BUILDING INFORMATION MODELLING LEVEL OF DEVELOPMENT IMPLEMENTATION FRAMEWORK:

A Critical Approach for BIM Managers

By

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ABSTRACT

Building Information Modelling (BIM) Level of Development (LOD) data specification is a major concern for the implementation of BIM management processes. In the UK, Level 2 BIM and Level 3 BIM industry maturity measures are drivers to BIM implementation. Product Data Templates (PDT) is a method used to specify BIM element data for Level 2 BIM processes. However, this method is not optimal for LOD specification. In order to advance towards Level 3 BIM LOD data standardisation, the study of data creation using Business Process Modelling Notation (BPMN) such as the Information Delivery Manual (IDM) was studied. It is hypothesised whether the IDM can create the right environment to specify LOD data across the wider Architectural, Engineering and Construction (AEC) industry and to advance in Level 3 BIM processes. The informational perspective of the IDM is investigated in this thesis using a novel method to test and validate the creation of BIM Model attributes by linking Exchange Requirements (ERs) to a LOD standard. However, the LOD can be specified differently in different countries making its definition within the IDM complex. Therefore, the IDM intrinsic perspectives were studied under a novel Framework for LOD Implementation created using Grounded Theory. This enabled the study of the behavioural IDM perspective on a small group of BIM professionals. The findings suggest that a LOD specified as per project stage is detrimental for project time, cost and quality performance. Although, the generalisation of study is limited to “made to stock” for electrical BIM use and “engineered to order” products for clash detection BIM use, this LOD Framework could help improve understanding of data specification using the LOD standard for any AEC project.

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In the loving memory of my father,



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Abbreviations

AGC- General Contractors of America

AEC- Architecture, Engineering, Construction

AIA- American Institute of Architects

APM- Association of Project Managers

BEMA- British Electrotechnical and Mechanical Authority

BEP- BIM Execution Plan

BIM- Building information Modelling

BIMM- Building Information Modelling and Management

BIM4M2- BIM for Manufacturers and Manufacturing

BPMN- Business Process Modelling Notation

BSI- British Standard Institution

BSRIA- Buildings Services Research and Information Association

CDE- Common Data Environment

CIBSE- Chartered Institute of Building Services

CIC- Construction Industry Council

CPIC- Construction Project Information Committee

COBie- Operations Building Information Exchange

ER- Exchange Requirement

EIR- Employer´s Information requirements [1]

GCS- Government Construction Strategy

GRIPs - Governance Railway Investment Projects

GSL- Government Soft Landings

ICU- Intention to Continue to Use

IDM- Information Delivery Manual

IFC- Industry Foundation Classes

IFD- International Framework of Dictionaries

IPR- Intellectual property rights

IS- Information System

LOD- Level of Definition /Level of Detail

MPDT- Model Production and Delivery Table

MPS- Model Progression Specification

MVD- Model View Definition

M3- Minimum Modelling Matrix

NBS- National Building Specification

1. Referred to as “Exchange Information Requirements” within the BS EN ISO 19650-1:2018

NIBS- National Institute of Building Sciences

PDT- Product Data Template

PEU- Perceived Ease of Use

PM- Process Map

PU- Perceived Usefulness

TAM: Technology Acceptance Model

RIBA- Royal Institute of British Architects

Sparkie- Electrical System information exchange

UK- United Kingdom

USACE- US Army Corps of Engineers

XML- Extensible Markup Language

Glossary of terms

Autodesk Revit is a building design software built for BIM that includes features for architectural design, MEP and structural engineering and construction

BIM FORUM is a working group created for accelerating the adoption of BIM in the AEC industry.

BIM Task Group supports and helps implementing the Government strategy to adopt Level 2 BIM by 2016.

BuildingSmart helps to implement BIM in the UK AEC industry by developing standards, tools and training.

BSRIA is a research, consultancy and test organisation that provides services for the AEC industry and publishes best practice guides.

LinkedIn is a professional network that has millions of members with professional profiles that can be easily searched by location or professional role.

VicoSoftware a company specialised in integrated construction processes.

CHAPTER 1: INTRODUCTION

1 Introduction

This chapter introduces the background of the research undertaken and describes the need for the research, aim and objectives, structure of the thesis and related publications.

1.1 BIM Implementation Importance

In the year 2016, the European construction sector output accounted to £1.1 trillion is approximately 9% of the region's GDP (EUBIM, 2017). In the United States, the figure was £467.5 billion, which accounted for the 3% of the region GDP (Trading Economics, 2019). A more domestic figure, for the United Kingdom (UK) BIM market, showed that Level 2 BIM Government procured projects accounted from the years 2012 to 2015 for a sum of £9 billion (Cabinet Office, 2011).

According to the EUBIM Task Group (2017), there is an opportunity to save 10% to 20% of capital project expenditure by using BIM processes in construction and infrastructure projects, which using the lower threshold accounts for £130 billion.

Although surveys do not show which percentage can be attributed to the implementation of BIM processes for achieving collaborative working and coordination, which is part of Level 2 and Level 3 BIM objectives, a survey conducted by the EUBIMTG

in 2016 across all active BIM programmes in European countries stated that a total of 10 % savings on time delivery could be achieved using BIM, which for public procured projects is equivalent to better value for public money (EUBIM, 2017).

An important aspect of BIM management is the definition of both geometric and non-geometric data along the project life stages. The LOD standard is the basis for LOD specification in a construction project. Unfortunately for its analysis, this concept is named differently depending on its origin and meaning: Level of Development, Level of Detail and other definitions are being further pushed by over 26 countries around the world over the last years (See Section 2.3).

In order to manage the LOD information in a project, several methods are implemented depending on the country. For example, in the UK this is defined within the PAS 1192. BIM managers in the UK has been using the CIC BIM protocol Model Product and Delivery Table (See Section 2.2.2). In relation to BIM management, 10% saving has been reported during the delivery phase for European public state owners.

Despite of the recognised benefits, still in the year 2018 there are still barriers to its implementation. According to the UK NBS-National BIM Report 2018, the non-adoption of BIM in an organisation is associated with several factors such as the lack of in-house expertise, no client demand, lack of training, cost, time, relevance to project among other factors. For instance, in relation with LOD implementation, 42% of the companies that adopted BIM lack of standardised tools and protocols (NBS, 2018).

Therefore, the relevance of exploring novel methods for the specification of LOD data within projects is interesting from the BIM implementation perspective.

1.2 BIM Implementation Scope

Building Information Modelling (BIM) is a descriptive term for the digital, spatial, parametric, integrated, interoperable and collaborative process used to drive design, construction and operation of the built environment (Eastman et al., 2011). However, it is potentially much more than this.

BIM is essentially value creating collaboration through the entire life-cycle of an asset (building), underpinned by the creation, collation and exchange of shared 3D models and intelligent, structured data attached to them (BIM Task Group, 2014).

In the UK there are several drives to BIM implementation. For example, the Government strategy for 2016, which aims to reach Level 2 BIM maturity on all public funded projects by 2016 (Cabinet Office, 2011). This driver in practice works as a top (Government) bottom (Industry) approach to adopt BIM in order to provide value for public money. To clarify, Level 2 BIM requires the coexistence of different discipline models in a single environment and coordination of managed 3D information models by all members of the team (Cabinet Office, 2011), (See Section 2.2.1, 2.2.2 and 2.2.3).

Another driver is the Digital Built Britain Strategy, which will help to transition from Level 2 BIM to Level 3 BIM by 2025 (HM Government, 2015). Level 3 BIM requires enhanced software interoperability. For example, the use of Industry Foundation Class (IFC) standards managed by a collaborative server (HM Government, 2015), (See Section 2.2.4).

BIM is often seen as just 3D modelling. However, can also be regarded as Building Information Modelling and Management (BIMM) as the presented drivers require a shift

in culture that affects the way the built environment and infrastructure works are designed and how these are delivered. Thus, expanding the BIM term to BIMM (BIM Task Group, 2014). Consequently, facilitating a more integrated design and construction process that reduces project duration and enhances buildings quality at lower costs (Cabinet Office, 2011).

The scope initially defined by a thorough review of the Literature (Chapter 2) was refined by carrying out workshops with the industry sponsor for Manufacturer Made to Stock Products at Technical Design stage to cover aspects of the IDM (Information Delivery Manual) Informational Perspective (Section 3.2.1 and Section 3.2.2) for the Electrical Design BIM Use. The research progressed to finally cover project Behavioural implementation aspects of design BIM Model data Specification in the context of the LOD (Level of Development) (Level 2) and IDM (Level 3) standards (Section 3.2.3 and Section 3.2.4) for Engineered to Order Products at Concept and Developed Design stages for the Coordination – Clash Detection BIM Use (See Figure 1-1).

