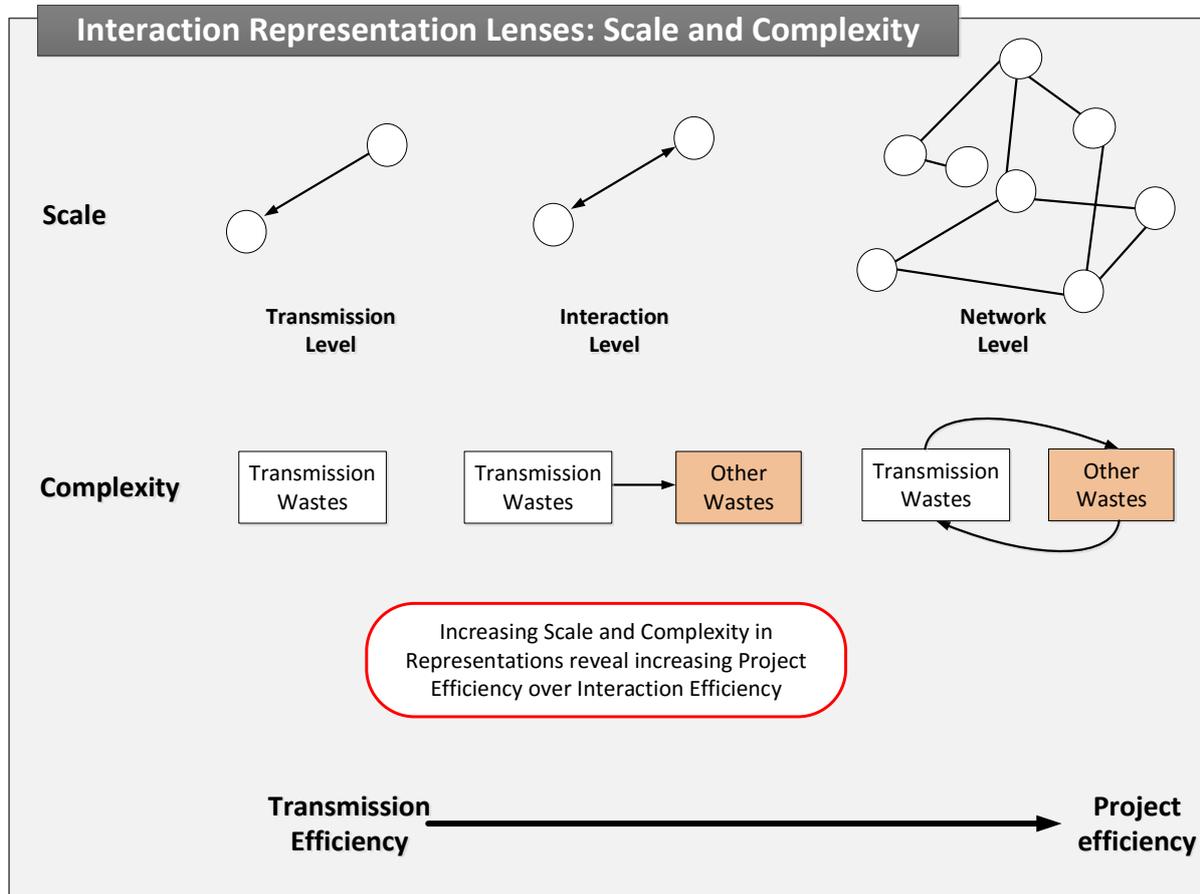


Figure 434. BIM Transmission Interaction Representation Lenses: Scale and Complexity

5.5 Implications of and recommendations arising from WIMBIM

The WIMBIM gives rise to a number of proposals. These range from logical implications to recommendations largely based on the reality of change management in the industry. These proposals are useful both as talking points in the model evaluation interviews and for considerations in future research. The main implications and recommendations are outlined below:

5.5.1 Industry wide proposals

- Complement the BIM maturity model based on communication Waste Types, i.e. identify what the dominant Waste Types are in each BIM maturity level.
- Complement BIM Standards based on Communication Theory and BIM communication waste.

5.5.2 Project-level proposals

- Assess BIM collaboration tools and collective BIM software configuration against BIM flow capabilities.
- Transmission best practice guide: Since a state of zero communication waste cannot be reached:
 - Identify critical transmissions
 - Identify critical *chains* of transmissions.
 - Identify the critical BIM flows for the purposes of critical transmissions and critical transmission chains.
 - Prioritise the adequate facilitation and/or “working around” the waste for Critical Transmission Chains and Critical Flows in Critical Transmissions.

- Produce “Transmission best practice guide”: a checklist for project collaboration protocols and software configuration.

5.6 Evaluation of the WIMBIM

The WIMBIM emerged out of research that - despite being conducted in an industry setting which was highly relevant to the domain and examining multiple perspectives of the domain - was, naturally, limited in relation to the anticipated scope of the model. The WIMBIM, in terms of its future applicability, therefore would benefit from evaluation by independent BIM experts. This section presents the principles and methodology behind the evaluation process, the evaluation process itself and the evaluation results.

The aim of the WIMBIM prescribed a set of desired characteristics (to provide a common reference, universality, robustness, actionability) governed the evaluation approach. The evaluation process was based around the following evaluation categories:

- Need for such a model
- Validity of model
- Utility of model
- Usability of model

5.6.1 *Semi-structured evaluation interviews*

A series of four semi-structured interviews with BIM experts were conducted in order to evaluate WIMBIM. The interviewees were selected because of their experience with BIM implementation, BIM standards implementation, and involvement in research and development efforts. The four interviewees were:

- Interviewee 1: Final year PhD researcher studying BIM standardisation with previous professional experience in quantity surveying.
- Interviewee 2: Author of BIM maturity model and BS1192 code of practice.
- Interviewee 3: Co-author of BS1192 and other consensus-based guidance and member of BSRIA
- Interviewee 4: Director of Technology and Data Solutions of a large engineering consultancy

The interviews lasted one hour and were structured as follows:

- Introduction to research (5 minutes)
- Basis for Model (5 minutes)
- Presentation of Model (20 minutes)
- Recommendations based on Model (5 minutes)
- Questions and answers (10 minutes)
- Questionnaire (15 minutes)

The evaluation process would include both closed-ended and open-ended questions and was designed to allow for the interviewees to ask for any clarifications during the interviews. A set of Power Point slides was used to structure the interviews (Appendix I). At the end of each interview, a

questionnaire (Appendix J), consisting of 28 closed questions (Likert scale) and 8 open-ended questions was handed out and the interviewees were given 15 minutes to complete it. The interviewer provided any necessary clarifications and referred back to the explanation of the model if needed.

5.6.2 Evaluation results

5.6.2.1 Discussions during interviews

The main themes emerging in the discussions that occurred during the evaluation interviews are presented in Table 12. They are categorised according to the relevant desired characteristic (or “performance indicator”) of the model and the elements in the model they refer to.

Table 12. The main themes emerging in the discussions in the evaluation interviews and their relevance to model characteristics/indicators and model elements.

Issue/comment	Desired characteristic / performance indicator					Model element
	Need	Originality	Validity	Utility	Usability	
Interviewee 2: His own experience shows that finding information is one of biggest challenges in the BIM process.	✓					
Interviewee 2: Agreed that there is currently no one collaboration solution that can "do everything".	✓					
Interviewee 2: "Level 3 needs a new set of concepts" (in terms of the supporting guidance and standards).	✓					
Interviewee 4: Was in agreement that the variability in software configuration poses a significant barrier but also noted that there is standardisation in this matter "coming in".	✓					
Interviewee 4: Agreed with the need to for the model to focus on user-container-user interactions.	✓					User-Container-User Transmissions

Interviewee 2: Explained that the “Communication Waste” concept was explored in the 90s and the developments of this idea gradually led to BS 1992.	✓	✓				Communicati on waste
Interviewee 4: Noted that a lot of the thinking in this model relate to the concepts in the Common Data Environment (BS1992).	✓	✓				
In all interviews: The “Coordination Tool” concept was much more difficult to explain than “Data Containers” and “Transmission Media” mainly because of lack of examples that readily reflect its definition.	✓	✓				Coordination tools
Interviewee 1: Inquired into how exactly this model arose.			✓			
Interviewee 1: Expressed the view that this model does not seem to recognise the variation in activities within a construction project and that it needs to understand the specifics of construction.			✓			
Interviewee 3: Observed the relation of the model to communication theory from the first few slides, before it was explicitly introduced in the presentation.			✓			
Interviewee 3: (on whether new BIM maturity levels predominantly eliminate different types of waste) expressed the view that BIM maturity is analogous to sophistication of tools and increased automation and that by definition this relates to changes in the types of wastes addressed.			✓			Efficiency states Waste types
Interviewee 4: (on whether new BIM maturity levels predominantly eliminate different types of waste) Expressed particular interest in this part/implication of the model and noted that this “theory” might prove to be true.			✓	✓		Efficiency states Waste types
Interviewee 4: (on Representations: Scale and Complexity) Agreed with including these concepts in the model as he is “currently living and breathing this” (meaning the implications of this effect).			✓	✓		Representati ons: Scale and Complexity

Interviewee 3: Noted that there is no coverage on non-electronic communication in this model. (completeness)			✓	✓	
Interviewee 3: (on BIM maturity levels and different waste types) Suggested that the research should propose partial answers as to whether BIM maturity levels address different types of waste. (completeness)			✓		BIM maturity levels and different waste types
Interviewee 2: (on waste as a result of containers, transmission media and coordination tools) Expressed the view that this model could help as a basis for evaluating tools like COBie.				✓	Waste as a result of Containers, Transmission Media and Coordination Tools
Interviewee 2: (on Efficiency States and BIM maturity levels) Explained that they (the BIM standards and guidance authors) are not sure how they want the next BIM collaboration software to be developed and that this model could help as a basis for its evaluation.				✓	Efficiency States, BIM maturity levels
Interviewee 3: (on Efficiency states and Communication Waste) Proposed modification/development of the model on the basis that “maturity levels are analogous to the <i>quantity</i> of communication” and that the <i>amount</i> of communication increases with BIM maturity and from that amount a smaller and smaller proportion is waste” (see digitised version of sketch in Figure 43). In summary, communication increases and the proportion of waste decreases.				✓	Efficiency States, Communication waste
Interviewee 3: (on Critical Transmissions) Asked whether Critical Transmissions are project-specific. Noted that in terms of creating a basis for standards and guidelines, it would only be justified if they were universal and not project specific.				✓	Critical Transmissions
Interviewee 1: As a general comment, noted that the model is quite abstract. (actionability)				✓	

Interviewee 3: (on Transmission Best Practice Guide and guidelines in general) Noted that we should be careful when recommending best practice guides. His experience as a guidance author for the AEC-FM industry showed that most people learn from their own mistakes and not from other's mistakes. He explained that the industry is "littered" with best practice guides and only very few of them are utilised. (actionability)				✓		Transmission Best Practice Guide
Interviewee 2: (on Communication waste) From the beginning of the presentation asked for clarification on what is meant by communication waste.					✓	Communication waste
Interviewee 3: (on Communication waste and its relation to other wastes in AEC-FM) Asked for examples of how Communication Waste leads to other wastes.					✓	Communication waste.
Interviewee 3: While completing the questionnaire question on Usability: Asked which slide represents the format.					✓	
Interviewee 3: (on Communication waste and its relation to other wastes in AEC-FM) Asked for examples of how Communication Waste leads to other wastes.						Communication waste.
Interviewee 2: Clarified the difference and relationship between the different tools listed under coordination tools (Information Delivery Manual, Model View Definitions, Model Production and Delivery Tables etc.) noting that they shouldn't be more						Coordination tools
Interviewee 2: Noted that Coordination Tool is a useful concept for such a model.						Coordination tools

Interviewee 4: Explained that the effect of what is explained in the Coordination Tool, and particularly the Model Production and Delivery Table (who needs what information and when) is attempted to be achieved through meetings at the beginning of the project. He noted that is process is much easier and effective when the collaborators are “mature” with BIM processes.						Coordination tools
In all interviews: it was more difficult to explain the Coordination Tool concept compared to “Data Containers” and “Transmission Media” mainly because of lack of examples that readily reflect its definition.						Coordination tools

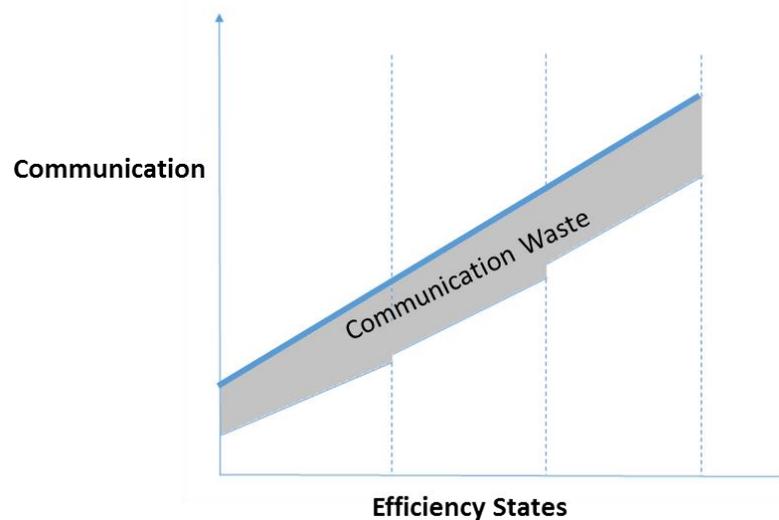


Figure 55 The relationship between communication and communication waste with Efficiency States as proposed by interviewee 3 (digitised version of sketch drawn during interview)

5.6.2.1.1 General comments from interviews

- In general, interviewees 2, 3 and 4 showed more interest and talked more about the bigger picture.
- Interviewee 4: Expressed his belief that this model might work in practice if “brought down” to a practical level by being related to instances of such transmissions.
- Interviewee 4: Explained that they discuss the concepts in the model but in an “unstructured way”. He explained that working with clients involves a “different conversation” to the one in the interview despite involving the same concepts.
- Interviewee 4: (as noted above) Expressed that a lot of the thinking in this model relate to the concepts in the Common Data Environment in BS 1192.

5.6.2.2 Questionnaire results

5.6.2.2.1 Responses to closed-ended questions

The questionnaire contained 28 closed-ended questions on the *Need* for such a model, the *Validity* of this model, the *Utility* of this model and the *Usability* of this model. The questions were of the Likert

Scale format; the interviewees responded with their level of agreement (1=completely disagree, 5=completely agree) with proposed statements. The individual and average responses are presented below (Note: due to limited time and other commitments, interviewee 3 did not complete the questionnaire):

5.6.2.2.1.1 Evaluation of the need for such a model

Table 13. Evaluation of the need for such a model

	Interviewee 1	Interviewee 3	Interviewee 4	Average
A better understanding of BIM communication waste is key for the development of standards.	4	4	4	4.00
A better understanding of BIM communication waste is key for the development of collaboration tools.	4	5	4	4.33
A better understanding of BIM communication waste is key for harmonised BIM adoption.	3	4	5	4.00
Current standards and codes of practice address BIM coordination more than BIM communication.	2	4	4	3.33
A better understanding of BIM from the "transmission level" is key for the development of standards.	3	4	4	3.67
A better understanding of BIM from the "transmission level" is key for the development of collaboration tools.	3	4	4	3.67
A better understanding of BIM from the "transmission level" key for harmonised BIM adoption.	2	3	5	3.33
BIM processes should primarily be informed by communication theory.	2	5	2	3.00
Our "fixation" on the capabilities of existing software is hindering our understanding of potential waste elimination in future BIM states.	4	4	2	3.33

5.6.2.2.1.2 Evaluation of the validity of the proposed model

Table 14. Evaluation of the validity of the proposed model

	Interviewee 1	Interviewee 3	Interviewee 4	Average
The "BIM flows" proposed are representative of BIM flows in practice.	3	4	4	3.67
The model is constructed in a logical way.	4	4	4	4.00
The concepts in the model are apparent universally within practice.	3	4	4	3.67

The concepts in the model will persist through time.	2	4	5	3.67
New functionality types eliminate primarily different waste types.	4	5	3	4.00
Higher BIM maturity levels eliminate primarily different waste types.	4	5	4	4.33

5.6.2.2.1.3 Evaluation of the utility of the proposed model

Table 15. Evaluation of the utility of the proposed model

	Interviewee 1	Interviewee 3	Interviewee 4	Average
The proposed model can complement the BIM maturity model.	2	4	3	3.00
“BIM flows” is a useful concept.	3	4	5	4.00
“BIM flows” are a good basis for evaluating collaboration tools.	3	4	3	3.33
“Coordination tool” is a useful concept.	3	2	4	3.00
“BIM Communication waste types” is a useful concept.	3	4	5	4.00
“Efficiency states” is a useful concept.	4	4	4	4.00
“Critical transmission chains” is a useful concept.	4	5	4	4.33
The proposed model can help in BIM collaboration tool development.	4	4	4	4.00
The proposed model can help in BIM standards development.	4	4	4	4.00
The proposed model can help in strategic BIM Execution Plans.	3	3	5	3.67
The proposed model can help in project-level BIM plans.	3	3	4	3.33
The proposed model can help define what a good BIM process transmission is.	3	4	4	3.67

5.6.2.2.1.4 Evaluation of the usability of the proposed model

Table 16. Evaluation of the utility of the proposed model

	Interviewee 1	Interviewee 3	Interviewee 4	Average
The format of the proposed model makes it usable.	3	4	2	3.00

5.6.2.2.2 Responses to open-ended questions

The sections on validity, utility, usability included open-ended questions. Additionally, the section “State of practice” captured views on current BIM practice on issues relevant to the model and the section “Improving the model” captured opinions on how to improve the model.

5.6.2.2.2.1 Evaluation of validity of the proposed model

The “BIM flows” proposed are representative of BIM flows in practice.

“Flows to be added?”

- Interviewee 1: Flows from different parties involved in construction processes.
- Interviewee 3: BIM data to be modified includes data removal from the BIM model.
- Interviewee 4: Not really a flow, but something on data creation... feels like it’s missing.

The model is constructed in a logical way.

“Where are the inconsistencies?”

- Interviewee 4: No inconsistencies within the model. Would have to be tested in practice to really see.

5.6.2.2.2.2 Evaluation of the utility of the proposed model

The proposed model can complement the BIM maturity model.

How?

- Interviewee 3: Supports the increase in communication and communication effectiveness (less percentage waste) as maturity level increases.
- Interviewee 4: If refined could be used as supplementary information to help explain BIM and maturity concepts

Why not?

- Interviewee 1: Because BIM maturity is not communication waste but familiarity with functions

5.6.2.2.2.3 Evaluation of the usability of the proposed model

The format of the proposed model makes it usable.

How?

- Interviewee 3: But could improve with some examples of real transmissions.
- Interviewee 4: The model is usable at a high level to explain the concepts, but would need to be refined turn it into a ‘toolkit’ or system for people to make use at a project or company to company level.

Why not?

- Interviewee 1: Consolidation into a simple and single model might be helpful in aiding understanding
- Interviewee 3: Include information transmissions to explain the key concepts

5.6.2.2.2.4 State of practice

Which of the presented types of waste currently leads to the biggest effective waste?

- Interviewee 3: Transmission of too much information, especially when the time available for its analysis is short (e.g. tendering)
- Interviewee 4: Transmission waste in too much or wrong information sent due to poor planning or understanding of requirements.

What is usually the bottleneck or blockage for critical flow?

- Interviewee 1: Understanding of what is expected in the process. Understanding of the activity in hand.
- Interviewee 3: The inability of current information practices to separate/sort information flows according to the needs/requirements of the recipients
- Interviewee 4: Not identifying the critical flow!

What concepts need to be standardised next in the AEC-FM industry?

- Interviewee 4: Standardisation within the FM that can be used to drive standardisation back through the project lifecycle.

5.6.2.2.2.5 Improving this model

How could this model be improved?

- Interviewee 1: Robustness through application in the different parts of the construction process.
- Interviewee 3: Examples, examples, examples
- Interviewee 4: Needs to come down a level so that it could be used practically.

5.6.3 **Summary of evaluation results**

5.6.3.1 *Is there a need for such a model?*

Discussions elucidated that Level 3 BIM will require a new set of concepts (in terms of the supporting guidance and standards). Additionally that the variability in software configuration is indeed a significant barrier and that a software agnostic model would help. There was also encouragement from participants on focusing on user-container-user interactions.

The questionnaire responses showed agreement that a better understanding of BIM communication waste is key for the development of collaboration tools.

There were varied views on whether a better understanding of BIM from the “transmission level” key for harmonised BIM adoption and whether BIM processes should primarily be informed by communication theory.

The open ended questions in the “State of practice” section which essentially inquired into the need for the model but allowing the respondents to use ideas from WIMBIM showed that transmission of too much information is indeed a considerable source of waste.

In terms of the perceived bottleneck or blockage for critical flow, the inadequacy of processes and the lack of understanding of required information in practice was emphasised rather than the inability of technology.

5.6.3.2 *Is this model valid?*

There were no significant disagreements with the definition of the elements in the model and the relationships between them or the implications of the model.

One of the most original assertions of the model: that new BIM maturity levels are concerned primarily with new types of communication waste was received positively. It was however, recommended that this assertion be made more specific i.e. to propose what kinds of waste each level is concerned with.

The questionnaire responses showed agreement that the model is constructed in a logical way (4.00) and that higher BIM maturity levels eliminate primarily different waste types (4.33).

5.6.3.3 *Is this model useful?*

This model can be used as a basis for evaluating new BIM collaboration tools and different BIM software configurations.

Additionally, the idea of changing (in kind and/or quantity or proportion) communication waste over new BIM maturity levels can be used to provide a shared understanding across the industry of the essence of new maturity levels. Overall, it was suggested in the interviews that this would provide supplementary guidance rather than complement the BIM maturity model.

“Critical transmission chains” was considered a useful concept in questionnaire responses (4.33) while the “Coordination Tool” as well as being the hardest concept to explain was not seen as very particularly (3.00).

5.6.3.4 *Is this model actionable?*

The model, at this stage, cannot provide any actionable recommendations. It can only be used as a basis for future guidance. Interviewee 3, who had considerable experience on consensus-based guidance noted that there is already excessive amounts of guidance documents in the industry which are not followed.

5.6.3.5 *Is this model usable?*

The current format of this model is suitable for explaining high level concepts but is not suitable for deployment. The concepts need to be consolidated into one or two pages and proposals need to be made clearer. For example, while Interviewee 3 was completing the questionnaire question on Usability he asked which slide represents the format. This indicates a lack of an obvious focal point in the way the model was presented. Additionally, all interviewees agreed that examples of real transmissions and communication waste would significantly enhance understanding of the model and its use.

5.6.3.6 *How can this model be improved?*

Through the interviews it was suggested that the model should be improved by:

- Achieving robustness by applying it in the different parts of the construction process.
- Providing more examples of transmissions and waste.

- Specify exactly how communication waste changes through new BIM maturity levels, i.e. address the quantity of communication and the proportion of communication waste across different BIM maturity levels.
- The model needs to be consolidated and “come down to a level” where it can be used practically.

5.6.4 *Discussion*

The interviews helped identify some necessary clarifications on the use of the model and its level of development. At this stage, it is not proposed that the exact content of the flows is known. Neither are the tools to facilitate those flows. This model merely sets a framework for a better understanding of BIM-enabled communication and what principles to follow in order to make it more efficient. Furthermore it was particularly useful in flagging up the need for conceptual models to account for User Interface User Experience, Semiotics as well as Human Cognition.

5.6.4.1 *Questions arising from model*

The evaluation process gave rise to a number of important questions in reference to the model:

- What can this transmission-level view of the BIM process offer?
- What waste types do the relevant BIM standards aim to eliminate?
- Are new functionality types eliminating different waste types?
- Are different BIM maturity levels eliminating different waste types?

5.7 Chapter Summary

WIMBIM, the Model for Waste in BIM process Interactions, is a set of interrelated concepts which can be used to better describe the communication waste that occurs within BIM process interactions. The aim of WIMBIM (the eradication of BIM communication waste through a better understanding of this waste and how it comes about) gives rise to the desired attributes of WIMBIM: the ability to provide a common reference, universality, robustness and actionability. The model was put in context with relevant literature and standards and was formalised through an iterative process. The presented version of the WIMBIM is a set of diagrams and supporting text. The model has the single BIM transmission as the focal unit of analysis and is then built up in a logical way.

The model was evaluated through semi-structured interviews with four BIM experts. The evaluation showed that there is indeed a need for a more explicit understanding of BIM communication waste. Additionally, the participants were in agreement with having the user-container-user transmission as the focal point of the model. WIMBIM was considered potentially useful in the domain of Requirements Engineering for BIM collaboration tools, however improved actionability would come by closely relating and illustrating the model to examples of BIM transmissions from practice and having better clarity within WIMBIM-based guidelines. Potential uses include evaluating new collaboration tool solutions based on their ability to eradicate BIM communication waste (as it is understood in WIMBIM). Additionally, this BIM communication waste can be used to express the difference between BIM maturity levels (or efficiency states).

6 CONCLUSIONS

6.1 Introduction

This research focused on BIM-enabled collaboration tools and the need for a conceptual model to support Requirements Engineering within this multi-disciplinary and highly dynamic domain. Chapter 6 presents the main conclusions from the research and relates them to the aim and objectives of the project. Subsequently, the limitations of research are discussed. Finally, relevant recommendations towards industry and future research are provided.

6.2 Main conclusions

The Literature Review and Review of Developments in BIM adoption in the UK during the course of the study (2011-2014) identified a significant disparity in BIM definitions and lack of harmonisation in research and development streams (e.g. the government construction strategy understands BIM mainly as structured building information while other researchers might focus on intuitive design or parametric design). This meant that the lack of definition of BIM is still the source behind real and pressing problems.

The research presented in chapter 4 was conducted in an industry-based setting (Asite, an online BIM collaboration tool vendor) and focused on five different perspectives within the domain of Requirements Engineering for BIM collaboration tools. The particular requirements from the conceptual model for use in Requirements Engineering for BIM collaboration tools (i.e. what it should be used for) as well as its basic elements were identified. These requirements and elements are outlined under the following headings.

6.2.1 *Issues within Requirements Engineering for BIM Collaboration tools*

- **Uncertainty** in the domain of BIM collaboration tools is a significant barrier which hinders confidence in product development.
- The primary data collected has also validated the there is significant **variability in software configuration** across projects (this was an observation in the review of development in BIM adoption during the period of this study). This stands as a barrier towards the development of a universal “language” to support Requirements Engineering for BIM collaboration tools. The inability to evaluate a collaboration environment constructively using universal terms leads to effects like non-intuitive environments characterised by lack of integration and non-immediacy.

6.2.2 *Requirements from BIM Collaboration Tools*

- There is a gap and opportunity for OCPs to support BIM communication in **early project stages**: Preparation and Conceptual design. This can only be achieved if collaboration tools better enable the flow of intent in interactions at the Preparation and Design phases.
- OCPs should provide informal communication channels and **foster user familiarity**. This also relates closely to the requirement for the “flow of intent” as well as to the association of project events that have occurred through face to face communication to the content in BIM collaboration tools.

6.2.3 *Requirements from the conceptual model*

- The **language** commonly used within research and software development is not able to support the discourse of Requirements Engineering for BIM collaboration tools effectively. There is no standard or guideline to support this i.e. provide common terms.
- There is a need to analyse and provide a formal, universal and robust description of a **BIM transmission** (or “BIM message” or “BIM interaction”).
- Discourse within the domain Requirements Engineering for BIM collaboration tools should be concerned primarily with the question: how can we work towards enabling the User to make the most of a BIM process transmission?
- The different **types and levels of representation**, including the representations of the various networks in a project have the power to elucidate efficiency (and waste) in different ways.
- Despite the recognition that different project phases require predominantly different types of collaboration environments, **project phases** should not be a fundamental concept-element for the purposes of the conceptual model developed in this study. Division according to project phases goes against the principle of phase-less workflow and endurance and seamless flow of project information.
- **Waste** provides an appropriate reference concept for an inclusive Requirements Engineering process and especially for the purpose of introducing new technological paradigms.
- The **capabilities of a container** of project information (e.g. semantic richness or the ability to “understand” the “explain” the meaning of its content to collaboration systems) significantly impact the efficiency of BIM interactions/transmissions.

6.2.4 *Main deliverable: WIMBIM*

The main outcome of the research is the concept of WIMBIM, a “Model for Waste in BIM process Interactions”. This is presented in chapter 5 in the form of a set of diagrams and explanatory text. The WIMBIM can be used as a practice lens which is more explicit, software platform-neutral and technology paradigm-independent, used to study and understanding BIM communication waste. This can be particularly useful during the development of new BIM collaboration tools.

The main principles behind WIMBIM are:

- Its focus on Communication Waste.
- The BIM process transmission being its focal unit of analysis.
- Being built up from the individual transmission in a logical way and related to concepts within the domain.

Practical uses of the WIMBIM include:

- Evaluation of BIM collaboration tool configurations.
- Understanding BIM maturity in terms of BIM communication waste.

The main benefits of WIMBIM as a conceptual model are that it:

- Provides robustness by being independent of:
 - technological paradigms
 - the types of software used within a BIM collaboration tool configuration

- Provides extensibility for the above reasons and by not being bound any strict formalism.
- Provides a common reference by being involved with concepts that are universal. This is a result of the multi-perspective research conducted in order to produce it.
- Provides exhaustiveness for the above reasons.
- Is a step towards a more scientific understanding of BIM in that it attempts to be partly derived from logical inferences and is therefore constructed in a way that lends itself to falsification.
- Is usable because of its simple and visual form.
- Is politically agnostic in that it puts the elimination of BIM communication waste as its target but does not explicitly assign that responsibility to any party within the Requirements Engineering domain.

6.3 Achievement of Aim and Objectives

The overall aim of the project – to develop a conceptual model to support requirements engineering for BIM collaboration tools – was achieved by the generation of the WIMBIM.

The five objectives set out at the beginning were met as described below:

1. The key aspects in the process of Requirements Engineering for BIM collaboration tools were identified through the Literature Review and addressed within the data collection (chapter 4) where each perspective-phase represented a key aspect.
2. The challenges faced in the Requirements Engineering for BIM collaboration tools were identified in the literature review and the scoping study; continuously evolving technology, variability in user requirements and software configurations and the associated uncertainty in the role of BIM-enabled OCPs.

The area found that would benefit from improved and more explicit conceptual models was BIM-based communication.

3. The concepts in WIMBIM are the key elements in this process (concepts that are universal and persist through time).
4. In WIMBIM, the relationships between these concepts are made explicit and are related to concepts found in current standards, literature and used in the discourse of Requirements Engineering for BIM collaboration tools.