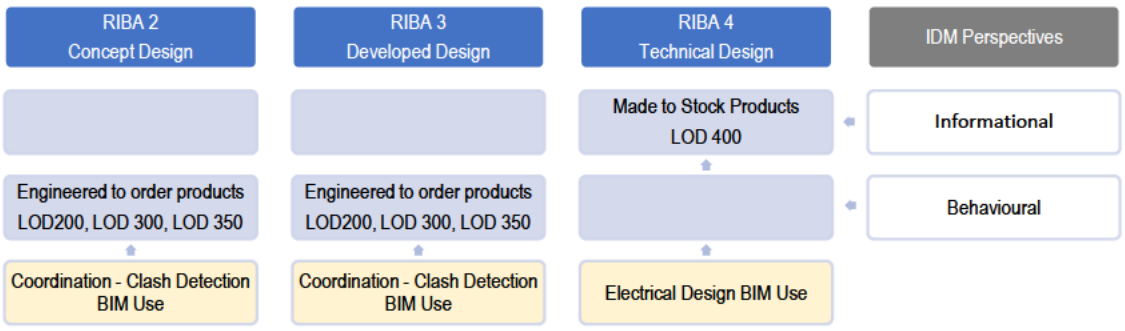


Figure 1-1: Research Scope

1.3 Problem Statement

The PDT elaboration process shown in Table 2-21, claims to be a methodology to provide accurate product data for its inclusion within IS Level 2 BIM context.

However, the construction industry relies on collaboration standards such as the LOD to specify BIM Model elements data along the different phases of a project (See Section 2.3) and this is not part of the PDT elaboration process.

The PDT knowledge collection process scenario requires collection of data from manufacturer paper product specifications and industry guidelines. The attributes found within these guidelines (see Table 1-1 for an example) are not enough to accurately define a BIM object LOD as the context of its use in practise is not included.

Table 1-1: VA attributes manual compared against CIBSE PDT

Physical Properties of BIM Objects & Elements	
Electrical Equipment attributes (VA CFM, 2010).	
100	Overall Length, Overall Width, Overall Height, Overall Area, Overall Volume
200	Length, Width, Height, Area, Volume, Maximum Size
300	Nominal Size, Connections, Capacity, Perimeter, Angle, Plane, Cross Section
Cable Tray lengths attributes (Legrand Electric Ltd., 2016)	
	Gauge, Width, Weight, Finish, Maximum load

*This Table has been published in publication number 4 of Section 1.7.

For example, the VA BIM Object Element Matrix Manual release v1.0 from the example, provides LOD attributes for general products such as electrical equipment. However, specific products such as cable trays also in Table 1-1 (found within manufacturer's product specifications), would require specific attributes (gauge, finish, or maximum load), which might differ from the attributes given within these guidelines.

It can be stated that these guidelines do not provide the data context (processes), therefore, complicating the manufacturer's task of LOD specification.

It has been found that the IDM process (see Table 2-22), which aligns with the Level 3 concept of software interoperability of data (See Section 2.2.4) provides a framework for the creation of BIM Model Element data to be included within the manufacturers and downstream and upstream agents IS. For example, these agents are designers, construction and facilities management contractors.

As it can be seen by comparing both processes, the PDT and IDM process differ on their approach to data implementation (collection and creation of data, respectively). However, both share the problem of not being able to capture the LOD standard concept within their processes.

1.4 Previous work

Method to Specify BIM Model data

While LOD BIM uses has been studied within the literature, for example from the perspective of "Cost" (Wood et al., 2014), "4D BIM" (Han et al., 2015) or "Sustainability" (Maria-Angeliki et al., 2014, Wu and Issa, 2015). However, there is no mentionable study in relation to the attributes that BIM models should contain to serve BIM processes.

Marzia Bolpagni (2016), provides a comprehensive review of LOD standards up to the year 2016 (Bolpagni, 2016). It must be noted that this information is communicated in a Blog and verification is required before trusting the source. However, it is a good starting point for any researcher to start a thorough review of the LOD standards. For example, some LOD attributes are found within the "LOD 2015 Element attributes table"

(BIM Forum, 2016b) and similar guidelines Table 2-5 and Table 2-15. However, a methodology used to deduct these attributes Table 1-1 has not been defined within these guidelines. This gap has been addressed within this thesis (See Objective 2).

Berard and Karlshoej (2012) state that the IDM Business Process Modelling Notation (BPMN) has been created with the aim to overcome problems associated with the functional, behavioural, informational, and organisational BPMN perspective (Section 2.3.1). From an informational perspective, research has shown that the IDM BPMN could be used to specify detailed data resulting in more effective interoperable data exchanges (Eastman et al., 2010). Berard and Karlshoej (2012), reviewed the bidding process for a design-built project from the functional perspective and found the IDM suitable for companies to develop business rules and attributes to be implemented within BIM objects. Furthermore, Recker (2010b) found flaws within the behavioural and organisational perspective (See Section 2.4). However, these are claimed to be solved within the IDM by the BuildingSMART guide for IDM development (Wix and Karlshøj, 2010). Despite these improvements, Lee et al.'s, (2016) study suggests that the IDM still lacks some specific criteria for defining Exchange Requirements (informational perspective under the present study).

Therefore, a criterion based on the LOD standard could help to overcome the inconsistencies in the development of the IDM Exchange Requirements. Current research on LOD has approached it from an applied research perspective; documenting functionality extensions to the core principles of the specification. For example, Wood et al. (2014) recommended using the LOD as a benchmark based on cost curves. Model progression validation using the LOD concept has also been studied (Hooper, 2015). Other

researchers have also examined the benefits of low and high detailed LODs in design and construction (Luth et al., 2014, Fai and Rafeiro, 2014, Xu et al., 2019, Tolmer et al., 2017, Cassano and Trani, 2017). Following a different line of research, a method for automatically extracting the geometric parametric values of multi-LOD BIM models has been studied based on a high-fidelity point-cloud data (Liu et al., 2019). However, none of the above studies on LOD are addressing the problems that arise from using models in context (informational and behavioural perspective (see section 1.2).

Maria-Angeliki et al.´s study (2014) is the only study that proposes using a business modelling language within the Informational perspective. This is the Integration Definition (IDEF) process modelling language used to identify critical decision actions and LOD exchanges for building performance analysis processes. Nevertheless, despite previous efforts, the study of LOD integration within the IDM BPMN that might help to raise clarity over the mentioned perspectives has not yet been studied. Therefore, the present thesis aim to study the IDM informational and behavioural perspectives of the LOD standard as defined within Section 1.2 (Figure 1-1).

Considering the previous points, within this thesis, it is hypothesised that:

1. The IDM BPMN can facilitate the right scenario to create Level 2 BIM LOD product data to be implemented within Information Systems (Objective1 and 2).
2. This process could be extended to the wider construction industry to advance in Level 3 BIM processes (Objective 3 and 4).

The novel Grounded Theory LOD Framework (Figure 4-5) led to the development of a sub-hypothesis to answer the second hypothesis:

A BIM element LOD specified as per the end of a project stage is detrimental for value engineering exercises and is considered a waste of time, cost and human resources in comparison with a more flexible approach where the LOD might be specified as per project milestones inside the project stage.

1.5 Aim and objectives

The aim of this research is to raise clarity on the data requirements in BIM models to fulfil the UK Government objectives of Level 2 BIM and Level 3 BIM maturity.

The following objectives and outputs were required to ensure that the aim of this research was fulfilled:

Objective 1 (Level 2 and Level 3 LOD Factors review): To understand the current Level 2 and Level 3 BIM implementation trends within the UK manufacturing industry through a systematic review of existing literature and collection of industry data.

Objective 2 (BIM data Method creation): To develop a method to create LOD non-graphical information for incorporation within BIM models by carrying out a practical case study into a company context. The outputs were used in Objective 4 to validate the proposed LOD framework from Objective 3.

Objective 3 (Theoretical LOD Framework creation): To identify the theoretical constructs around the LOD concept and constitute the creation of a Grounded Theory Framework for LOD implementation for Level 2 and Level 3 BIM purposes.

Objective 4 (Validation of the Theoretical LOD Framework): To validate the proposed LOD framework from Objective 3 using the outputs of Objective 2.

1.6 Novelty and Contributions

The research novelty and contributions are summarised below:

- The main research contribution and novelty to the knowledge is the identification of the link between the BPMN informational perspective and the LOD to create fit to purpose data to be included within BIM models (Conference paper 1 and journal papers 2 and 3).
- The main research novelty is the creation of a framework for LOD implementation within BIM projects. The framework identifies which are the individual theoretical constructs that define the LOD concept. The framework defines Net benefits for pairwise relationships between the theoretical constructs. The relationships can be weakened or strengthened based on future research additions (Journal paper 4 and journal paper to be submitted 5).

1.7 Publications

Some of the work presented in this thesis is published in three scientific journals and in one conference proceedings. One remaining unpublished journal will be submitted to Automation in Construction. The manuscripts below included in this thesis can be found in Appendix D (publication 2) and Appendix E (publication 4). When any manuscript information is included within the body of this thesis it will be appropriately referenced at the beginning of the section.

Conference papers

1 GIGANTE-BARRERA, A. & RUIKAR, D. 2016. *BIM maturity implementation for Electrical Manufacturers within the UK: Model Element LOD Creation Using the Information Delivery Manual Standard*. In: YABUKI, N. & MAKANAE, K. (eds.) Proceedings of the 16th International Conference on Computing in Civil and Building Engineering. Osaka, Japan: ICCCBE2016 Organizing Committee. ISBN 978-4-9907371-2-2.

Journal papers

2 GIGANTE-BARRERA, A., RUIKAR, D., CRUNDEN, M. & RUIKAR, K. 2017. *LOD object content specification for manufacturers within the UK using the IDM standard*. Journal of Information Technology in Construction, ITcon Vol. 22, pg. 80-103, http://www.itcon.org/2017/5.

3 GIGANTE-BARRERA, A., DINDAR, S., KAEWUNRUEN, S. & RUIKAR, D. 2017. LOD BIM Element specification for Railway Turnout Systems Risk Mitigation using the Information Delivery Manual. IOP Conference Series: Materials Science and Engineering, 245, 042022. doi:10.1088/1757-899x/245/4/042022.

4 GIGANTE-BARRERA, A., RUIKAR, D., SHARIFI, S. & RUIKAR, K. A Grounded Theory based Framework for Level of Development Implementation within the Information Delivery Manual. International Journal of 3-D Information Modeling (IJ3DIM), 7(1), 30-48. doi:10.4018/IJ3DIM.2018010103.

Journal paper (to be submitted)

5 GIGANTE-BARRERA, A., RUIKAR, D., SHARIFI, S. & RUIKAR, K. Explaining LOD constructs usage: Comparing two LOD standards as per clash detection use. (Automation in Construction).

Book chapter contribution (Review stage)

1 GIGANTE-BARRERA, A., RUIKAR, D., SHARIFI, S. & RUIKAR, K. A Grounded Theory based Framework for Level of Development Implementation within the Information Delivery Manual. International Journal of 3-D Information Modeling (IJ3DIM), Driving Transformational Change in the Built Environment (IGI Global).

1.8 Thesis structure

The thesis has been divided into five chapters which are described below:

CHAPTER 1 (INTRODUCTION) explains the research background and scope. It also presents the need for the research and describes the aim and objectives of the present study identifying publications.

CHAPTER 2 (REVIEW OF RELATED LITERATURE) discusses the key features that characterises a BIM model as per Level 2 BIM and Level 3 BIM requirements and identifies the LOD theoretical constructs needed to create a LOD framework. It also contains a review of research design, strategy and methods.

CHAPTER 3 (RESEARCH METHODOLOGY) establishes and justifies the research methods applied for achieving Objectives 1 to 4. It contains the applied research strategy and methods.

CHAPTER 4 (RESEARCH RESULTS) provides the results of the applied methodologies through which the research was carried out.

CHAPTER 5 (CONCLUSIONS) discusses the impact of the proposed LOD framework for its application within research. The conclusions are presented along a critical evaluation of the research limitations and recommendations for future research

CHAPTER 2: REVIEW OF RELATED LITERATURE

2 Literature review

2.1 Introduction

This chapter presents the current state of Level 2 BIM and Level 3 BIM informational processes and standards in the UK and explores the LOD management aspects in a wider international scope. A brief introduction to BIM models is made, then aligned with the UK Level 2 and Level 3 BIM standards and protocols. Then the LOD standard phenomena implementation is analysed internationally. To finally revise methods for the accomplishment of the research objectives.

2.1.1 Knowledge in BIM objects

From a computer science point of view, BIM objects are used in object-oriented programs, which contains data and instructions to execute tasks and the programming code required to handle the messages received by the object. These objects might contain graphical and non-graphical information such as specification, material, vendors, price or other data embedded that depends on its associated use (Ibrahim and Krawczyk, 2003). BIM objects can be studied from the following perspectives:

Parametric behaviour. This is defined as the mechanisms to automate generation of building information that can be expressed as geometry or domain expertise, also

known as domain knowledge. Rules or constraints are needed to embed this parametric domain knowledge. This enables domain-specific objects to display intelligent behaviour related to their application domain (Lee et al., 2006).

Data Interoperability: Interoperability is another characteristic of BIM objects. A desired state of interoperability can be defined as the exchange of information between multiple parties that use different software vendors without loss of information, thus enabling collaboration (Grilo and Jardim-Goncalves, 2010, Steel et al., 2012).

Data interoperability entails *"mapping parts of each participating application's internal data structure to a universal data model and vice versa"* (Grilo and Jardim-Goncalves, 2010, p. 525). For example, the BuildingSMART Model View Definition (MVD) data structure depicts data exchange requirements that are useful for software validation (See et al., 2012).

One of its aspects is semantic interoperability, which consist on the ability to make BIM object data exchangeable regardless of the language used, data sources and participants that do not share the same concept about a design (Yang and Zhang, 2006).

Another interoperability feature is the parametric behaviour of a BIM object. Within this case, parametric behaviour can be transcribed into an interoperable format where design intensions must be maintained after model exchange (Ji et al., 2011).

Data contractual support: Data should be reliable enough to be able to support BIM contracted data exchanges (See et al., 2012). These data exchanges are understood as part of BIM processes. These can be given contractual support by establishing organisational and contractual structures:

For example, in the UK, Level 2 Building Information Models are defined by the Building Information Model (BIM) Protocol. Within that document, the Model Production and Delivery Table (MPDT) allocates both the responsibility of designing the models and the "Level of Definition" (LOD) (CIC, 2013b).

Another example of BIM contractual support is the pre-tender document Employer Information Requirements (EIR) which is important to answer the deliverables and processes adopted along with the required data exchanges or "Data Drops" required by the employer at an agreed project stage (BIM Task Group, 2013).

Furthermore, as BIM objects attributes can support life-cycle processes (McAdam, 2010), data requirements can be contractual. In the special case of the UK, the format required by the government for data submissions is the COBie MVDXML. These data submissions or "Data Drops" are required as key milestones along the project to check the availability of the data in terms of design intent, carbon and cost (Cabinet Office, 2011).

The data contractual support of BIM objects is further developed within the current chapter.

2.2 UK Level 2 and Level 3 BIM

2.2.1 UK Level 2 BIM standards

The application of Level 2 BIM has been defined in the UK by the standards, documents and guides as shown in Figure 2-1. The information presented in this figure has been compiled from different sources (BSI, 2013, BSI, 2014a, BSI, 2014b, Cabinet Office, 2012, CIC, 2013b, BSI, 2015b, NBS, 2015, CIBSE, 2015b). The Dr Anne Kemp

presented the different documents in a BIM seminar hold the 22nd of July 2014, at the "University of Birmingham" hosted by the "ICE West Midlands (WM) Graduates and Students (G&S) Committee" (Kemp, 2014). This document compilation has been updated within this research with documents such as the "PAS 1192-3:2014", the "BS 1192-4:201", the "PAS 1192-5", the "Government Soft Landings" and the "National Classification System".

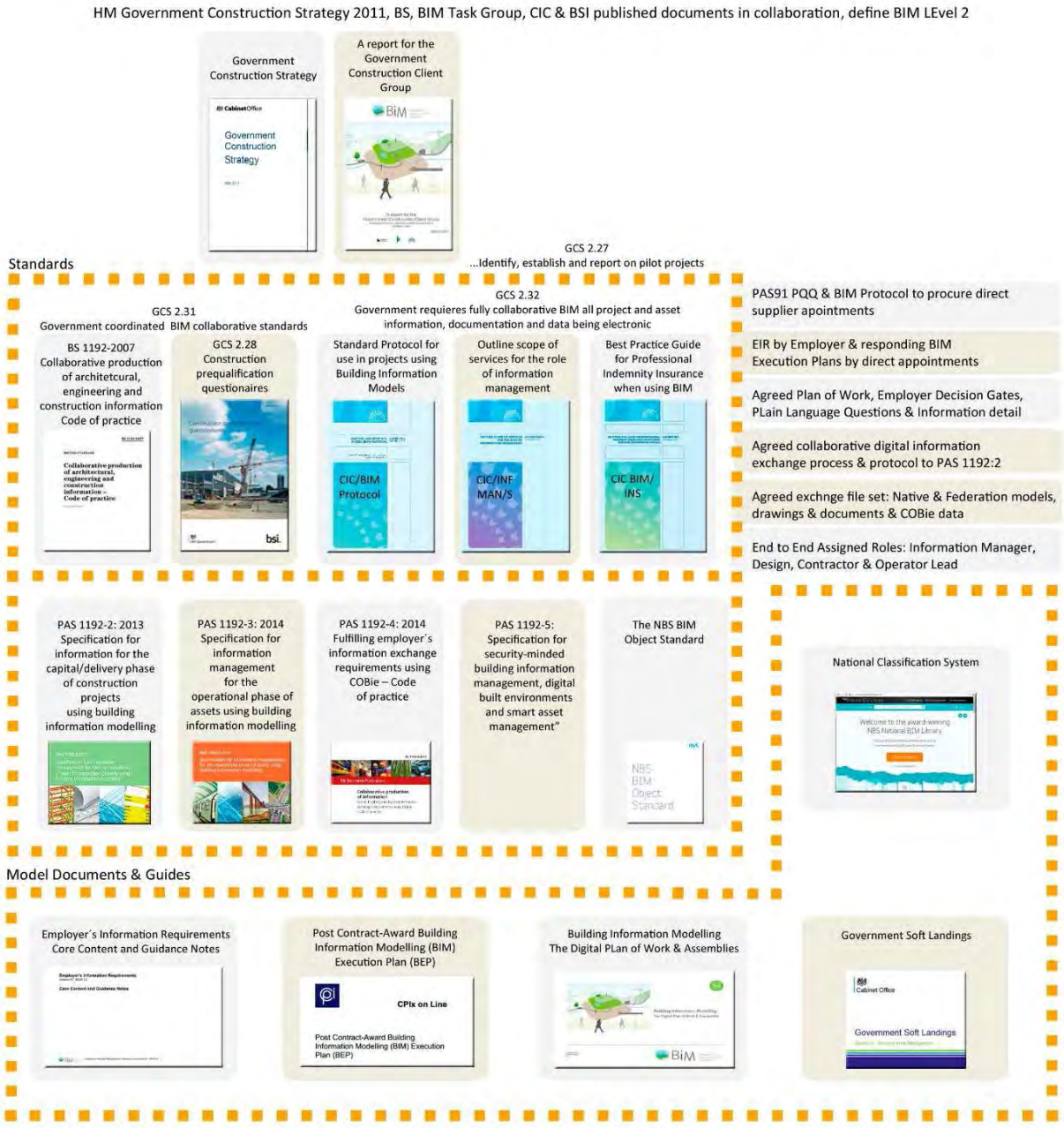


Figure 2-1: Level 2 BIM documents. Adapted and from (Kemp, 2014)

Whilst in Figure 2-1 documents were of importance to define Level 2 BIM up to 2014 within the UK; the following table shows the updates up to 2020.