6.4 Limitations of the study

The main limitations of the research and the WIMBIM are described below

6.4.1 *Limitations of the research*

In all of the perspectives-stages of chapter 4 the data used related to just only one of many BIM collaboration tools. This suggests issues and concepts present in other tools could have been omitted which in turn would hinder the generalisability of the outcome. Additionally, the research did not closely examine projects where Asite cBIM was used properly as the BIM collaboration tool. This was because the very limited projects it was used for, used it on an experimental basis and where at their early project stages during the study.

In a number of occasions and particularly in Perspective 4 (use of software and patterns in digital communication) the document-centric communication paradigm was contrasted to the model-centric

communication paradigm. The main premise in this feat was as follows: if this depiction (e.g. metric like number of comments on documents etc.) describes a typical communication setting in a construction project then the challenge is to create an effective model-based environment to (1) more efficiently satisfy the collaboration requirements identified and (2) ideally eliminate any unnecessary, non-value adding steps-procedures. The two following arguments criticise this premise and provide clarifications.

- Many of these 2D documents were generated from a 3D model. It is often much easier for people to interact around (e.g. check and approve) 2D drawings. It should be clarified, therefore, that it is not proposed that 2D working should be eliminated, rather, more efficient ways of interacting with information should be sought.
- The research has not produced any solid evidence that document-centric is inefficient and BIM would be more efficient. This assumption is based on the general perception of what benefits BIM would bring.

6.4.2 *Limitations of the WIMBIM*

The main limitation of WIMBIM lies in the fact that the model was not developed using a formal and repeatable process. This means that there could be considerable bias and subjectivity in this process. In other words, one could argue that WIMBIM is one of many possible outcomes of the research conducted and the given research aim.

The model has not yet been tested against examples of real BIM process transmissions. As pointed out during the interviews, this would “ground” the model by relating it to particular instances hence making it more understandable as well as testing its applicability and validity.

Additionally, it could be argued that such a model is construction-specific only to a limited degree. Other industries, and predominantly the manufacturing industry are concerned with collaborative product modelling and are likely to have deployed similar conceptual models. It is well established, that Product Lifecycle Management systems used in Manufacturing are more advanced than the design and collaboration systems used in AEC-FM. An important premise supporting the development of a model like WIMBIM however, as Koskela (2013) points out, is that when developing methodologies aiming to understand waste explicitly and reduce it (such as Lean methodologies) we should be concerned with the wastes which are construction-specific since they are often display particularities.

Finally, the model, as it is presented, is contained to digital communication i.e. it omits face-to-face communication which will always form a significant part of project communication and will have an effect on digital communication. A similar argument can be proposed for paper-based communication (the difference being that most agree that paper-based communication should be brought down to a minimum). It should be noted, however, that the principles, many elements, importantly the transmission elements, hold true for any type/medium of communication (i.e. there is always reference to a model and there is always the need to satisfy the client requirements regardless of whether communication is digitally-mediated or not). Therefore, despite the model currently omitting a

significant portion of project communication it could be extended to include non-digitally-mediated communication which will naturally always be a part of overall project communication.

6.5 Recommendations for industry and research

The main recommendations for industry and research coming out of this study are explained below.

Need for harmonisation of research and practice: New research directions should be based on the actual needs of industry. Efforts should be aligned and harmonised by coordinating industry developments and research projects. It has been a main premise in this study that the two domains still don't really speak the same language and it is anticipated that a model like WIMBIM could help.

BIM theory should incorporate Communication Theory: BIM in practice is a characteristically diverse topic. It should follow that, in a study aiming to improve collaborative BIM working, a diverse range of disciplines should be understood and consulted. Communication theory is a relatively recent discipline but one that is rooted in scientific principles. Additionally, it provides a framework for modelling a phenomenon which is often overlooked by many BIM-related studies: that a communication act starts from a human being as a sender and ends at a human as a receiver (and the executor of an action).

Need for the models used in BIM product development to account for User Interface, User Experience, Human Cognition and Semiotics: A careful application of communication theory which would include the specifics of Human Cognition and Semiotics and how they affect the BIM collaboration tool user's experience is required. These phenomena are often overlooked since because of the structure of the industry and the nature of project software configuration, typically, no party is assigned the responsibility for overall user experience.

6.5.1 *Recommendations on the use of WIMBIM*

In BIM practice, communication waste was it is understood in WIMBIM could be incorporated in the descriptions of BIM maturity levels. This proposal was received positively from BIM experts during the WIMBIM evaluation interviews. Furthermore, it was suggested that WIMBIM can provide a framework for evaluating BIM collaboration tools, new paradigms and standards i.e. any development should be scrutinised against its potential to reduce communication waste.

In regards to research WIMBIM provides a lens for academic analysis of BIM collaboration tools. A model like WIMBIM would become much more rigorous and valuable if (1) its concepts are assigned more clearly to specific instances and (2) if its concepts are assigned metrics, aiding more objective analysis. Additionally, the set of proposals emerging out of WIMBIM could be evaluated. The model evaluation process gave rise to a number of important questions in reference to the model:

- What can this transmission-level view of the BIM process offer?
- What waste types do the relevant BIM standards aim to eliminate?
- Are new functionality types eliminating different waste types?
- Are different BIM maturity levels eliminating different waste types?

7 REFERENCES

- Abanda, F. Henry, Joseph HM Tah, and Ramin Keivani. "Trends in built environment semantic Web applications: Where are we today?." *Expert Systems with Applications* 40.14 (2013): 5563-5577.
- AIA California Council. (2007). "Integrated project delivery: A guide."*
- AIA. (2008). Document E202 TM – 2008. Contract.*
- Akkermans, H., & Gordijn, J. (2006, September). What is This Science Called Requirements Engineering?. In *Requirements Engineering, 14th IEEE International Conference* (pp. 273-278). IEEE
- Allemang, D., & Hendler, J. (2011). Semantic web for the working ontologist: effective modeling in RDFS and OWL.
- Alshawi, M., & Ingirige, B. (2003). Web-Based Project Management (Vol. 44).*
- Anumba, C. J., Pan, J., Issa, R. R. A., & Mutis, I. (2008). Collaborative project information management in a semantic web environment. *Engineering, Construction and Architectural Management*, 15(1), 78-94.
- Anumba, C. J., Ugwu, O. O., Newnham, L., & Thorpe, A. (2002). Collaborative design of structures using intelligent agents. *Automation in construction*, 11(1), 89-103.
- Anumba, C. J., Ugwu, O. O., Newnham, L., & Thorpe, A. (2002). Collaborative design of structures using intelligent agents. *Automation in construction*, 11(1), 89-103.
- Aouad, G., & Arayici, Y. (2010). Requirements Engineering for Computer Integrated Environments.
- Aouad, G., Lee, A., & Wu, S. (2005). nD modelling for collaborative working in construction. *Architectural Engineering and Design Management*, 1(1), 33-44.
- Arayici, Y., Ahmed, V., & Aouad, G. (2006). A REQUIREMENTS ENGINEERING FRAMEWORK FOR INTEGRATED SYSTEMS DEVELOPMENT FOR THE CONSTRUCTION INDUSTRY. *Requirements Engineering*, 11(October 2005), 35–55.
- Asite (2013), www.asite.com
- Asite Solutions (2013), www.asite.com
- Ballard, G., & Howell, G. (1998). WHAT KIND OF PRODUCTION IS CONSTRUCTION ? Proceedings IGLC ' 98.
- Bastian M., Heymann S., Jacomy M. (2009). Gephi: an open source software for exploring and manipulating networks. *International AAAI Conference on Weblogs and Social Media*.
- Becerik, B. & Pollalis, S.N.(2006) "Computer aided collaboration in managing construction", Harvard Design School, Department of Architecture, Design and Technology Report Series 2006-2

Becerik, B., & Pollalis, S. N. (2006). Computer aided collaboration in managing construction, Harvard Design School, Department of Architecture, Design and Technology Report Series 2006-2. Technology.

Beetz, J., van Berlo, L., de Laat, R., & van den Helm, P. (2010). BIMserver. org—An open source IFC model server. Proceedings of the CIB W78 conference.

Bertelsen, S., Henrich, G., Koskela, L. J., & Rooke, J. A. (2007). Construction physics. In *Proceedings of the 15th Annual Conference of the International Group for Lean Construction* (pp. 13-26).

Bertelsen, S., Koskela, L. J., Henrich, G., & Rooke, J. A. (2006, July). Critical flow—towards a construction flow theory. In *Proceedings of the 14th Annual Conference of the International Group for Lean Construction* (pp. 31-40).

BIM Task Group (2013).Employers-Information-Requirements-Core-Content-and-Guidance.

BIM Task Group | A UK Government Initiative. (n.d.). BIM Task Group. Retrieved July 23, 2014, from <http://www.bimtaskgroup.org/>

BIS, 2011, BIM management for value, cost and carbon improvement, A report commissioned by the Department of Business, Innovation and Skills, July, 2011. URN 11/948

BRE (2014). BRE Group: Level 2 BIM On Trial - a buildingSMART UK User Group Event. BRE Group: Level 2 BIM On Trial - a buildingSMART UK User Group Event. Retrieved July 24, 2014, from <http://www.bre.co.uk/page.jsp?id=3368>

British Standards (2007). BS ISO 1192:2007 Collaborative production of architectural , engineering and construction information – Code of practice.

Bryman, A., & Bell, E. (2011). Business Research Methods 3e. Oxford university press, General Evaluation methods are presented in Table 10-1 (Carter, 2008).

BS ISO 29481-1:2010 Building Information Modelling - Information Delivery Manual Part 1: Methodology and Format.

BSI (2007). BS ISO 1192:2007 Collaborative production of architectural , engineering and construction information – Code of practice.

BSI (2011). B/555 Roadmap Design, Construction & Operation Data & Process Management.

BSI (2012) "BS ISO 29481-2:2012 Building information models — Information delivery manual Part 2 : Interaction framework"

BSI (2012) "BS ISO 29481-2:2012 Building information models — Information delivery manual Part 2 : Interaction framework"

BSI (2013) PAS 1192-2 : 2013 "Specification for information management for the capital / delivery phase of construction projects using building information modelling"

BSI (2014). Specification for information management for the operational phase of assets using building information modelling.

BSI, 2011. B/555 Roadmap Design , Construction & Operation Data & Process Management. , pp.1–6.

BSI, 2011. B/555 Roadmap Design , Construction & Operation Data & Process Management. , pp.1–6.

BSI. (2013). PAS 1192-2 : 2013 Specification for information management for the capital / delivery phase of construction projects using building information modelling.

Buchanan, R. (1992). Wicked problems in design thinking. Design issues, 5-21.

Build London Live. (2012). Build London Live. Retrieved July 31, 2014, from <http://www.buildlondonlive.com/>

Building Smart (2014) BIM Collaboration Format. Available at: <http://www.buildingsmart-tech.org/specifications/bcf-releases/bcf-intro>

Building Smart (2014) BIM Collaboration Format.". Building Smart, 2014. Web. 13 Oct. 2014. <<http://www.buildingsmart-tech.org/specifications/bcf-releases/bcf-intro>

Building Smart International (2010). Investors Report, Building Information Modelling.

Building Smart UK (2014) UK and Ireland buildingSMART website. Home of openBIM UK and Ireland. Retrieved July 24, 2014, from <http://www.buildingsmart.org.uk/>

Cabinet Office (2011). Government Construction Strategy

Cabinet Office (2012). Government Property Unit. The Government Soft Landings Policy – September 2012.

Cabinet Office and BSI (2013) COBie Data Drops.

Caldas, C. H., Soibelman, L., & Gasser, L. (2005). Methodology for the integration of project documents in model-based information systems. Journal of Computing in Civil Engineering, 19(1), 25-33.

Cerovšek, T. (2012). Process Reuse in Product Development with 5D Models: Concepts, Similarity Measures and Querying Techniques. In Virtual and Networked Organizations, Emergent Technologies and Tools (pp. 253-262). Springer Berlin Heidelberg.

Cerovsek, T., 2011. A review and outlook for a "Building Information Model" (BIM): A multi-standpoint framework for technological development. Advanced Engineering Informatics, 25(2), pp.224–244.

Cherbakov, L., Galambos, G., Harishankar, R., Kalyana, S., & Rackham, G. (2005). Impact of service orientation at the business level. IBM Systems Journal, 44(4), 653-668.

CIC (2013) Fiatch Award 03 July 2013, Retrieved July 24, 2014, from <http://cic.org.uk/news/article.php?s=2013-07-03-fiatch-award>

CIC, Computer Integrated Construction Research Group. (2009). *BIM project execution planning guide*. The Pennsylvania State University.

CIC, Construction Industry Council (2013a). *BUILDING INFORMATION MODEL PROTOCOL CIC / BIM Pro*.

CIC, Construction Industry Council (2013b). *Best Practice Guide for Professional Indemnity Insurance when using Building Information Models first edition 2013*.

Clarke, A., & Dawson, R. (1999). *Evaluation research: An introduction to principles, methods and practice*. Sage.

Coates, P. et al., 2010. *The limitations of BIM in the architectural process*. *Knowledge Creation Diffusion Utilization*, (December), pp.15–17

Coates, P., Arayici, Y., Koskela, L., Kagioglou, M., Usher, C., & Reilly, K. O. (2010). The limitations of BIM in the architectural process. *Knowledge Creation Diffusion Utilization*, (December), 15–17.

Crotty, M. (1998). *The foundations of social research: Meaning and perspective in the research process*. Sage.

Cutting-Decelle, A. F., Young, R. I. M., Anumba, C. J., Baldwin, A. N., & Bouchlaghem, N. M. (2003). *The Application of PSL to Product Design across Construction and Manufacturing*.
doi:10.1177/106329303032816

Dainty, A., Moore, D., & Murray, M. (2007). *Communication in construction: Theory and practice*. Routledge. Dave, B., Koskela, L. J., Kiviniemi, A. O., Tzortzopoulos Fazenda, P., & Owen, R. L. (2013). *Implementing lean in construction: lean construction and BIM*.

Demian, P. & Walters, D., 2013. "The advantages of information management through building information modelling" *Construction Management and Economics*, (May), pp.1–13. Available at: <http://www.tandfonline.com/doi/abs/10.1080/01446193.2013.777754>

Dubois, A. & Gadde, L.-E., 2002. *The construction industry as a loosely coupled system: implications for productivity and innovation*. *Construction Management and Economics*, 20(7), pp.621–6313

East, E. W., Love, D., & Nisbet, N. (2010). *A life-cycle model for contracted information exchange*. Virginia Tech, Department of Building Construction.

Eastman, C. M., et al. "A Guide to Building Information Modeling for Owners, Managers, Architects, Engineers, Contractors, and Fabricators." (2008): 32-40.

EI-Diraby, T.E., (2012) "Epistemology of Construction Informatics" *Journal of Construction Engineering and Management*, (January), pp.53–65.

Elghamrawy, T., & Boukamp, F. (2010). Managing construction information using RFID-based semantic contexts. *Automation in construction*, 19(8), 1056-1066.

European Commission, 2010. European Interoperability Framework (EIF) for European public services

Fellows, R. F., & Liu, A. M. (2015). *Research methods for construction*. John Wiley & Sons.

Fernie, S., Leiringer, R. & Thorpe, T., 2006. Change in construction: a critical perspective. Building Research & Information, 34(2), pp.91–103

Froese, T. M. (2010). The impact of emerging information technology on project management for construction. *Automation in Construction, 19(5)*, 531–538. doi:10.1016/j.autcon.2009.11.004
Ballard, G., Koskela, L., Howell, G., & Zabelle, T. (2001). PRODUCTION SYSTEM DESIGN IN CONSTRUCTION. *Construction, 1–15*.