Table 2-1: Level 2 BIM documents

TITLE 1	TITLE 2	SUPERSEDED BY
BS 8536-1:2015	Briefing for design and construction. Code of practice for facilities management (Buildings infrastructure) (BSI, 2015a)	
BS 8536-2:2016	Briefing for design and construction. Code of practice for asset management (Linear and geographical infrastructure) (BSI, 2016)	
BS 1192:2007 + A2:2016	Collaborative production of architectural, engineering and construction information. Code of practice (BSI, 2007).	BS EN ISO 19650
PAS 1192-2:2013	Specification for information management for the capital/delivery phase of construction projects using building information modelling (BSI, 2013).	BS EN ISO 19650
PAS 1192-3:2014	Specification for information management for the operational phase of assets using building information modelling (BIM) (BSI, 2014b).	
BS 1192-4:2014	Collaborative production of information. Fulfilling employer's information exchange	

TITLE 1	TITLE 2	SUPERSEDED BY
	requirements using COBie. Code of practice (BSI, 2014a).	
PAS 1192-5:2015	Specification for security-minded building information modelling, digital built environments and smart asset management (BSI, 2015b).	
PAS 1192-6:2018	Specification for collaborative sharing and use of structured Health and Safety information using BIM (BSI, 2018)	
BS EN ISO 19650-1:2018	Organization and digitization of information about buildings and civil engineering works, including building information modelling -- Information management using building information modelling: Concepts and principles (ISO, 2018a)	
BS EN ISO 19650-2:2018	Organization and digitization of information about buildings and civil engineering works, including building information modelling -- Information management using building information	

TITLE 1	TITLE 2	SUPERSEDED BY
	modelling: Delivery phase of the assets (ISO, 2018b)	
PD 19650-0:2019	Supplies transitional guidance. National Foreword explaining terminology (ISO, 2019)	
(BIM) PROTOCOL 2013	Building Information Model (BIM) protocol, Standard Protocol for use in projects using Building Information Models (CIC, 2013b)	(BIM) PROTOCOL 2018
(BIM) PROTOCOL 2018	BUILDING INFORMATION MODELLING (BIM) PROTOCOL SECOND EDITION Standard Protocol for use in projects using Building Information Models (CIC, 2018)	
Government Soft Landings	It supports a common framework for collaboration between those who design and construct and asset with those who subsequently operates it (Cabinet Office, 2012).	
National Classification System	It codes the building component parts so that they can be uniquely identified (NBS, 2015).	

TITLE 1	TITLE 2	SUPERSEDED BY
Digital Plan of work	Describes the processes, methodologies and responsibilities of the stakeholders involved in the project (CIBSE, 2015b).	

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2.2.2 UK Level 2 BIM protocol

For the stakeholders to agree on the data shared at different stages of the project in a consistent way, the UK Government through the "Government BIM strategy" supports the contractual arrangements on construction projects working at Level 2 BIM. The "Building Information Model (BIM) Protocol" is the standard formulary intended to be used by the "Project Team Members" (CIC, 2013b).

The BIM Protocol, commissioned by the Construction Industry Council (CIC) as a response to the needs imposed by the UK Government BIM strategy, supports the contractual arrangements on construction projects working at Level 2 BIM. One of the objectives of the Protocol is to enable the production of BIM Models at defined stages of a project. It is intended to be used by the project team members, who are required to have a BIM Protocol appended to their contracts. Remarkably, the Protocol allows the adoption of common standards, working procedures and establishes the Intellectual Property Rights (IPR) required to protect the rights of the Project Team Members. The IPR is compound of the "Information Requirements" (IR) and the MPDT.

The IR defines how a model must be developed. Its content is flexible, and it contains requirements taken from tender documents. In the Protocol, this is defined as

the “Employer´s Information Requirements” (EIR). The EIR might contain aspects such as the “Common Data Environment” (CDE) and the software used in the delivery of the project, the professionals involved in the delivery of the models and files and layer conventions, among others. It might also contain a description of the project procedures, required standards, parties involved in the project and the appointment of an “Information Manager” who is the professional in charge of implementing the “Project Information Plan” and “Asset Information Plan” (CIC, 2013b). The “Information Manager” role is covered in the “Outline scope of services for the role of Information Management” (CIC, 2013c).

The other document included in the BIM Protocol is the MPDT. The MPDT allocates both the responsibility of designing the models and the LOD based on the PAS 1192-2:2013 (CIC, 2013b). The MPDT document aligns the LOD with project stages such as for example the Association of Project Managers (APM) project stages classification. The APM Project Stages provides the better standard to be benchmarked with when working with building and infrastructure project stages such as the Network Rail´s Governance Railway Investment Projects (GRIPs) or the Royal Institute of British Architects (RIBA) Plan of Work (CIC, 2013b).

2.2.3 UK Level of Definition

In the “United Kingdom” (UK), Level 2 “Building Information Models” are defined by the “PAS 1192-2:2013”, document published by the “British Standards Institution” (BSI) (BSI, 2013). This document outlines the “Level of Definition” which is described as two different defining aspects; the “Level of Model Detail”, which defines the graphical

component of models and the "Level of Information Detail", which stands for the non-graphical content of models.

2.2.4 UK Level 3 BIM

The Digital Built Britain Strategy, is a roadmap that considers some steps to reach Level 3 BIM by 2025 (HM Government, 2015). The main driver for Level 3 BIM is software interoperability. This can be accomplished by using the interoperable format standard IFC or the International Framework of Dictionaries (IFD).

The IDM and MVD can define data exchanges for particular tasks, processes and particular uses of BIM (This will be further explained in Section 2.4.2). Further, this can be implemented for IFC validation, thus improving data interoperability between proprietary software. However, interoperability is not completely addressed by implementing IFC, thus a parallel effort should be made to implement collaboration on a global scale. This is separating the schema concepts from the descriptions and names (Shayeganfar et al., 2013). More specifically, the IFD (ISO 12006-3) provides a solution for linking different databases which contain product and project specific data to an IFC model as well as providing multilingual capabilities (BuildingSMART, 2014).

The concept of the IFD is based on the separation of the concept, from a particular language instance (Mahdavi et al., 2008). For example, the term "door" (puerta, porta, etc) will refer to the underlying abstract concept. Within this context, tags and names will be substituted by identification numbers attached to concepts called "Global Unique

Identifier" (GUID), used to reference the abstract concept in all instances (buildingSMART International Ltd, 2007).

Another IFD is closely related to the concept of semantic web. A semantic web system provides a machine readable semantic structure that keeps interdependency of its components (Tjoa et al., 2005). IFD contains different domain specific ontologies (buildingSMART International Ltd, 2007), which are the base for a semantic based system. One of the advantages of integrating web-based technology with domain specific ontologies is that the building model can be integrated with web services (Mahdavi et al., 2008). Some research projects have studied online product libraries based on IFC (Owolabi et al., 2003, Yang and Zhang, 2006), whereas others make use of Semantic Web technology libraries of products using the "Ontology Web Language" (OWL) (Beetz and de Vries, 2009), which is an industry standard used as a base to create enterprise semantic applications (Tjoa et al., 2005). Similarly, the link to IFD is studied by Mahdavi et al., (2008), who presented an IFD library based on semantic technologies to bridge the gap between designers and manufacturers, making the selection of specific product criteria for certain projects possible

2.3 LOD constructs industry review

This section has been partially published in the publication number 4 of Section 1.7.

2.3.1 LOD as a Process oriented standard

The BIM Project execution Planning Guide from the US makes explicit use of IDM process maps, recommending their use as a method to specify project data. Thus, BIM

model non-graphical data can be efficiently exchanged within the BIM workflow (NIBS, 2007). Berard and Karlshoej (2012) suggest that the IDM BPMN language consists of the following perspectives (see Figure 2-2): "process map (behavioural), narratives (organisational), exchange requirements (informational), and narrative business rules (functional)". Aram et al. (2010) and Curtis et al., (1992) provides description of the previous perspectives to study the LOD phenomena into the IDM context (see Table 2-2 and Figure 2-2).

Table 2-2: BPMN perspectives adapted from Curtis et al. (1992).

Perspectives	**Question answered about the process performed**	**Example**
Behavioural	When or How the process is performed	Project stage (design stage) or project activities actions (quantify system loads)
Organisational	Who performs the process	Roles involved within the process such as architect or structural engineer
Informational	Informational output	Attributes exchanged such as height or voltage drop
Functional	What informational entity is relevant for the process	Attributes values such as window width

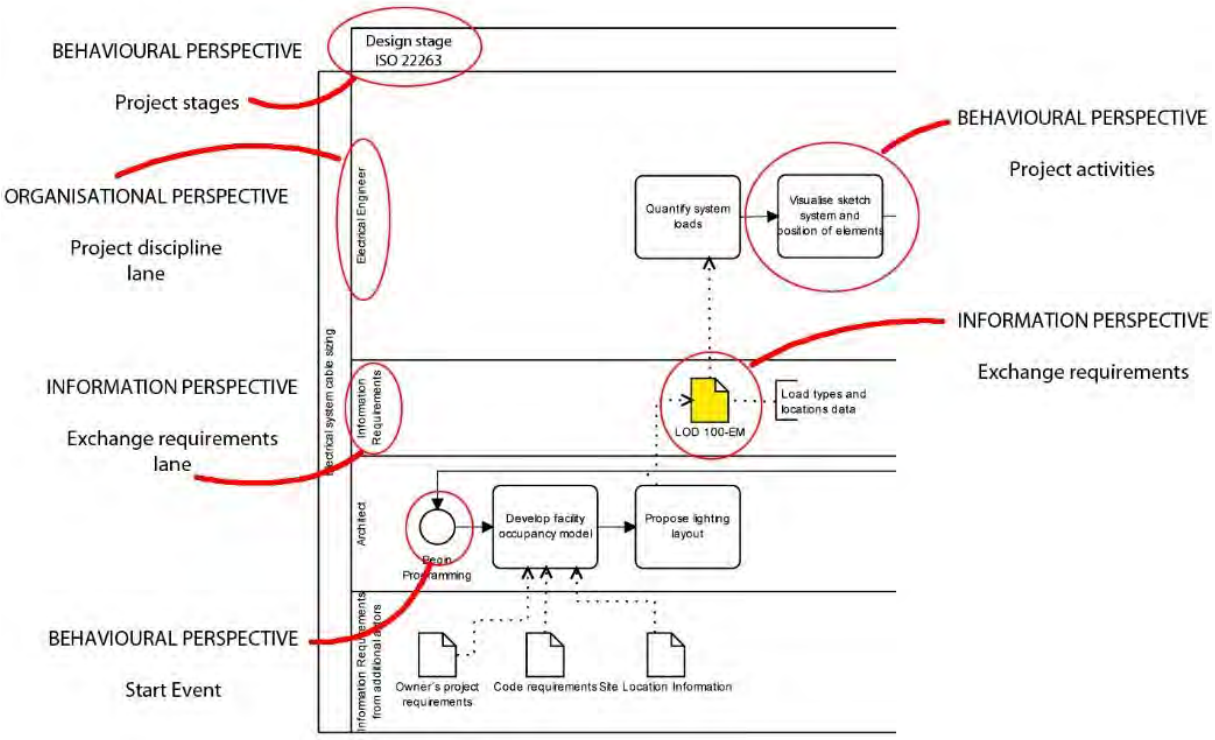


Figure 2-2 : IDM BPMN perspectives adapted from (Aram et al., 2010)

Prescriptive or process-oriented standard could play a role within the LOD specification. Process oriented standards are used to provide a methodology to perform tests and processes in a consistent and repeatable way (Allen and Sriram, 2000). According to this definition, the ISO 29481-1 and ISO 29481- 2 defines the Information Delivery Manual (IDM), which is a process standard that allows to define data exchanges within a context for the creation of subsets of the IFC interoperable format (NIBS, 2007).

These IFC subsets are called MVD and are used by software developers to create interoperable compliant software (Nawari, 2012). For example, Autodesk Revit and related plugins allows the exchange of IFC and (Extensible Markup Language) XML data. In contrast to other ways of specifying data, such as specification guidelines like the BIM Forum Specification or the BIM object Element Matrix, the IDM defines Information

Exchanges within a context. This context is represented within Process Maps (PM). PMs include, author, stage and process for a certain BIM use as seen in Figure 2-3 (NIBS, 2007). Because of this, MVD could be used to organise structured data within a project as part of a contractual agreement.

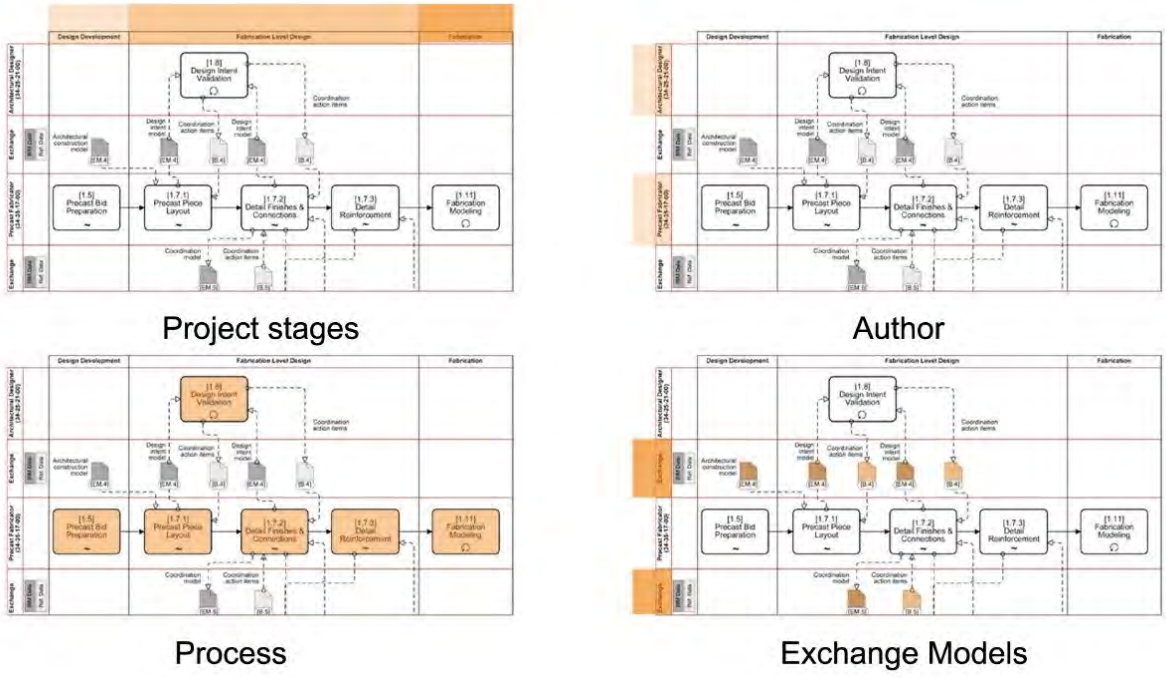


Figure 2-3: Process map structure

BIM model non-graphical data can be efficiently exchanged within the BIM workflow. Table 2-3 presents COBie properties for a BIM model. This data has been specified using the IDM standard. This is an example of how structured data can be specified consistently between the different stakeholders working in the same project.

Table 2-3: COBie Parameters (ISO, 2014).

COBie parameters	COBie parameters
COBie.Type	COBie.Type.WarrantyDescription

COBie.Type.CreatedBy	COBie.Type.NominalLength
COBie.Type.CreatedOn	COBie.Type.NominalHeight
COBie.Type.Name	COBie.Type. ModelReference
COBie.Type.Category	COBie.Type.Shape
COBie.Type.Description	COBie.Type.Size
COBie.Type.AssetType	COBie.Type.Color
COBie.Type.Manufacturer	COBie.Type.Finish
COBie.Type.ModelNumber	COBie.Type.Grade
COBie.Type.WarrantyGuarantorParts	COBie.Type.Material
COBie.Type.WarrantyDurationParts	COBie.Type.Constituents
COBie.Type.WarrantyDurantionLabor	COBie.Type.Features
COBie.Type.WarrantyDurationUnit	COBie.Type.AccesibilityPerformance
COBie.Type.ReplacementCost	COBie.Type.SustainabilityPerformance
COBie.Type.ExpectedLife	COBie.Type.Area
COBie.Type.DurationUnit	COBie.Type.Length

2.3.2 LOD as an Interoperability standard

Finally, for the correct exchange of data between object-based systems, interoperable standards are needed. Interoperability allows to exchange physical entities or data between different proprietary systems without losing information during the process (Steel et al., 2012). Several examples exist in the sense of BIM collaboration between stakeholders. Collaboration within BIM processes entail exchanging information by using a federated model, which is a common database for the entire BIM team (BSI, 2007). Engineers, architects and MEP professionals would use different interoperable formats depending on the level of BIM maturity within their industry. For example, the Extendible Markup Language (XML), which enables the exchange of relational data is used currently as a by step towards the total implementation of the IFC in the UK.

Currently, Building Smart international is an institution that aims to provide open standards for the Architecture, Engineering and Construction (AEC) industry and oversees the publication and development of IFC updates and MVDs (BuildingSMART, 2016b). They are as well in charge of certifying IFC interoperable software. The current published MVD are the following shown in Table 2-4. The table shows the name of the last IFC release and the supported uses.