Goes, R. & Santos, E., (2011) "Design Coordination with Building Information Modelling: A case study" Proceedings of the CIB W78-W102 2011: International Conference –Sophia Antipolis, France, 26-28 October, (FIESP 2008), pp.26–28.

Grilo, A., & Jardim-Goncalves, R. (2010). Value proposition on interoperability of BIM and collaborative working environments. *Automation in Construction, 19(5)*, 522-530.

GSA (2007). BIM Guide Overview. The National 3D-4D-BIM Program Office of the Chief Architect, Public Buildings Service, US General Services Administration.

Harty, C., 2005. Innovation in construction: a sociology of technology approach. Building Research & Information, 33(6), pp.512–522

Holzer, D., 2007. ARE YOU TALKING TO ME ? WHY BIM ALONE IS NOT THE ANSWER. In Paper presented at the 4th International Conference of the Association of Architecture Schools of Australasia.

Hughes, W. P., Ancell, D., Gruneberg, S. and Hirst, L. (2004) Exposing the myth of the 1:5:200 ratio relating initial cost, maintenance and staffing costs of office buildings. In: Khosrowshahi, F (ed) Proceedings of the 20th Annual ARCOM Conference, Heriot-Watt University, Edinburgh, pp. 373-381. ISBN 0953416194

Hull, E., Jackson, K., & Dick, J. (2005). Requirements engineering (Vol. 3). London: Springer.

Huovila, Pekka, Lauri Koskela, and Mika Lautanala. "Fast or concurrent: the art of getting construction improved." *Lean construction* (1997): 143-159.

Ilich, M., Becerik, B., & Aultman, B. (2006). Online collaboration: why aren't we using out tools?. *The Construction Zone, 6(3)*, 10.

Information, B., Bim, M. & Party, W., 2011. A report for the Government Construction Client Group. Communications, (March)

Isikdag, U., & Underwood, J. (2010). Two design patterns for facilitating Building Information Model-based synchronous collaboration. *Automation in Construction, 19(5)*, 544–553. doi:10.1016/j.autcon.2009.11.006

- Isikdag, U., & Underwood, J. (2010). Two design patterns for facilitating Building Information Model-based synchronous collaboration. *Automation in Construction*, 19(5), 544–553.
doi:10.1016/j.autcon.2009.11.006
- Isikdag, U., & Underwood, J. (2010). Two design patterns for facilitating Building Information Model-based synchronous collaboration. *Automation in Construction*, 19(5), 544–553.
doi:10.1016/j.autcon.2009.11.006
- ISO 16739 (2013). Industry Foundation Classes (IFC) for data sharing in the construction and facility management industries, International Organization for Standardization, Geneva.*
- Koskela, L. & Vrijhoef, R., 2001. Is the current theory of construction a hindrance to innovation? Building Research & Information, 29(3), pp.197–207*
- Koskela, L. (1997). Lean production in construction. *Lean Construction*, 1-9.
- Koskela, L. J., Sacks, R., & Rooke, J. A. (2012). A brief history of the concept of waste in production.
- Kreider, Ralph G. and Messner, John I. (2013). "The Uses of BIM: Classifying and Selecting BIM Uses". Version 0.9, September, The Pennsylvania State University, University Park, PA, USA.
<http://bim.psu.edu>.
- Laiserin, J. (2007) To BIMfinity and Beyond! Cadalyst, 24(11), pp. 46-48.*
- Lee, A., Wu, S., Marshall-Ponting, A., Aouad, G., Cooper, R., Tah, J. H. M., ... & Barrett, P. S. (2005). nD Modelling Roadmap: A Vision for nD Enabled Construction. *University of Salford, Salford.*
- Lee, G., & Eastman, C. (2008). 3D MODEL-BASED COLLABORATION IN DESIGN DEVELOPMENT AND CONSTRUCTION OF COMPLEX SHAPED BUILDINGS. *Control*, 13(September 2007), 458–485.
- Lee, G., & Eastman, C. (2008). 3D MODEL-BASED COLLABORATION IN DESIGN DEVELOPMENT AND CONSTRUCTION OF COMPLEX SHAPED BUILDINGS. *Control*, 13(September 2007), 458–485.
- Liu, N., Kagioglou, M., & Liu, L. (2011, March). An overview of the marketed functionalities of web-based Construction collaboration extranets. In *Information Science and Technology (ICIST), 2011*
- Liu, N., Kagioglou, M., & Liu, L. (2011, March). An overview of the marketed functionalities of web-based Construction collaboration extranets. In *Information Science and Technology (ICIST), 2011*
- Manziona, L., Wyse, M. & Melhado, S.B. (2011) "Key performance indicators to analyse and improve management of information flow in the BIM design process" In *CIB W78-W102 2011: International Conference –Sophia Antipolis, France, 26-28 October. pp. 26–28.*
- Matthews, J., & Lockley, S. R. (2013). A study of bim collaboration requirements and available features in existing model collaboration systems.

McMahon, C., Caldwell, N., Darlington, M., Culley, S., Giess, M., & Clarkson, J. (2009). The development of a set of principles for the through-life management of engineering information (KIM Project Document kim40rep007mjd10). *Bath, UK: University of Bath*. Retrieved October, 27, 2010.

Messner, J, Hunter, S and Anumba, C (2010) Project Execution Planning for Building Information Modelling (BIM) A BuildingSMART Alliance Project. Penn State University.

MoJ, Ministry of Justice, (2013) Early Adopters Project- HMYOI Cookham Wood: New House Block and Education Building, BIM Lessons Learnt, Report Version 3 Available at: <http://www.bimtaskgroup.org/wp-content/uploads/2012/03/Cookham-Wood-Consolidated-Lessons-Learned-version3-with-intro.pdf> - accessed 06/06/2012

Mondrup, T. F., Karlshøj, J., & Vestergaard, F. (2012) “Communicate and collaborate by using building information modelling” CIB W078 2012 Conference.

Mooney, J. D. (1947). *The principles of organization*. New York, Harper.

National BIM Standard - United States Version 2. Available at: http://www.nationalbimstandard.org/nbims-us-v2/pdf/NBIMS-US2_Foreword.pdf [Accessed January 21, 2013].

NBIMS (National Building Information Modeling Standard), Version 1,

NBS (2011) Building Information Modelling Report March 2011. Building, (March), pp.1–21.

NBS (2012) Building Information Modelling Report 2012, pp.1–21.

NCCTP. (2006). Proving Collaboration Pays Study Report.

Nisbet, N. (2012). COBie-UK-2012.

NIST (2004). Cost analysis of inadequate interoperability in the US capital facilities industry. National Institute of Standards and Technology.

OmniClass (2012) Table 31 – Phases. Available at: <http://www.omniclass.org/>

Part 1 (2007). “Overview, Principles, and Methodologies”, National Institute

Pryke, S. (2012). Social network analysis in construction. John Wiley & Sons.

Rezgui, Y. & Zarli, A., 2006. Paving the Way to the Vision of Digital Construction : A Strategic Roadmap. Journal of Construction Engineering and Management, (July), pp.767–776.

Rezgui, Y. et al., 2011. Past, present and future of information and knowledge sharing in the construction industry: Towards semantic service-based e-construction? Computer-Aided Design, 43(5), pp.502–515

Rezgui, Y., & Zarli, A. (2006). Paving the way to the vision of digital construction: a strategic roadmap. *Journal of Construction Engineering and Management, 132(7), 767-776.*

Rezgui, Y., Beach, T., & Rana, O. (2013). A governance approach for BIM management across lifecycle and supply chains using mixed-modes of information delivery. *Journal of Civil Engineering and Management*, 19(2), 239-258.

RIBA (2013), RIBA Plan of Work. Available at: <http://www.ribaplanofwork.com/>

Riley, S. M (2007). Case Study : BAA – Monitoring and quantifying cost of using an internet-based project collaboration system, Code: IT052 0607, Published by The IT Construction Forum

Sacks, R., Koskela, L., Dave, B. a., & Owen, R. (2010). Interaction of Lean and Building Information Modeling in Construction. *Journal of Construction Engineering and Management*, 136(9), 968. doi:10.1061/(ASCE)CO.1943-7862.0000203

Saunders, M. N., Saunders, M., Lewis, P., & Thornhill, A. (2011). *Research methods for business students*, 5/e. Pearson Education India.

Sawhney, A. & Maheswari, J.U. (2013) "Design Coordination Using Cloud-based Smart Building Element Models", pp.445–453.

Saxon, R (2002) A Vision for the Construction Industry. 1st Annual Be Conference, London, 27 November

Scriven, M. (1996). The theory behind practical evaluation. *Evaluation*, 2(4), 393-404.

Sebastian, R. (2011). Bim in different methods of project delivery. In *CIB W78-W102 2011: International Conference –Sophia Antipolis, France, 26-28 October* (pp. 26–28).

Simon, H. A. (1969). The sciences of the artificial. *Cambridge, MA*.

Shannon, C. E., & Weaver, W. (2002). The mathematical theory of communication.

Shelbourn Mark, Bouchlaghem, D., Anumba, C., & Carrillo, P. (2006). Planning & Implementing Effective Collaboration in Construction.

Shelbourn, M., Bouchlaghem, N. M., Anumba, C., & Carrillo, P. (2007). Planning and implementation of effective collaboration in construction projects. *Construction Innovation: Information, Process, Management*, 7(4), 357–377. doi:10.1108/14714170710780101

Simatupang, T. M., & Sridharan, R. (2005). The collaboration index: a measure for supply chain collaboration. *International Journal of Physical Distribution & Logistics Management*, 35(1), 44–62. doi:10.1108/09600030510577421

Simon, H. A. (1981). The sciences of the artificial, 1981.

Sinclair, D. (2012). BIM overlay to the RIBA outline plan of work. London, UK: RIBA.

Singh, V., Gu, N., & Wang, X. (2011). A theoretical framework of a BIM-based multi-disciplinary collaboration platform. *Automation in construction*, 20(2),

Smith, D.; Tardif, M. *Building Information Modelling: A Strategic Implementation Guide for Architects, Engineers, Constructors, and Real Estate Asset Managers*; Wiley: New York, NY, USA, 200

Son, J., Rojas, E. M., Ph, D., & Asce, A. M. (2011). Evolution of Collaboration in Temporary Project Teams: An Agent-Based Modeling and Simulation Approach. *Journal of Construction Engineering and Management*, (August), 619–628. doi:10.1061/(ASCE)CO.1943-7862.0000331.

Son, J., Rojas, E. M., Ph, D., & Asce, A. M. (2011). Evolution of Collaboration in Temporary Project Teams: An Agent-Based Modeling and Simulation Approach. *Journal of Construction Engineering and Management*, (August), 619–628. doi:10.1061/(ASCE)CO.1943-7862.0000331.

Succar, B. (2009). Building information modelling framework: A research and delivery foundation for industry stakeholders. *Automation in Construction*, 18(3), 357-375.

Succar, B. (2009). Building information modelling framework: A research and delivery foundation for industry stakeholders. *Automation in Construction*, 18(3), 357-375.

Succar, B. (2010). The five components of BIM performance measurement. In *Proceedings of CIB World Congress*, Salford.

Succar, B., 2009. Building information modelling framework: A research and delivery foundation for industry stakeholders. Automation in Construction, 18(3), pp.357–375.

Succar, B., 2009. Building information modelling framework: A research and delivery foundation for industry stakeholders. Automation in Construction, 18(3), pp.357–375.

Technology Strategy Board (2014). A digital tool for building information modelling. Retrieved July 24, 2014, from <https://www.innovateuk.org/-/a-digital-tool-for-building-information-modelling>

Tribelsky, E. & Sacks, R. (2006) “Measures of Information Flow for Lean Design in Civil Engineering”

Tribelsky, E., & Sacks, R. (2010). Measuring information flow in the detailed design of construction projects. *Research in Engineering Design*, 21(3), 189–206. doi:10.1007/s00163-009-0084-3

Tribelsky, E., & Sacks, R. (2010). The Relationship between Information Flow and Project Success in Multi-Disciplinary Civil Engineering Design. In *Proc. 18th Annual Conf. Intl. Group for Lean Construction*.

Underwood, J. & Isikdag, U., 2011. Emerging technologies for BIM 2.0. Construction Innovation: Information, Process, Management, 11(3), pp.252–258

Vanlande, R., Nicolle, C. & Cruz, C., 2008. IFC and building lifecycle management. *Automation in Construction*, 18(1), pp.70–78.

Venugopal, M., Eastman, C. M., Sacks, R., & Teizer, J. (2012). Semantics of model views for information exchanges using the industry foundation class schema. *Advanced Engineering Informatics*, 26(2), 411-428.

Waterhouse, R., Chapman, I., Poulter, J., Munkley, J., Anwyl, J., & Ball, T. (2014). *NBS National BIM Report*.

Wilkinson, P. (2005). *Construction collaboration technologies: the extranet evolution*. Taylor & Francis.

Wilkinson, P. (2014). *Extranet Evolution: construction collaboration*. Retrieved from <http://www.extranetevolution.com>

Wong, A. K., Wong, F. K., & Nadeem, A. (2011). *Government roles in implementing building information modelling systems: Comparison between Hong Kong and the United States*. *Construction Innovation: Information, Process, Management*, 11(1), 61-76.

Yang, Q. Z., & Zhang, Y. (2006). *Semantic interoperability in building design: Methods and tools*. *Computer-Aided Design*, 38(10), 1099-1112.

Yeomans, S. G. (2005). *ICT-enabled collaborative working methodologies in construction* (Doctoral dissertation, © Steven Yeomans).

Yeomans, S. G., Bouchlaghem, N. M., & El-Hamalawi, A. (2006). *An evaluation of current collaborative prototyping practices within the AEC industry*. *Automation in Construction*, 15(2), 139-149.

Yurchyshyna, A., & Zarli, A. (2009). *An ontology-based approach for formalisation and semantic organisation of conformance requirements in construction*. *Automation in Construction*, 18(8), 1084-1098.

8 BIBLIOGRAPHY

Eastman, C., Eastman, C. M., Teicholz, P., & Sacks, R. (2011). *BIM handbook: A guide to building information modeling for owners, managers, designers, engineers and contractors*. John Wiley & Sons.

Hull, E., Jackson, K., & Dick, J. (2010). *Requirements engineering*. Springer Science & Business Media.

Simon, H. A. (1996). *The sciences of the artificial* (Vol. 136). MIT press.

Wiener, N. (1988). *The human use of human beings: Cybernetics and society* (No. 320). Da Capo Press.

Wilkinson, P. (2005). *Construction collaboration technologies: the extranet evolution*. Taylor & Francis.

9 APPENDICES

9.1 Appendix A: Questionnaire Survey for Perspective 1

Research in partnership with:



A S I T E
Get to it.



Loughborough
University

Centre for Innovative and Collaborative
Construction Engineering

EPSRC

Pioneering research
and skills

George Charalambous

Unit E2 – 3rd Floor,
Zetland House,
5-25 Scrutton Street,

Monday, 21May/2012

Dear Sir/Madam;

My name is George Charalambous and I am a Research Engineer at Asite Solutions.

I am currently investigating the involvement of different disciplines within the process of collaborating around a shared BIM model over the lifetime of a built asset as partial fulfilment of my Engineering Doctorate studies at Loughborough University.