Table 2-4: IFC release and support (BuildingSMART, 2015)

IFC Release	IFC support
IFC4 Reference View	Coordination planning Clash detection Background reference Quantity take-off Construction sequencing Visual representation
IFC4 Design Transfer View	Coordination planning and execution Integrated reference (i.e. loading an IFC model from a different discipline) Handover the complete discipline model for the IFC4 Reference View Enhanced support for the IFC4 Reference View
IFC2x3 Coordination View V2.0	It supports several exchange requirements such as exporting from architectural, MEP and structural engineering software applications
IFC2x3 Structural Analysis View	It supports structural exchange requirements from a structural design application to a structural analysis application.
IFC2x3 Basic FM HandOver View	It supports data Facilities Management data exchanges from BIM planning, design, construction and commissioning software and the

IFC Release	IFC support
	Computer Aided Facility Management (CAFM) and Computerised Maintenance Management System (CMMS) applications.

Unfortunately, the LOD has not been transcribed to a MVD, which makes LOD product data specification unreliable as discussed before.

The LOD specification in relation to measure, performance, process, and interoperable standards has been analysed. However, within this research, the elaboration process of a standard is of high importance as the LOD has been under different levels of adoption as well as definition processes. According to the process followed to elaborate the standard there exist two main classifications, de jure and formal standardisation which will be described in the next section.

2.3.3 Measurement of BIM Model Progression in North America

In the United States, diverse companies and institutions have proposed different definitions to effectively describe Model Element progression along AEC projects. By the year 2016, 24 Specifications, Protocols, guides and manuals were created from private companies, universities, state agencies and professional associations. As shown in Table 2-5, three standards define the Model Element Progression as Level of Detail, whereas twenty define it as Level of Development and one as Accuracy and Grade.

Table 2-5: BIM model Element Definitions in North America

Year	Organisation and standard name	Model Element Definition	Inherited from
2005	[VS] Model Progression Specification v1	Level of Detail	Not Found

Year	Organisation and standard name	Model Element Definition	Inherited from
2008	[AIA] E202-2008 BIM Protocol Exhibit	Level of Development	[VS] v1 2005
2010	[VA] The Veteran Affairs BIM Guide v1.0	Level of Development	[AIA] 2008
2010	[VA]The VA BIM Object Element Matrix Manual Release v1.0 (attributes)	Level of Development	[AIA] 2008
2010	[VS] Model Progression Specification v2	Level of Detail	[VS] v1 2005
2011	[VS] Model Progression Specification v3	Level of Detail	[VS] v2 Not Found
2011	[OD o AS] State of Ohio BIM Protocol	Level of Development	[AIA] 2008
2011	[UF] BIM Execution Plan v1.1	Level of Development	[AIA] 2008
2012	[NYC DDC] BIM Guidelines	Level of Development	[AIA] 2008
2012	[PSU] BIM Planning Guide for Facility Owners v1.0	Level of Development	[AIA] 2008
2012	[TPA o NY NJ] E, A design division BIM standard manual	Level of Development	[AIA] 2008
2012	[USC] Building Information Modeling (BIM) Guidelines v1.6	Level of Development	[AIA] 2008
2013	[AIA] Document G202™–2013, Project BIM Protocol Form	Level of Development	[AIA] 2008
2013	[AGC, AIA, BIM Forum] Level of Development (LOD) Specification v2013	Level of Development	[AIA] 2013
2013	[AIA] E203-2013 BIM and Digital Data Exhibit	Level of Development	[AIA] 2013
2013	[AIA] Guide, Instructions and Commentary to the 2013 AIA Digital Practice Documents	Level of Development	[AIA] 2008, [AIA] 2013
2013	[NIBS] National BIM Standards US v3_2.7	Level of Development	[AIA] 2013, [AIA] 2013, [AGC, AIA, BIM Forum] 2013
2013	[PSU] BIM Planning Guide for Facility Owners v2.0	Level of Development	[AIA] 2013
2013	[PSU] The uses of BIM Classifying and	Level of Development	[AIA] 2013

Year	Organisation and standard name	Model Element Definition	Inherited from
	selecting BIM uses v0.9		
2014	[AGC, AIA, BIM Forum] Level of Development (LOD) Specification v2014	Level of Development	[AIA] 2013, [AGC, AIA, BIM Forum] 2013
2014	[USACE] Minimum Model Element Matrix M3 v1.3 (attributes)	Level of Development (accuracy) and grade	Not Found
2015	[AGC, AIA, BIM Forum] LOD Specification v2015	Level of Development	2013 [AIA], [AGC, AIA, BIM Forum] 2014
2015	[AGC, AIA, BIM Forum] LOD Specification v2015 (attributes)	Level of Development	2013 [AIA], [AGC, AIA, BIM Forum] 2014
2016	[AGC, AIA, BIM Forum] LOD Specification v2016	Level of Development	[AIA] 2013, [AGC, AIA, BIM Forum] 2015
2016	[AGC, AIA, BIM Forum] LOD Specification v2016 Part I (BIM Forum, 2016a)	Level of Development	[AIA] 2013, [AGC, AIA, BIM Forum] 2015
2016	[AGC, AIA, BIM Forum] LOD Specification v2016 Part II (attributes) (BIM Forum, 2016b)	Level of Development	[AIA] 2013, [AGC, AIA, BIM Forum] 2015
2017	[AGC, AIA, BIM Forum] LOD Specification v2017 Part I (BIM Forum, 2017a)	Level of Development	[AIA] 2013, [AGC, AIA, BIM Forum] 2016
2017	[AGC, AIA, BIM Forum] LOD Specification v2017 Part II (attributes) (BIM Forum, 2017b)	Level of Development	[AIA] 2013, [AGC, AIA, BIM Forum] 2016
2017	[VA] VA BIM Standard. BIM Manual v2.2 (VA, 2017)	Level of Development	[AGC, AIA, BIM Forum] 2017
2018	[AGC, AIA, BIM Forum] LOD Specification	Level of Development	[AIA] 2013, [AGC,

Year	Organisation and standard name	Model Element Definition	Inherited from
	v2018 Part I (BIM Forum, 2018a)		AIA, BIM Forum] 2017
2018	[AGC, AIA, BIM Forum] LOD Specification v2018 (attributes) Part II (BIM Forum, 2018b)	Level of Development	[AIA] 2013, [AGC, AIA, BIM Forum] 2017
2018	[UoSF] BIM Guidelines and Standards (UoSF, 2018)	Level of Development	Not Found
2019	[AGC, AIA, BIM Forum] LOD Specification v2019 Part I (BIM Forum, 2019a)	Level of Development	[AIA] 2013, [AGC, AIA, BIM Forum] 2018
2019	[AGC, AIA, BIM Forum] LOD Specification v2019 Part II (attributes) (BIM Forum, 2019b)	Level of Development	[AIA] 2013, [AGC, AIA, BIM Forum] 2018
2019	[TOSU] BIM Project Delivery Standards v4.0 (TOSU, 2019)	Level of Development	[AGC, AIA, BIM Forum] 2018
2019	[TPA of NY NJ] E, A Design Division BIM Standard Manual (TPA of NY & NJ, 2019)	Level of Development	[AGC, AIA, BIM Forum] 2018

However, many of these standards inherit the definition from a parent standard (see Figure 2-4). This relationship of standards through inheritance give raise to a hierarchy. A shown in Table 2-5, the Vico Software (VS) Model Progression Specification v1, the (AIA) E202-2008 BIM Protocol Exhibit, the AIA Document G202™–2013, the Project BIM Protocol Form, the [AGC, AIA, BIM Forum] Level of Development (LOD) Specification v2013 and the (USACE) Minimum Model Element Matrix M3 v1.3 (attributes) are the mother standards from which the other standards are derived.