This questionnaire has been distributed to a cross section of Asite's clients and the AEC sector as a whole. The findings are intended to reveal issues related to the adoption of BIM processes and BIM technologies. I would be grateful if you could devote 10 minutes of your time to answer 19 short questions. All information will be treated with confidentiality. Individual and company names will not be published.

Thank you very much for your cooperation.

Yours Faithfully,

George Charalambous, MEng
Research Engineer

T: 0207 749 7896

M: 07432 714 636

E-mail: gcharalambous@asite.com



“Mapping the Whole-life Collaborative Building Information Modelling Process”

A- You and your organization

1. Name:

2. Email Address:

3. What is your role within a construction project?
Client
Contractor
Architect
Project Manager
Structural Engineer
MEP-HVAC
Cost Consultant
Facilities Manager
Fabricator
Other

4. What position/title do you hold?

5. Company name:

6. Company turnover:

7. Number of employees in your company:

Section B

8. Are you currently implementing BIM?

Yes

For how long have you been implementing BIM?

More than 36 months.....

Last 12-36 months.....

Last 0-6 months.....

No

When do you plan on implementing BIM?

Next 0-6 months.....

Next 6-12 months.....

Next 12-36 months.....

After 36 months.....

9. At what level of BIM maturity are the majority of your projects?

Level 0 (unmanaged CAD)

Level 1(managed CAD in 2D or 3D)

Level 2 (managed 3D environment)

Level 3(fully open and integrated process)

My team does not track performance against the BIM maturity index

Other (please specify)

[More info on BIM maturity](#)

10. What are the drivers for your company adopting BIM?

Government mandate

Client requirement

Information exchange across project partners

Direct business benefits

Other (please specify)



11. How do you achieve a common language or compatibility across your project team?

	In how many of your projects?			
	All	Majority	Minority	None
We require that all project partners use compatible commercial products (e.g. Autodesk Revit product family)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
We use a common platform such as "Asite cBIM"	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
We only use products that are compliant with an external standard such as IFC	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

12. If you use any other methods for achieving a common language or compatibility across your project team please explain.

13. From your experience, how beneficial do you qualify BIM for each of these aspects?

	Very beneficial	Beneficial	No difference	Hindrance
Design Quality	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Coordination	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Cost efficiency	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Time efficiency	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Constructability	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Risk reduction	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Business performance	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>





Section C

14. Which of the following methods is most widely used within your organisation's project procurement processes?

For each of the life cycle phases provided please identify;

- What deliverables (e.g. Feasibility Study, Preliminary Cost Plan) are expected from you, if any (maximum 3)
- Your relationship with the model i.e. producer, contributor or reviewer
- The 3 primary software tools you use (e.g. Revit, Navisworks, Archicad etc.)

	a) Deliverable(s)	b) Involvement with model			c) Software tools
		Producer	Contributor	Reviewer	
Preparation	<input type="text"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="text"/>
Design	<input type="text"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="text"/>
Pre-construction	<input type="text"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="text"/>
Construction	<input type="text"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="text"/>
Use	<input type="text"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="text"/>

15. For each of the life cycle phases provided please identify:

- The level of BIM embeddedness in your processes
- Your requirements and expectations from BIM

	a) BIM embeddedness					b) Requirements and expectations from BIM
	Full	Partial	Marginal	Not embedded	N/A	
Preparation	<input type="checkbox"/>	<input type="text"/>				
Design	<input type="checkbox"/>	<input type="text"/>				
Pre-construction	<input type="checkbox"/>	<input type="text"/>				
Construction	<input type="checkbox"/>	<input type="text"/>				
Use	<input type="checkbox"/>	<input type="text"/>				



16. How beneficial do you expect web-based collaboration around a shared Building Information Model will be for each of these aspects?

	Very beneficial	Beneficial	No difference	Hindrance
Design quality	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Coordination	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Cost efficiency	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Time efficiency	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Constructability	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Risk reduction	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Business performance	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

17. Is there any additional information you would like to add?

D- Thank you

18. Would you like to receive a summary of the results?

- Yes
 No

19. Would you be available for a follow up interview within the next month?

- Yes (please provide any details)
 No

Please either

[publish the completed questionnaire](#)

or

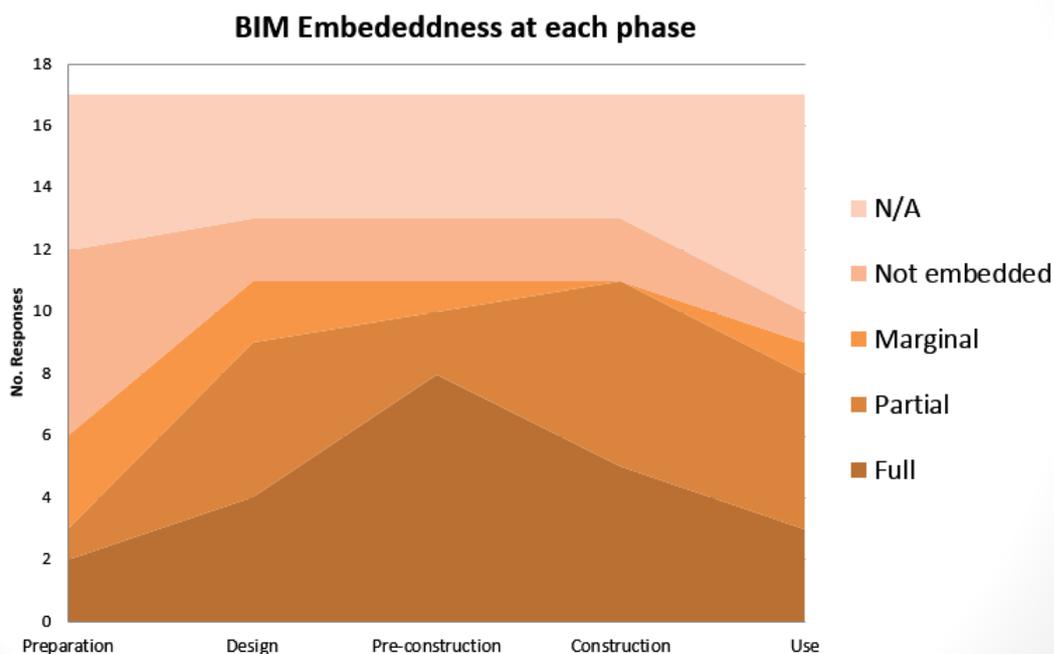
[email to gcharalambous@asite.com](mailto:gcharalambous@asite.com)

9.2 Appendix B: Semi-structured interview for Perspective 2

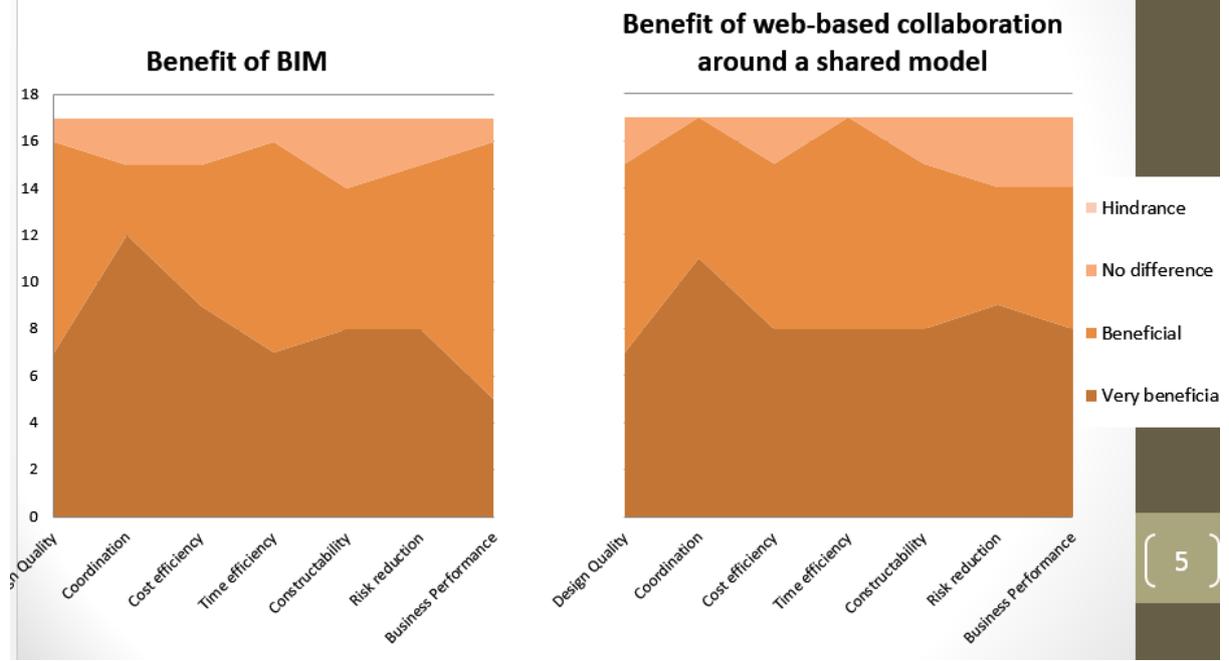
Investigating emerging requirements from Online Collaboration Platforms

- Introduction to work carried out
- Findings from questionnaire
- ICT enabled vision for AEC/FM
- Interoperability
- “Fill in the map” exercise
- Knowledge Management
- cBIM adoption
- Any other comments?

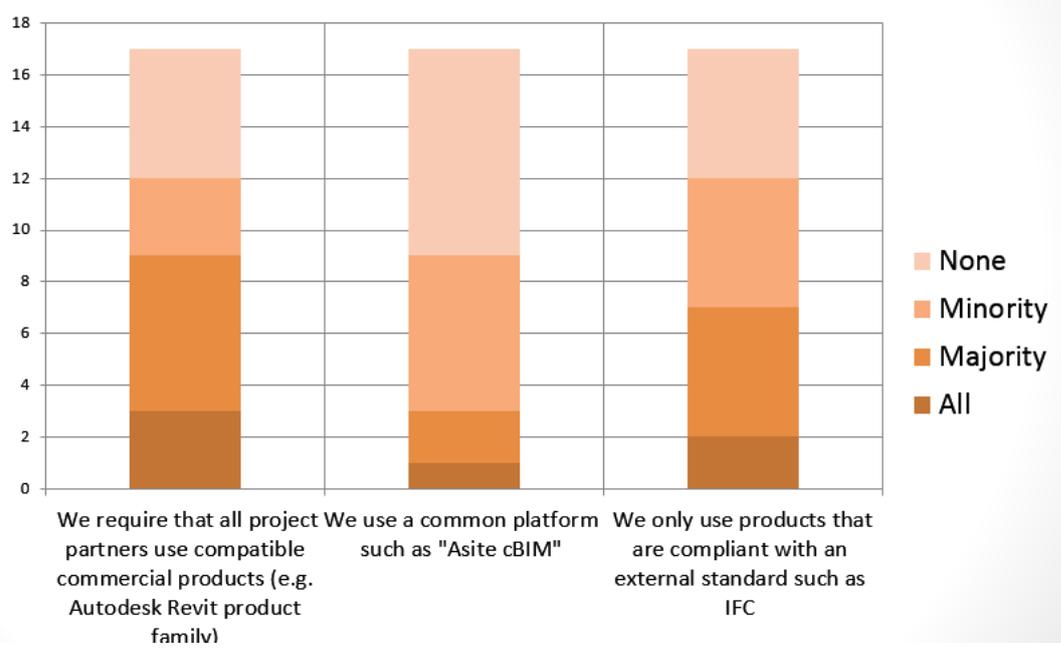
Questionnaire Findings



“Benefit of BIM vs. benefit of web-based collaboration (specifically)”



“How do you achieve compatibility across the project team?”



Literature Review and Related Questions

ICT driven Vision

How can ICT (BIM software , Cloud computing , online collaboration platforms etc.) transform the AEC/FM industry ?

Source	Context	Descriptors of Vision	Dimensions in path towards vision																														
Underwood and Sikdag (2011)	"Emerging technologies and BIM" Research based on literature and technology review	"...an integrated environment of distributed information which is always up to date and open for derivation of new information..."	<ul style="list-style-type: none"> Timeliness of information Integration Evolvability of building information model 																														
Rezgui et al. (2011)	"synthesis of related ICT industry needs" "preliminary roadmap for the wide industry diffusion of the proposed approach" Research based on literature and corroborated by industry experience	"semantic service-based e-construction" "e-processes" "knowledge-rich ontologies"	<ul style="list-style-type: none"> Semantic richness Integration of... <ul style="list-style-type: none"> Internal assets Inter-organisational processes (Static integration) → (Dynamic integration) 																														
Rezgui and Zarki (2006)	"a synthesis of the construction industry needs and requirements in relation to the adoption and use of information and communication technologies" Research based on European initiative on ICT in construction and wide industry consultation	"... Sustainable construction is driven by total life cycle performance through knowledge intensive and functional integration of products and processes using a model-based approach to pave the way toward a knowledge driven industry."	<table border="0"> <tr> <td>Invasive Technology</td> <td>→</td> <td>Human Centred</td> </tr> <tr> <td>File based exchange</td> <td>→</td> <td>Flexible interoperability</td> </tr> <tr> <td>Cost-driven Activities</td> <td>→</td> <td>Performance driven process</td> </tr> <tr> <td>Document driven support for teamwork</td> <td>→</td> <td>Collaborative virtual teams</td> </tr> <tr> <td>Configurable and customized ICT systems</td> <td>→</td> <td>Adaptive systems</td> </tr> <tr> <td>Application Centric ICT</td> <td>→</td> <td>Total Life Cycle</td> </tr> <tr> <td>Re-invented knowledge</td> <td>→</td> <td>Knowledge re-use</td> </tr> <tr> <td>Network Accessibility to Information</td> <td>→</td> <td>Ambient access</td> </tr> <tr> <td>Document-centric information exchange</td> <td>→</td> <td>Model-based ICT</td> </tr> <tr> <td>Traditional contractual practice</td> <td>→</td> <td>Legal and contractual governance</td> </tr> </table>	Invasive Technology	→	Human Centred	File based exchange	→	Flexible interoperability	Cost-driven Activities	→	Performance driven process	Document driven support for teamwork	→	Collaborative virtual teams	Configurable and customized ICT systems	→	Adaptive systems	Application Centric ICT	→	Total Life Cycle	Re-invented knowledge	→	Knowledge re-use	Network Accessibility to Information	→	Ambient access	Document-centric information exchange	→	Model-based ICT	Traditional contractual practice	→	Legal and contractual governance
Invasive Technology	→	Human Centred																															
File based exchange	→	Flexible interoperability																															
Cost-driven Activities	→	Performance driven process																															
Document driven support for teamwork	→	Collaborative virtual teams																															
Configurable and customized ICT systems	→	Adaptive systems																															
Application Centric ICT	→	Total Life Cycle																															
Re-invented knowledge	→	Knowledge re-use																															
Network Accessibility to Information	→	Ambient access																															
Document-centric information exchange	→	Model-based ICT																															
Traditional contractual practice	→	Legal and contractual governance																															
American Institute of Architects (2007)	Integrated Project Delivery "a tool to assist owners, designers and builders to move toward integrated models and improved design, construction and operations processes"	"Open and interoperable data exchanges based on disciplined and transparent data structures...Because open standards best enable communications among all participants, technology that is compliant with open standards is used whenever available"	<ul style="list-style-type: none"> Interoperability Transparency Open Standards Dimensions of Modelling (time, cost etc.) 																														
Hannus (2007)	Capital Projects Technology Roadmap Vision devised by FIATECH, a consortium of organisations	"Highly automated...integrated across all phase... information is available on demand, wherever and whenever it is needed to all interested stakeholders. Such an integrated environment could enable all project partners and project functions to interconnect— instantly and securely—all operations and systems... Scenario-based planning"	<ul style="list-style-type: none"> Automation Integration Interoperability Availability of Information 																														
British Standards Institute (2011)	BIM Roadmap for the UK AEC/FM industry	"Fully open process and data integration enabled by IFC / IFD. Managed by a collaborative model server...potentially employing concurrent engineering processes."	<ul style="list-style-type: none"> Level of detail (of Building Information Model) Interoperability Standards Guides Classifications 																														

Vision

Q: How does / can Asite help in reaching this vision?

...does Asite have its own vision for the AEC/FM industry?

...does it agree with the above visions?

Q: How does Asite provide interoperability?

1. Technical (data) interoperability

“Planning of technical issues involved in linking computer systems and services.”

2. Semantic interoperability

“Precise meaning of exchanged information which is preserved and understood by all parties”

3. Business (organisational) interoperability

“Coordinated processes in which different organisations achieve a previously agreed and mutually beneficial goal.”

Q: Do you agree that providing interoperability at all levels is central to the service of an Online Collaboration Platform?

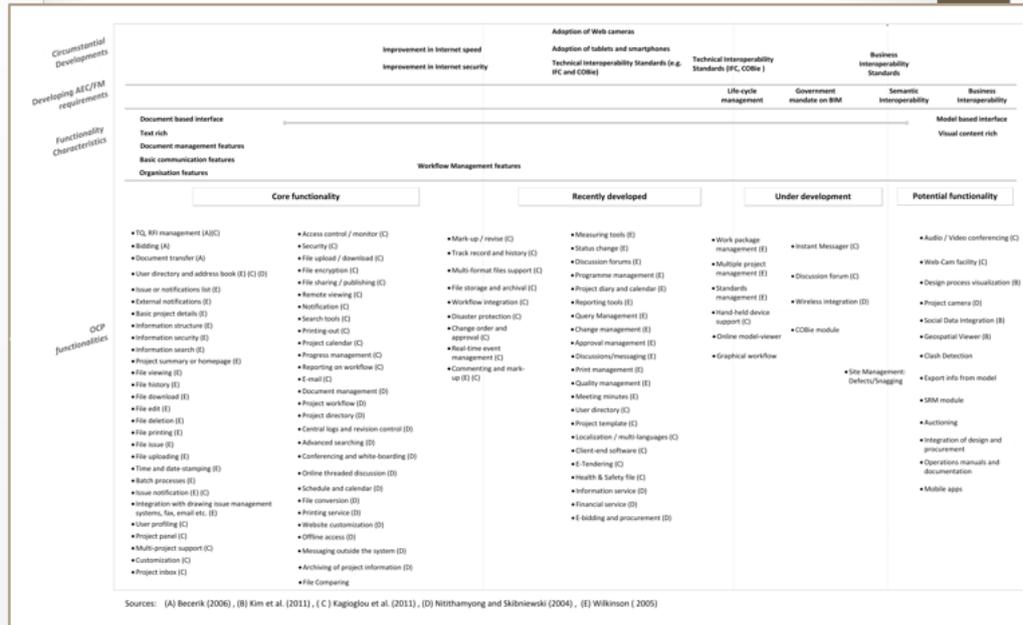
....Does interoperability provide a good metric?

Q: How does Asite make use of interoperability standards?

e.g.
Host them...

Comply with them....

Fill in the map



Q: Should Asite become a Knowledge Management tool?

“systems to capture and distribute information to all relevant persons and parties while maintaining a master database for use and archiving”

“Knowledge management (KM) comprises a range of strategies and practices used in an organization to identify, create, represent, distribute, and enable adoption of insights and experiences. Such insights and experiences comprise knowledge, either embodied in individuals or embedded in organizations as processes or practices.”

Knowledge...

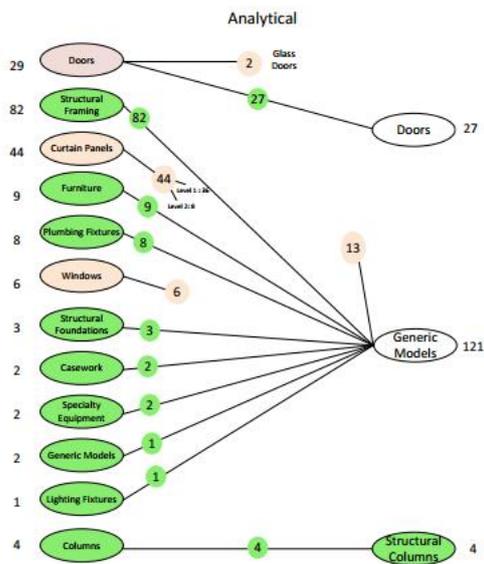
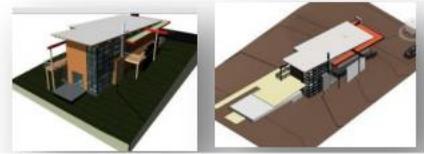
... is information that is contextual, relevant, and actionable. It indicates recognition of the intellectual property rights that any organization owns. Knowledge is tied to the experiences, many years of work, **completion of several projects**, and it mainly resides in peoples' minds. For knowledge to be used for organizational success, it should be recognized as a form of capital, and must be exchanged between people and organizations. Managing knowledge assets can be a **challenge**, especially in the AEC industry where **short-term working contracts and temporary coalitions of individuals can inhibit knowledge sharing**.

Q: What are the barriers to cBIM adoption today?

Any other comments?

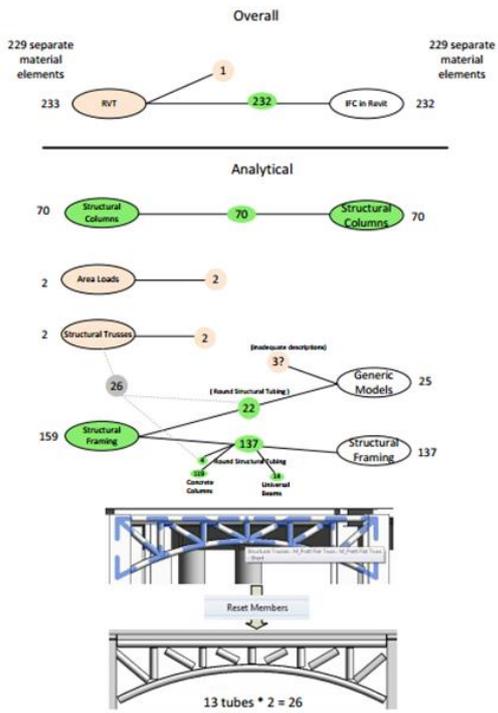
9.3 Appendix C: Data fidelity: .rvt to IFC conversion mapping graphs for Perspective 3

1. "Basic Architectural Sample" model

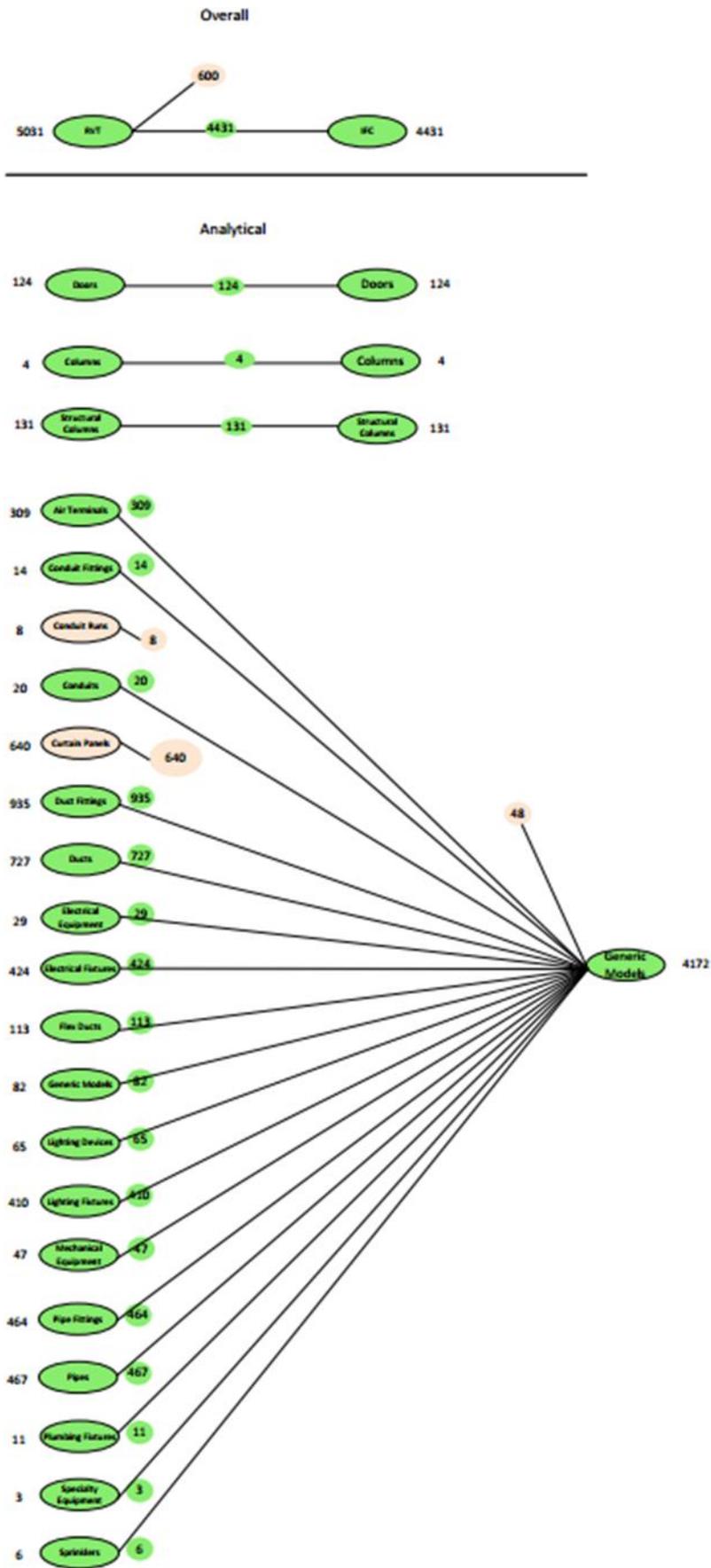


2. "Basic Structural Sample" model

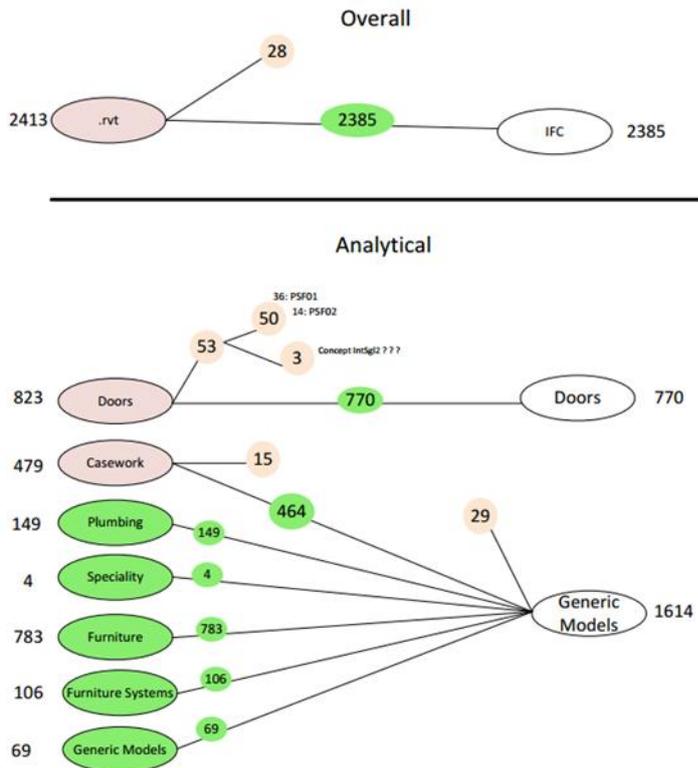
- In the .rvt schedule the trusses exist both as Sets of Elements ("Structural Trusses") and as separate elements ("Round Structural Tubing"). In the IFC schedule the trusses only exist as the separate constituent elements.
- Area Loads (not elements but physical loading) are not maintained.