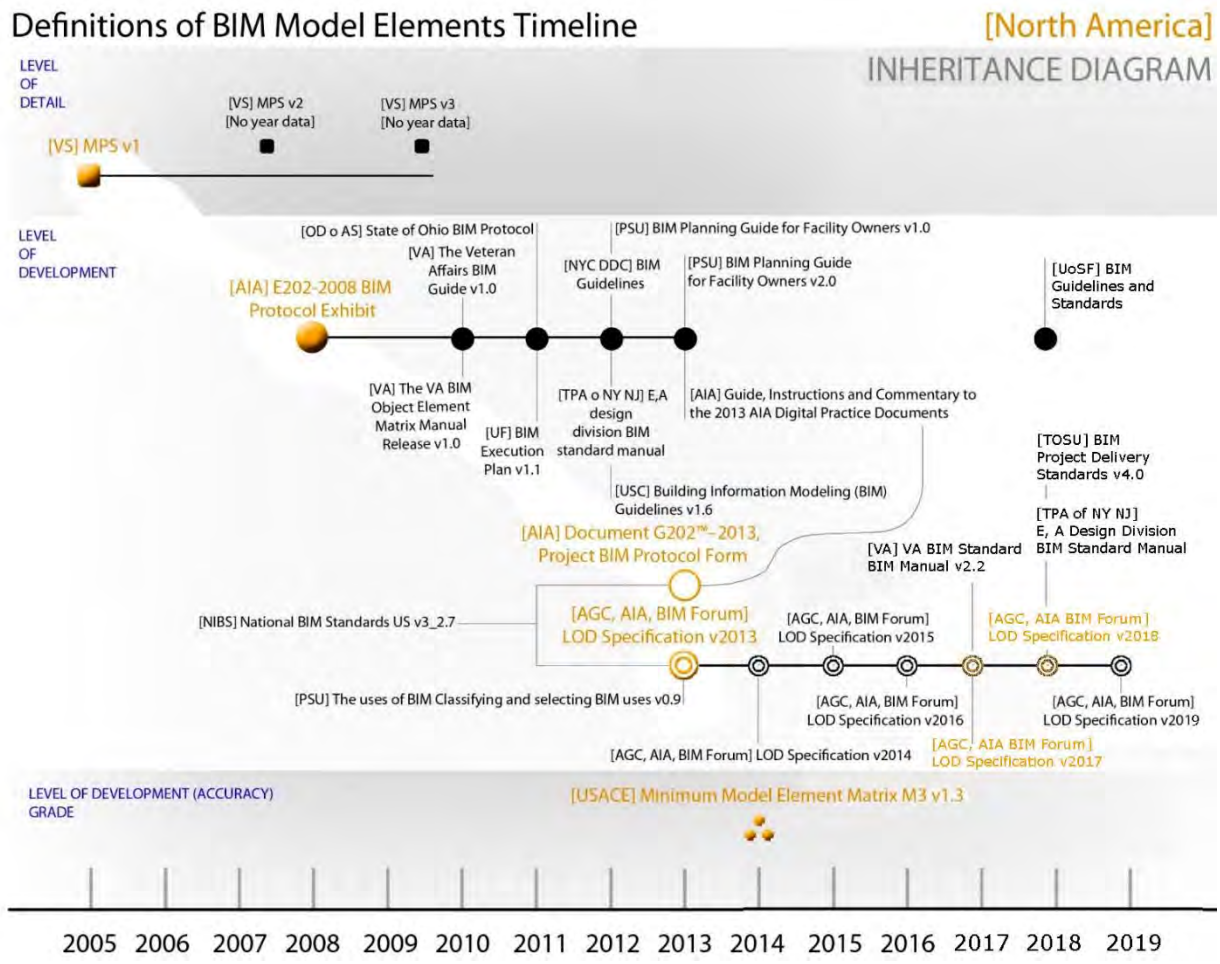


Figure 2-4: North America Timeline-Inheritance diagram

The United States is considered as the first country to create a description of BIM model progression along a predefined set of graphical and non-graphical definitions. This includes 3D models and embedded attributes. However, the first effort recorded belongs to a private company called Vico Software in 2005 (VicoSoftware, 2016). This effort was created with the aim to support 5D content planning. They created the "Model progression Specification" (MPS) which contained characteristics to define a BIM model within a project. The MPS v1 provided a primary guidance on how to create a BIM model.

The American Institute of Architects (AIA) California Council's IPD Task Force, refined the MPS v1 with the consent of Vico Software and in 2008 published the AIA E202-

2008 BIM Protocol Exhibit (AIA, 2008). Usually, the AIA review the documents every ten years. However due to the fast development of BIM, the AIA Document G202™–2013 (AIA, 2013b), Project BIM Protocol Form was published in 2013 to substitute the AIA E202.

In 2011, the BIM Forum started to use AIA definitions to create illustrated examples for each building system. Three guides have been published since 2013 with support from industry professionals: BIM Forum Specification 2013 to 2015 (BIM Forum, 2013, BIM Forum, 2014, BIM Forum, 2015a)

Similarly, Canada is in the process of creating a Canadian Practice Manual for BIM which will be released by the end of 2016 and certified by The Institute of BIM in Canada (IBC) and Building SMART Canada (BuildingSMART International Ltd, 2016). Over 60 voluntary expert practitioners are involved in the creation of the standards. It is then open for complementary studies to review the adoption of the LOD within Canada.

To summarise, a detailed description of the BIM Model Element Definitions found within the twenty-four North America standards from Table 2-6 is given below.

Table 2-6: North America LOD features

Year	Organisation and standard name	Classification	Stage and dependency	BIM use	LOD types	Illustrations or attributes
2005	[VS] Model Progression Specification v1	Uniformat	% of the traditional stage / Not dependent	Geometry, Scheduling, Estimating	Not Found	Not Found
Not Found	[VS] Model Progression Specification	Uniformat	% of the traditional stage / Not	Geometry, Scheduling, Estimating	M0, M1,M2,M3,M4, M5,M6	Not Found

Year	Organisation and standard name	Classification	Stage and dependency	BIM use	LOD types	Illustrations or attributes
	v2		dependent		S1,S2,S3,S4,S5,S6 E1,E2,E3,E4,E5,E6 and its combinations (252)	
Not Found	[VS] Model Progression Specification v3	Uniformat	% of the traditional stage / Not dependent	Geometry, Scheduling, Estimating	M0, M1,M2,M3,M4, M5,M6 S1,S2,S3,S4,S5,S6 E1,E2,E3,E4,E5,E6 reduced to a predefined set of combinations (6)	Not Found
2008	[AIA] E202-2008 BIM Protocol Exhibit	UniFormatTM, MasterFormat, Omniclass	End of project stage / Not dependent	Construction, Analysis, Estimating, Scheduling, Other uses	100,200,300,400,500 (5)	Not Found
2013	[AIA] Document G202™–2013, Project BIM Protocol Form	UniFormatTM, MasterFormat, Omniclass	Project milestones / Not dependent	Coordination, Analysis, Estimating, Scheduling, Other uses	100,200,300,400,500 which can be defined for each BIM use for each project	Not Found

Year	Organisation and standard name	Classification	Stage and dependency	BIM use	LOD types	Illustrations or attributes
					milestone (20)	
2013	[AGC, AIA, BIM Forum] Level of Development (LOD) Specification v2013	UniFormat 2010	Not dependent	Geometry, Scheduling, Estimating, Coordination	100,200,300,350,400 (5)	Illustrations
2014	[USACE] Minimum Model Element Matrix M3 v1.3	UniFormatTM, MasterFormat, Omniclass	Not dependent	Not found	Accuracy ●,100,200,300 Grade A,B,C,+,-, ● (24)	Not Found

Vico Software Model Progression Specification (Level of Detail)

In 2005, Vico Software proposed the "Model Progression Specification" as a collaboration tool for unifying criteria in a multi-company environment (VicoSoftware, 2016). This matrix is elaborated by assembling Level of Detail, stages, building element categories, aspects and their classes, along with primitives (VicoSoftware, 2016)(see Figure 2-7). However, the matrix has evolved during time to acknowledge the intricacies of the model description. For example, while the first matrix (MPSv1) defined the model by assembling Level of Detail, stages, building element categories, aspects; the second matrix incorporates classes (MPSv2), whereas the third incorporates primitives (MPSv3)

as an attempt to refine the MPSv2. The MPS characteristics are further analysed in relation to its benefits and barriers of implementation within a project (VicoSoftware, 2016).

The Vico Software Level of detail is a definition of element completeness in terms of geometry, scheduling information, and estimating data. “Building Element Categories” are defined using the Uniformat classification. This is needed for example, in a cost-oriented BIM model, to have a consistent naming convention when linking the extracted quantity take-off from a design software to a cost analysis software cost database (VicoSoftware, 2016). Furthermore, this naming convention allows to add granularity as we detail further the BIM model, i.e at a lower level Foundation substructure would be the most appropriate name for an undefined element but as we progress within the model this term could be refined to express more characteristics of a foundation such as continuous footings or slab on grade (VicoSoftware, 2016). For example:

- LOD 100 (Conceptual massing).
- LOD 200 (Approximate elements sizes, generic representation).
- LOD 300 (Diversification of size and materials).
- LOD 400 (Construction documentation)

Multiple of 100 to allow for future expansion of the structure. It was noticed that the specification was too general and subject to interpretation by the designers (VicoSoftware, 2016) (see Figure 2-5).

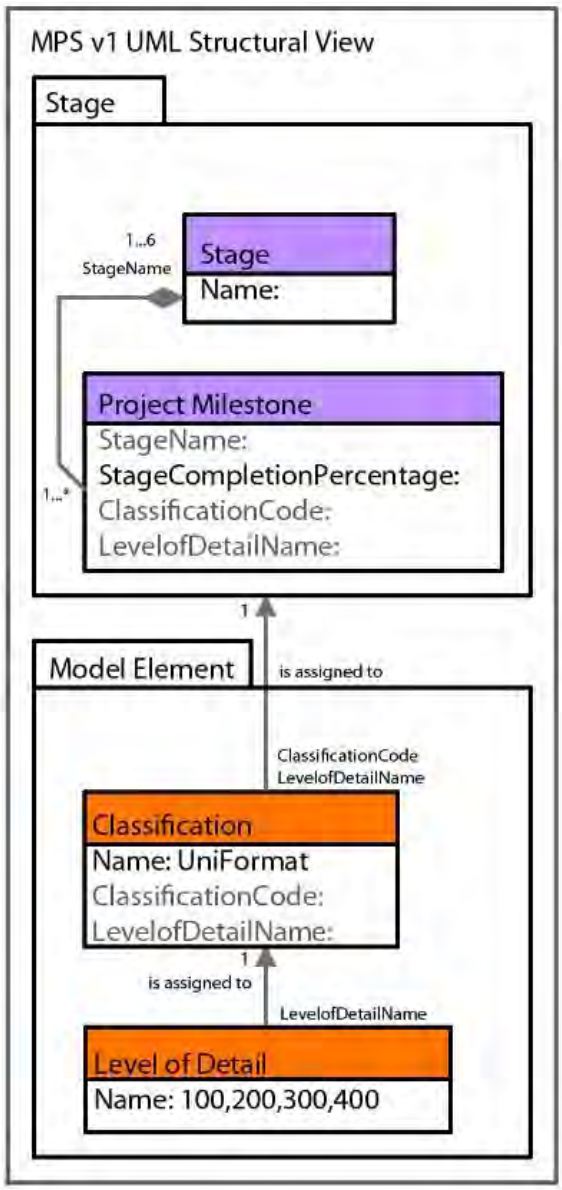


Figure 2-5: VicoSoftware MPS v1 Unified Modeling Language Structural View

The definition of "Building Element" LOD incorporates a characteristic called "Aspect" that defines the purpose the model will be used for. The model then, within the Vico Software MPS is described in terms of visualisation, scheduling and estimating purposes (VicoSoftware, 2016). However, it was detected that the "Aspect" attribute did not allow to describe the BIM model evolution through time, therefore each of the LOD

"Aspects" was further developed into different "Classes" according to the model progression. This requirement was introduced within the MPSv2 (see Figure 2-6).