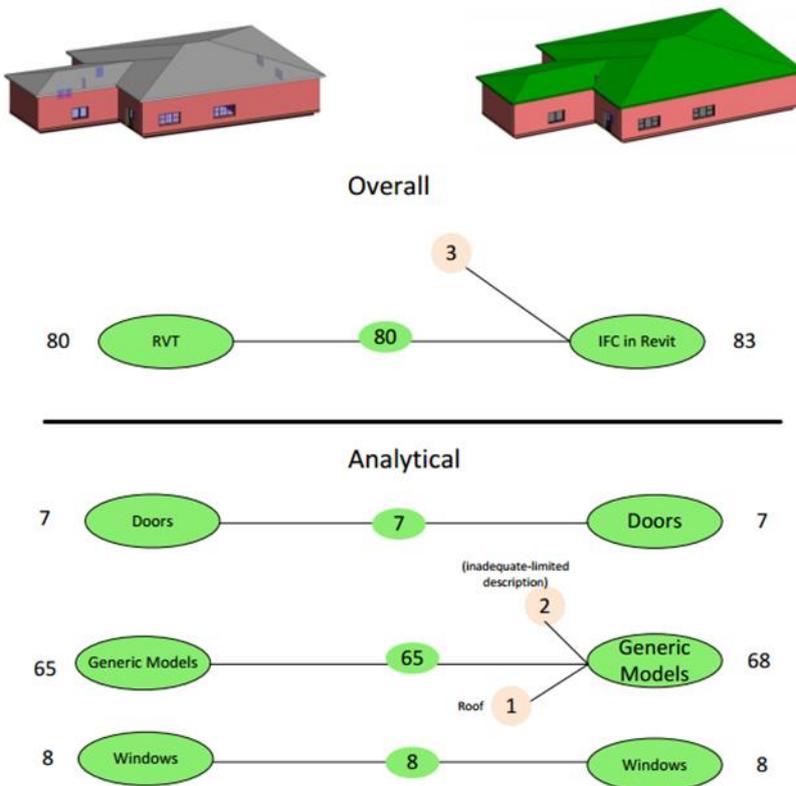
3. "Basic MEP Sample" model



4. High-rise model from real project



5. Asite supplier model



9.4 Appendix D: Semantic technology-based functionalities and their evaluation (Perspective 5)

Functionality	Positive Impact	Technical Metric	Potential adverse effects/ inconsistencies	BIM Uses supported Heuristics Followed			
(1) Semantic search with search recommendations e.g. role-based e.g. project phase-based	Elimination of information overload from irrelevant retrieved resources.	Precision (bigger fraction of relevant resources amongst retrieved resources)	<ul style="list-style-type: none"> • Info overload (from recommendations) • Overreliance 	<ul style="list-style-type: none"> ○ Tracking ○ Coordinating ○ Validating 			
	Benefit of additional relevant resources	Recall (bigger fraction of relevant retrieved resources amongst all available resources).			<ul style="list-style-type: none"> ○ Intuitive environment ○ Integration of content ○ Easy access to info ○ Visibility ○ KM Intra-project 		
<i>Demand</i>	<i>Value</i>	<i>Disruption</i>				-2	2
(2) Recommended or automatic associations of content e.g. based on tag meta-data e.g. based on ontology meta-data e.g. based on content	User's time in associating content	User seconds	<ul style="list-style-type: none"> • Info overload (from recommendations) 	<ul style="list-style-type: none"> ○ Coordinating ○ Tracking ○ Validating ○ Integration of content ○ Intuitive environment ○ Visibility/transparency ○ KM Intra-project 			
	Benefit from association of otherwise non-associated content	(In design) design decision accuracy (in finding content) user seconds			<ul style="list-style-type: none"> ○ Validating ○ KM Inter-project ○ Visibility/transparency 		
<i>Demand</i>	<i>Value</i>	<i>Disruption</i>				1	-3
(3) Notification of relevant content in other project workspace	User's time in associating content	User seconds	<ul style="list-style-type: none"> • Info overload (from recommendations) • Data privacy issues 	<ul style="list-style-type: none"> ○ Validating ○ KM Inter-project ○ Visibility/transparency 			
	Benefit from association of otherwise non-associated content	(In design) design decision accuracy. (in finding content) user seconds					
<i>Demand</i>	<i>Value</i>	<i>Disruption</i>			7	7	1
(4) User/role-based recommendation for recently uploaded documents	User's time in finding the content (if user seeks for it)	User seconds	<ul style="list-style-type: none"> • Disrupts protocols for content distribution (existing automated processes) 	<ul style="list-style-type: none"> ○ Qualifying ○ Tracking ○ Role-based configurability ○ Intuitive environment ○ Easy access to relevant info. 			
	Benefit from using otherwise "missed" content	Various, not specified					
<i>Demand</i>	<i>Value</i>	<i>Disruption</i>			6	5	2
(5) Recommend individual in project team based on model/document content or meta-data	User's time in finding individual	User seconds	<ul style="list-style-type: none"> • Disrupts protocols for content distribution (existing automated processes) 	<ul style="list-style-type: none"> ○ Validating ○ Coordinating ○ Role-based configurability ○ KM Intra-project 			
	Benefit from engaging individual (if otherwise not engaged)	Various, not specified					
<i>Demand</i>	<i>Value</i>	<i>Disruption</i>			-2	6	3
(6) Recommend standard, guideline or regulation based on model/document content or meta-data	User's time in looking for standard	User seconds	<ul style="list-style-type: none"> • Over-reliance 	<ul style="list-style-type: none"> ○ Validating ○ Easy access to relevant info. 			
	Benefit from finding relevant standard (if otherwise not engaged)	Various, not specified					
<i>Demand</i>	<i>Value</i>	<i>Disruption</i>			-2	1	5
(7) Recommend listed supplier for object within model	User's time in looking for supplier	User seconds	<ul style="list-style-type: none"> • Most contractors have preferred suppliers 	<ul style="list-style-type: none"> ○ Prescribing ○ Integration of features ○ Role-based configurability 			
	Benefit from finding relevant supplier (if otherwise not found)	Various, not specified					
<i>Demand</i>	<i>Value</i>	<i>Disruption</i>			5	4	6

* Columns/fields for future work: "Economic Metric", "Technical Feasibility" and "Supporting Ontologies"

9.5 Appendix E: Presentation used in semi-structured interviews for Perspective 5

Search recommendations

The screenshot shows a search interface for the term "door". At the top left, there is a search input field containing the text "door" and a magnifying glass icon. To the right of the search bar is the ASITE logo, which consists of a red square with a white arrow pointing right, followed by the text "ASITE" and "Get to It" below it. Below the search bar, the results are displayed in two columns. The left column is titled "Results" and contains a list of items: "Door 1", "Door 2", and three ellipses "...". The right column contains five recommendation boxes, each with a red border and italicized text: "My last viewed 'doors'", "'Door' suppliers", "Relevant users", "'Door' IFC objects", and "Recently uploaded 'doors'". To the right of the recommendation boxes is a small cartoon character of a rabbit-like creature with a white body, red ears, and a red bow tie, holding a red object in its right hand.

door

ASITE
Get to It

Results

- Door 1
- Door 2
- ...
- ...
- ...

My last viewed "doors"

"Door" suppliers

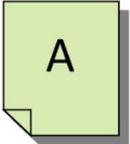
Relevant users

"Door" IFC objects

Recently uploaded "doors"

Recommended or automatic association

User has just uploaded document A



"A" has similar **tags** with "B"

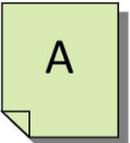
Associate documents/models?





ASITE

User has just uploaded document A



"A" has similar **content** with "B"

Associate documents/models?

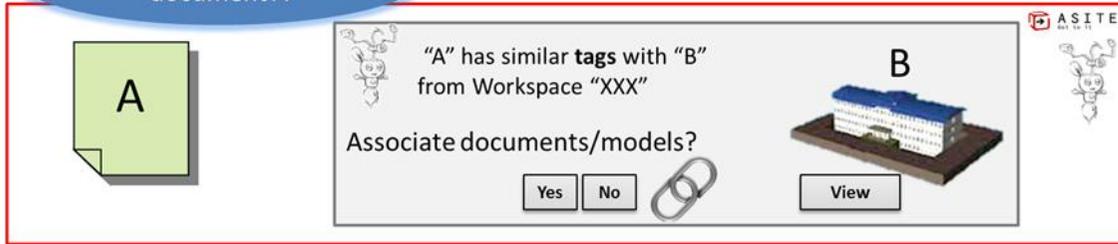




ASITE

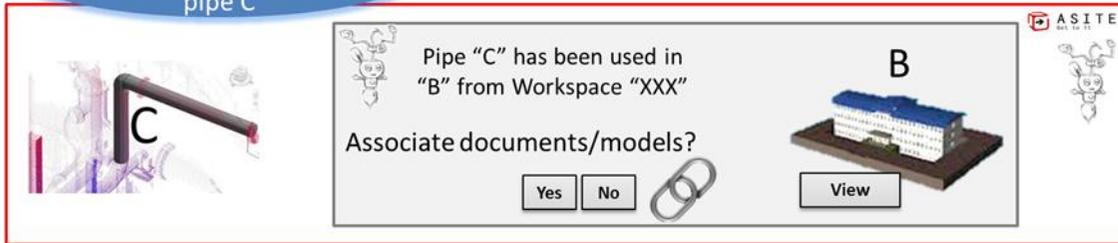
Notification of relevant content in other workspace

User has just uploaded document A



A notification box with a red border. On the left is a green document icon labeled 'A'. The main text reads: "A" has similar tags with "B" from Workspace "XXX". Below this is the question "Associate documents/models?" followed by "Yes" and "No" buttons, a paperclip icon, and a "View" button. On the right is a 3D model icon labeled 'B'. The ASITE logo is in the top right corner.

User has just uploaded a model containing pipe C



A notification box with a red border. On the left is a 3D model icon labeled 'C' showing a pipe. The main text reads: Pipe "C" has been used in "B" from Workspace "XXX". Below this is the question "Associate documents/models?" followed by "Yes" and "No" buttons, a paperclip icon, and a "View" button. On the right is a 3D model icon labeled 'B'. The ASITE logo is in the top right corner.

User/role-based recommendation for recently uploaded documents

User Jenny Architect has just logged into Asite

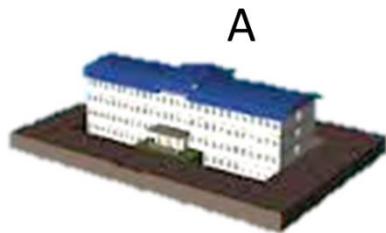
Based on your profile information, the following recently published or modified documents may be of interest.

- 
 - Publisher: Alan Architect
 - Published: Yesterday
 - ...[View](#)
- 
 - Publisher: Alan Architect
 - Published: Yesterday
 - ...[View](#)
- 
 - Publisher: Alan Architect
 - Modified: Yesterday
 - ...[View](#)



Recommend individual in project team based on model/document content or meta-data

User Alan Architect has uploaded model A



Based on building information, Jenny Architect has worked on similar projects.



- Role: ...
- Projects: ...
- Last logged in: ...

View Profile

Send message

Assign Action



Recommend standard, guideline or regulation based on model/document content or meta-data

User Alan Architect has uploaded model A



ASITE



A



Based on building information, the following regulation/guideline might be of interest.



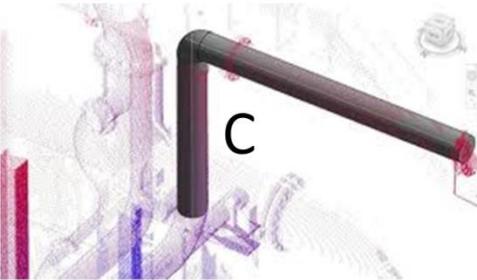
- Used in projects:
 - XXX
 - YYY
- Used by:
 - Jenny Architect

View

View relevant users

Recommend listed supplier for object within model

User has opened model containing pipe C



Supplier D can supply the type of pipe C.



- Price: £80
- Used in projects:
 - XXX
 - YYY

Order

View supplier

9.6 Appendix F: Feedback sheet used in semi-structured interviews for Perspective 5

		<i>Level of demand from users</i>	<i>Perceived value</i>	<i>Perceived disruption/inconsistency</i>	<i>Comment</i>
		<i>Rank</i>			
1	Search recommendations				
2	Recommended or automatic association				
3	Notification of relevant content in other workspace				
4	User/role-based recommendation for recently uploaded documents				
5	Recommend individual in project team based on model/document content or meta-data				
6	Recommend individual in project team based on model/document content or meta-data				
7	Recommend listed supplier for object within model				

9.7 Appendix G: Review of WIMBIM-relevant resources

A review and outlook for a Building Information Model: Multi-standpoint framework for technological development- Bilal Succar 2009

Kinds of Waste addressed

"The developments should focus on support for all teamwork stages. Collaborative environments for BIM should enable collaborative modelling and the use of models to provide a complete answer, not only to "Who did what and when?" but also to "Why was it done?" (intent) and how the information was used"

Semantic Exchange Modules - Eastman and Venugopal, 2013

Context

Explains purpose, process, nature, challenges and limitations of Model View Definitions. (Authors have experience from IDM development and US NBIMS)"

Comments

Very much in-line with proposed study.

--- Rich in demonstrating Waste Classes interaction.

--- ...However: Does not closely address the instruction/management information part of the interaction.

-- "" Two sets of semantics are at the core of any successful Imodel exchange. One of which is the user or application functional semantics defining the information that must be exchanged and the other being the representational semantics available in IFC or other data modeling schema representing the user intentions""

Types of interaction/transmission

A Use-case defines the information exchanges between any two actors in a project aimed at achieving a specific goal, within a specified phase at a project's lifecycle. These information exchanges are defined as Model Exchanges. ...for effective Model Exchanges we need to define Model Views... virtual, specialised and structured subsets of data, compiled dynamically from databases. --- The content of the information exchanges for each Use Case are termed Exchange Requirements.

Kinds of Waste addressed

“At the other end of the spectrum, an exchange file can be structured to represent piece-type aggregations or hierarchies that define design intent, procurement groupings, production methods and phasing, and other pertinent information about the building and its parts”

Purpose of Interactions/Transmissions

Illustrates with 4 examples of exchange purposes: clash detection, fabrication, sequencing, aggregation
schema which satisfies the requirements for a particular model exchange in the industry

--- A model view is a subset of the entire (IFC)

Containers

Subset of IFC model as defined by Exchange Requirements

Genres of Communication Interfaces in BIM-enabled Architectural Practice- Abdelmohsen 2013**Context**

Ethnographic study in design (concept to construction drawings) phase. ... Explored within the realm of distributed cognition.
analysis was used as a basis for analytic induction

--- Grounded theory coding and

Comments

Very much in-line with proposed study.

--- Emphasis on non-design information (goals, needs, motivations and intentions)

--- Key observation " a lot of representations and communication channels external to the model are still required upon interaction to achieve effective communication among teams"

Relevant Terminology

distributed cognition, internal representations, external representations, external representational artifacts, interaction, communication, socio-cognitive glue, cognitive burden

Types of Interactions/Transmissions

Two main **modes of interaction**:

- 1) interaction related to exchanging data among AEC design teams by means of a shared BIM model, and
- 2) socio-cognitive interaction related to exchanging views and arguments among and across teams by means of a shared design problem "

5 Genres of Communication Interface

- (1) Multiple BIM-authoring tools
- (2) Sketching and BIM-authoring tool
- (3) BIM authoring tool and analysis tool
- (4) CAD modelling tool and analysis tool
- (5) Multiple analysis tools

Kinds of Waste addressed

- (1) "From the study, it was found that as the teams started using the BIM tools to exchange information about the project, peripheral communication external to the BIM model was needed"
- (2) "The dullness and rigidity of the BIM model representation resulted in an insufficient and incomplete expression of design ideas and intent while exchanging the BIM models among the teams and individuals. The accumulated process of switching and translation from one representation to the other often results in an output that is apparently richer in content but that may not necessarily reflect the full capacity of the design thinking process"
- (3) "incompatibility among different modelling and analysis tools ... requiring that participants input data from scratch in their domain-specific analysis tools"

rather than dealing with unreliable data" " designers do not fully understand the needs of analysts or other participants. This may lead to missing data or an inaccurate representation of data in the BIM-authoring tool."

(4) " Issues of inaccuracy and misrepresentation of 3D geometry are at stake in this type of indirect communication, which often requires the designer or analyst to input data manually in each of the modelling or analysis tools

(5) "tool incompatibility and interface limitations between both analysis tools could lead the MEP engineer to develop a more accurate model based on domain-specific assumptions and calculations rather than relying on presumably flawed or misrepresented geometrical data from the architect"

Conclusion: " proposing more intuitive interfaces, translators and automated data exchange mechanisms, and integrating these representations and communication channels within BIM-enabled practice would provide more effective communication, enable social interaction among and across teams, and reduce the cognitive burden upon design teams"

Purpose of interaction

high level 1: information exchange

high level 2: social interaction, knowledge construction, negotiation

(Genre 1) not specified, (Genre 2) conceptualization, communication/visualization, (Genre 3) analysis, simulation, (Genre 4) not specified, (Genre 5) not specified

Containers

"Representations":

(1) BIM Platform

(2) BIM authoring tool and Freehand sketches

(3) BIM authoring tools and domain-specific analysis tools

(4) CAD modelling tools and analysis tools

(5) domain-specific analysis tools

9.8 Appendix H: Relevance of WIMBIM to other work

Source	Relevance	Relevant elements/ What does WIMBIM add?
<p>Cerovsek (2011)</p> <p>A review and outlook for a “Building Information Model” (BIM): A multi-standpoint framework for technological development.</p> <p>Advanced Engineering Informatics</p>	<p>Theoretical basis for proposed study:</p> <ul style="list-style-type: none"> • Acknowledges continuous evolution of tools and processes and proposes evolutionary ontology • Proposes model-based communication • Explores standards • Proposes more focus on semiotics of communication • Based on Communication Theory <ul style="list-style-type: none"> • Builds model (“BIM-cube framework”) of multi-dimensional, multi-layered nature of BIM. <ul style="list-style-type: none"> • Provides an appropriate definition on a “BIM Schema” (a very central concept in the study) <p>“Communicative intent” is one of the standpoints.</p> <p><u>5.3. Recommendations for BIM model sharing:</u></p> <ul style="list-style-type: none"> • Available • Accessible • Searchable 	<p>WIMBIM adds:</p> <ul style="list-style-type: none"> • Focus on making waste observable • Focus on interactions • Links communicative intent to BIM model • Incorporates non BIM model data in message (like Abdelmohsen(2013) and IDM-2 suggest) <p>A tool/basis for suggesting how to configure BIM collaboration tools in order to eliminate interaction waste.</p>

	<p>Teamwork features</p> <p>View-based collaboration</p> <p>BIM context and reference carriers</p> <p>BIM transformation carrier</p>	
<p>Huovila, Pekka, Lauri Koskela, and Mika Lautanala. " Fast or concurrent: the art of getting construction improved." Lean construction (1997): 143-159.</p>	<ul style="list-style-type: none"> • Proposes three ways of modelling construction <ul style="list-style-type: none"> ○ Conversion ○ Flow ○ Value generation 	<p>Relevant elements</p> <ul style="list-style-type: none"> • Domain • Interaction/transmission flow • → Interaction/transmission Waste
<p>Huovila</p> <p>Which are the Wastes of Construction?</p>	<p>Identifies the peculiarities of construction which would define its lead wastes.</p> <p style="padding-left: 40px;">The 7 wastes of production are not applicable to AEC</p> <p>Explains why wastes in the design stage should be accounted</p> <p>Making-do , Failure to speak and failure to listen</p> <p>Chains of Waste</p> <p style="padding-left: 40px;">Core waste and Lead waste</p> <p>Types of task interdependencies</p> <p style="padding-left: 40px;">Pooled</p> <p style="padding-left: 40px;">Sequential</p>	<p>Relevant elements</p> <p>Waste type: Latency</p> <p>Interaction lenses:</p> <p style="padding-left: 40px;">Complexity</p> <p>(interdependence between tasks means that increasing examination of complexity reveals more of project effectiveness over interaction/transmission efficiency)</p>

	<p>Reciprocal</p> <p>Waste is in relation to the flow perspective. Value loss is in relation to the value perspective.</p>	
<p>Koskela et. al (2012)</p> <p>A brief history of the concept of waste in construction</p>	<p>Philosophical-level analysis.</p>	<p>General</p>
<p>Bertelsen et. al(2006)</p> <p>Critical Flow – Towards a Construction Flow theory (2006)</p> <p>Bertelsen et. al(2007)</p> <p>Construction Physics (2007)</p>	<p>Types of Flow in Interactions/transmissions</p> <ol style="list-style-type: none"> 1. Physical flows: plant, materials 2. Psychological flows –[not included in model] 3. Human creations: works information, design, production system <p>Critical Flow: the flows that cause significant delay and hence decides the speed.</p> <p>Construction Physics: Non-transformational stages: Waiting, Moving, Inspection</p> <p>7 flows Koskela (2000)</p> <ul style="list-style-type: none"> • Information • Materials 	<p>Relevant elements</p> <p>Domain: Flows</p> <p>Interaction/transmission representations</p> <ul style="list-style-type: none"> • River Model • True Process Model

	<ul style="list-style-type: none"> • Crew • Equipment • Previous work • Following work • External Conditions 	
Abdelmohsen (2013) “Genres of Communication Interfaces in BIM-enabled Architectural Practice”	<ul style="list-style-type: none"> • Defines 5 Genres of Communication interface 	<ul style="list-style-type: none"> • Interaction/transmission types • Single medium interaction/transmissions • Multiple medium interaction/transmissions
Eastman and Venugopal, 2013 Semantic Exchange Modules	A good example of eliminating waste in BIM model exchanges <ul style="list-style-type: none"> • Implicitly identifies a number of Waste Types • Develops solutions for eliminating them • Presents spectrum of semantic richness 	Relevant elements <ul style="list-style-type: none"> • Waste types WIMBIM adds WIMBIM is in-line with IDM and MVDs/SEMs in that it does not rigidly divide phases and disciplines and their corresponding tools but supports a more flexible and phase-independent way of facilitating BIM-based communication.
ISO 29481-2 (2012) Information Delivery Manual – Part 2: Interaction Framework	“sets out a methodology and format for describing coordination acts between actors in a construction project... enable standardization of interaction”	Relevant elements <ul style="list-style-type: none"> • Interactions/transmissions • Interaction/transmission purposes

BIM Collaboration Format, Building Smart	Defines elements of Flow through its schema	
Kreider and Messner, Penn State (2012) The Uses of BIM	Analogous to proposed study in that it defines a set of concepts. Explains the methodology for creating such an ontology	Relevant elements <ul style="list-style-type: none"> • (can be used to define Domain?) • Interaction/transmission purposes • (→) Waste types WIMBIM adds <ul style="list-style-type: none"> • Can the “BIM Use purposes” be used as a language to define the domain of User-Container-User interactions? Do these interactions only immediately concern “Communicate” purposes (Visualize, Draw, Transform, and Document). What interaction concepts do the “BIM User purposes” not capture?
Sacks, R. et al. (2010) Interaction of Lean and Building Information Modeling in Construction Journal of Construction Engineering and Management	Relates BIM functionalities to Lean principles → helps in clarifying waste elimination properties and identifying waste Types.	Relevant elements <ul style="list-style-type: none"> • Waste types • Translation between Waste Types

<p>Becerik & Pollalis (2006) Computer aided collaboration in managing construction Harvard Design School</p>	<p>Offers a methodology for classifying and quantifying benefits of collaboration platforms</p>	<p>Relevant elements</p> <ul style="list-style-type: none"> • Feeds into Waste Types and translation between them
<p>Shafiq, Matthews, Lockley (2012, 2013) Requirements for model server-enabled collaborating on building information models and A study of BIM collaboration requirements and available features in existing model collaboration systems. International Journal of 3-D Information Modelling (IJ3DIM) and Journal of IT in Construction</p>	<p>Various</p>	<p>Relevant elements</p> <ul style="list-style-type: none"> • Waste type: UI-related waste
<p>McMahon et. al (2009) Knowledge Information Management through life (KIM project)</p>	<p>Sets out principles for engineering project information management which can be associated to Waste Types and Containers and their Attributes.</p>	<p>Relevant elements</p> <ul style="list-style-type: none"> • Waste types • Containers <ul style="list-style-type: none"> ○ Attributes:

		<ul style="list-style-type: none"> ▪ Spectra of fitness ▪
<p>Rezgui, Y. et al. (2011)</p> <p>Past, present and future of information and knowledge sharing in the construction industry: Towards semantic service-based e-construction?</p> <p>Computer-Aided Design</p>	<ul style="list-style-type: none"> • Describes vision and roadmap • Contrasts between data model and ontology paradigms. • Compares between States. Data-centric application integration vs. ontology-based business process support 	<p>Relevant elements</p> <p>Container types</p> <p>Attributes</p>
<p>Timo Hartmann (2012)</p> <p>A semiotic analysis of BIM Systems</p>	<ul style="list-style-type: none"> • Explores Semiotics explicitly • Relates Semiotics to BIM. BIM systems “as carrier of meaning”. • Relates to UI and explores UI issues. 	<p>Relevant elements</p> <ul style="list-style-type: none"> • Interaction Media • Waste type (waste in carrying meaning)
<p>Succar (2009)</p> <p>Building information modelling framework: A research and delivery foundation for industry stakeholders.</p> <p>Automation in Construction</p>	<p>Analogous to proposed study:</p> <ul style="list-style-type: none"> • Constructs a BIM Framework and expresses it as an Ontology by defining and relating concepts (filters, lenses, maturity stages, steps) <p>Succar explores the whole BIM adoption and maturity domain.</p>	<ul style="list-style-type: none"> • (methodology) • Interaction lenses • Efficiency states • Interactions/transmissions (2.2.1 BIM data flows: only accounts for flow of BIM data and other documents)

<p>NIST(2004)</p> <p>Cost of Inadequate Interoperability in the US Capital Facilities Industry</p>	<p>Offers a methodology for classifying and quantifying cost of interoperability</p>	<ul style="list-style-type: none"> • Efficiency States (counterfactual scenario) • Translating between States
<p>B/555 BIM Roadmap (BS, 2011)</p>	<p>Defines BIM Maturity Levels and corresponding standards</p>	<ul style="list-style-type: none"> • Efficiency states
<p>Underwood & Isikdag (2011)</p> <p>Emerging technologies for BIM 2.0.</p> <p>Construction Innovation: Information, Process, Management</p>	<p>Describes vision and how emerging technologies can facilitate it.</p>	<ul style="list-style-type: none"> • Efficiency states
<p>Chinowsky & Taylor (2012)</p> <p>Networks in engineering: an emerging approach to project organization studies</p> <p>The Engineering Project Organization Journal</p>	<ul style="list-style-type: none"> • Examines the applications of SNA within engineering project organization. <p>(communication efficiency → collaboration → expanded scope of application and methodologies)</p>	<ul style="list-style-type: none"> • Interaction/transmission representations: <ul style="list-style-type: none"> ○ Network Representation

<p>Whyte, Reading (2013)</p> <p>Digital interaction patterns</p>	<p>Studies interaction patterns through organisational network analysis.</p>	<ul style="list-style-type: none"> • Interaction representations <ul style="list-style-type: none"> ○ User-Container-User Network Graph
<p>Tamer E. El-Diraby (2013)</p> <p>Domain Ontology for Construction Knowledge</p> <p>JOURNAL OF CONSTRUCTION ENGINEERING AND MANAGEMENT, ASCE</p>	<ul style="list-style-type: none"> • Can help evaluate the methodology • Can help in identifying gaps in ontologies in AEC • Explains what an ontology is. Explains at philosophical level. • Creates an iteration for an ontology for construction knowledge (DOCK 1.0) • Explains previous work on ontologies in AEC. 	<ul style="list-style-type: none"> • (methodology)
<p>Tamer E. El-Diraby (2012)</p> <p>Epistemology of construction informatics</p> <p>JOURNAL OF CONSTRUCTION ENGINEERING AND MANAGEMENT, ASCE</p>	<ul style="list-style-type: none"> • Can inform the methodology of proposed study <p>Epistemology is “the means by which one knows or creates assumptions about knowledge” ... “meant to act as the guidelines for the development of informatics systems and, more importantly, the ontologies they use”</p> <ul style="list-style-type: none"> • Calls for constructivism (bottom up) at micro level and contemporary pragmatism at macro level. 	<ul style="list-style-type: none"> • General methodology • Waste type: folksonomy-related waste

	<ul style="list-style-type: none">• Calls for the use of folksonomies	
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9.9 Appendix I: Slides used in semi-structured interviews for model evaluation

Model for Waste in BIM Process Interactions

- Evaluation Interview

Researcher:

George Charalambous

Supervisors:

Prof. Tony Thorpe
Dr. Peter Demian
Dr. Steven Yeomans



Outline of Interview (1 hour)

- (A) Intro to Research (5min)
- (B) Basis for Model (5min)
- (C) Presentation of Model (20min)
- (D) Recommendations based on Model (5min)
- (F) Q&A (10min)
- (E) Questionnaire (15min)

(A) Intro to Research

- Motivation
 - Rapid adoption of BIM in the UK.
 - Rising demand for BIM collaboration solutions.
- Setting
 - Industry-based: Asite (online collaboration vendor).
- Aim
 - Support long-term development of BIM collaboration tools and collaborative practice.

(A) Intro to Research

- Nature of field of application
 - Complex, diverse, dynamic → Uncertainty

→ Nature of main output

- Model for long-term development which is universally applicable.

...Collaboration tools can be evaluated against BS 1192 but without all aspects being addressed...

- **Questions:**

What characteristics should this model have?

Which concepts (e.g. phases, actors, LODs, revisions) should it focus on?

(B) Basis for Model

- Persistent lack of a common understanding on BIM.
 - Need to understand BIM from **first principles** and from what **benefits** it can bring.
- Continuously evolving technology, standards, codes of practice.
 - Need for **robustness** in guidelines.
- Variability in software configuration across projects.
- Diversity of requirements from collaboration tools across project actors. Not everyone's requirements are met.
 - Need for **universality of concepts** (hence **flexibility**) within guidelines.
- Standards primarily address **coordination**, not **communication**.
- We are not talking enough about the **communication waste** within BIM model-based interactions.

(B) Basis for Model

- Purpose of Model
 - Improve understanding on BIM communication waste.
 - Provide a common reference through universal concepts.
 - Provide robust (persistent through time) concepts.
 - Provide a basis for meaningful metrics for assessing collaboration tools.

(C) Model

- Characteristics and focus of proposed model
 - Based on the definition of a single BIM process **transmission** and constructed from the **bottom-up**.
 - Focused on **communication waste**.

(C) Model: Fundamental Assumptions

- **Flow**

- The AEC-FM process consists of interdependent flows (material, crew, information etc.)
 - The BIM process is a sub-process of the AEC-FM process and interacts with the other sub-processes
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- **Basics of communication waste**

- Data, information, knowledge, ideas and instructions are rarely adequately communicated.
- Communication waste is subsequently translated into other forms of waste.

- **Communication and Coordination**

- BIM communication depends on coordinated information and coordinated responsibilities.
- Tools for coordination exist in the form of:
Model Production and Delivery Tables, Information Delivery Manuals, MVDs, Access Rights Matrices, CDE, Governance Models etc.

Model for waste in BIM process interactions – Evaluation Questionnaire

Evaluation of the need for such a model

	Strongly Disagree	Disagree	Neither agree nor disagree	Agree	Strongly Agree
A better understanding of BIM communication waste is key for the development of standards.					
A better understanding of BIM communication waste is key for the development of collaboration tools.					
A better understanding of BIM communication waste is key for harmonised BIM adoption.					
Current standards and codes of practice address BIM coordination more than BIM communication.					
A better understanding of BIM from the "transmission level" is key for the development of standards.					
A better understanding of BIM from the "transmission level" is key for the development of collaboration tools.					
A better understanding of BIM from the "transmission level" key for harmonised BIM adoption.					
BIM processes should primarily be informed by communication theory.					
Our "fixation" on the capabilities of existing software is hindering our understanding of potential waste elimination in future BIM states.					

9.10 Appendix J: Model Evaluation Questionnaire

Evaluation of validity of the proposed model

	Strongly Disagree	Disagree	Neither agree nor disagree	Agree	Strongly Agree
The "BIM flows" proposed are representative of BIM flows in practice.					
Flows to be added?					
Flows to be removed?					
The model is constructed in a logical way.					
Where are the inconsistencies?					
The concepts in the model are apparent universally within practice.					
The concepts in the model will persist through time.					
New functionality types eliminate primarily different waste types.					
Higher BIM maturity levels eliminate primarily different waste types.					

Evaluation of the utility of the proposed model

	Strongly Disagree	Disagree	Neither agree nor disagree	Agree	Strongly Agree
The proposed model can complement the BIM maturity model.					
How?					
Why not?					
"BIM flows" is a useful concept.					
"BIM flows" are a good basis for evaluating collaboration tools.					
"Coordination tool" is a useful concept.					
"BIM Communication waste types" is a useful concept.					
"Efficiency states" is a useful concept.					
"Critical transmission chains" is a useful concept.					
The proposed model can help in BIM collaboration tool development.					
The proposed model can help in BIM standards development.					
The proposed model can help in strategic BIM Execution Plans.					
The proposed model can help in project-level BIM plans.					
The proposed model can help define what a good BIM process transmission is.					

Evaluation of the usability of the proposed model

The format of the proposed model makes it usable.		Strongly Disagree					
How?							
Why not?							

State of practice

Which of the presented types of waste currently leads to the biggest effective waste?
What is usually the bottleneck or blockage for critical flow?
What concepts need to be standardized next in the AEC-FM industry?

Improving this model

How could this model be improved?

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