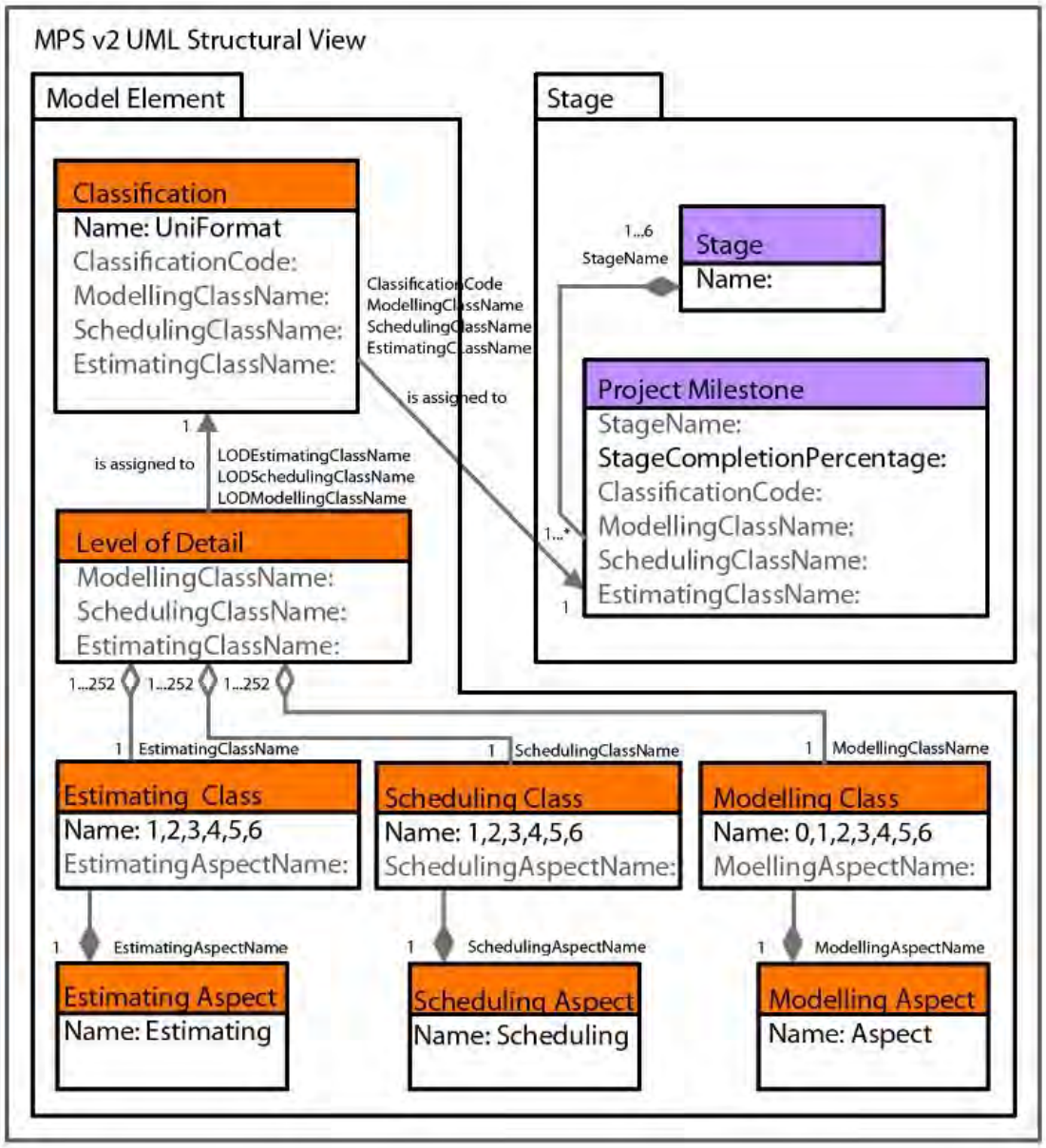
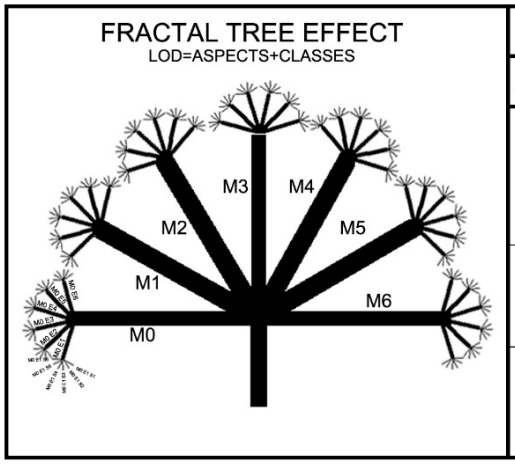


Figure 2-6: VicoSoftware MPS v2 Unified Modeling Language Structural View

The combination of Building Element, Aspect and class derived into multiple LOD descriptions for each of the building elements required to define a BIM project (VicoSoftware, 2016). For example, a LOD 200 could combine M2, E3 and S2 classes (refer

to Figure 2-7). Formerly it was though that the project should be flexible enough to define a model that combines the LOD, aspect and model for each of the building elements. However, this iteration of building element, aspect and class derived on a fractal tree effect that was counterproductive for the standardisation of the specification (VicoSoftware, 2016).

The Vico Software MPSv2 encompasses 3 Aspects, which correspond to modelling, estimating, and planning (VicoSoftware, 2016). The modelling aspect is divided to 7 classes and the Estimating and Planning Aspect to six classes each. Figure 2-7 represents a fractal tree image for the MPSv2 Vico Software.



ASPECTS AND CLASSES

ASPECTS	CLASSES	DESCRIPTION
MODEL M	M0	No model
	M1	Buildin/Spatial Room Massing
	M2	Building ELements with approximate dimension
	M3	Building Elements with Design Dimension
	M4	Construction Model
	M5	Fabrication/Virttual Mockup
	M6	As built
COST E	E1	Division Level Ranges
	E2	Massing Driven Ratios & Ranges
	E3	Element Driven-Assumption Based-Resource Level and Ranges
	E4	Element Driven-Specification Based-Resource Level
	E5	Element Driven-Subcontractor Based-resource Level
	E6	Actual Cost
TIME S	S1	Milestone Schedule
	S2	ELement Based-avergae production rates
	S3	Phase Schedule-activity based using resource hour estimates
	S4	Phase schedule-subcontratcor production commitments
	S5	Weekly workplans
	S6	Actual Progressed Schedule

MPS MATRIX

TARGET LOD	CLASSES
000	M0 E1 S1
050	M0 E2 S2
100	M1 E2 S2
200	M2 E3 S2

Figure 2-7: MPSv2 Vico Software aspects and classes

This iteration problem of aspects and classes lead to 252 possible LOD definitions for only one building element. To illustrate the magnitude of the problem, for a simplified case, where the classes for each of the aspects has the same number of definitions, the total LOD definitions can be mathematically calculated with the following formula:

*Total LOD definitions = (nº of Classes * nº of Aspects) nºof Building elements*

Equation 2-1: MPSv2 Total LOD definitions equation.

For example: in a model with 10 building elements, the total number of LOD definitions needed for the aspects M (class M2 and M3) and E, (class E2 and E3), would be (2 * 2) 10= 40 LOD definitions.

Within Vico Software, each of the LOD definitions should be predefined in terms of cost and schedule to be automatically attached to the BIM model (Building Element) (VicoSoftware, 2016). For example, each LOD holds a database with estimating information as well as a task list for scheduling. Therefore, the combination of multiple classes definitions per each building element creates a problem of scalability (VicoSoftware, 2016). Therefore, within the MPSv3, Primitives are created for each of the Building Elements. Primitives are predefined LODs with set Aspects, classes and corresponding linked database of cost and schedule information (VicoSoftware, 2016). This drastically reduces the number of LOD definitions in terms of modelling, scheduling, and estimating needed to describe a Building Element. The following table represents a Primitive for a Wall progression from LOD level 400 to LOD 500. For example, the LOD 400 for a wall would be predefined using the M4, E5 and S4 definitions, whereas, the LOD 500 would only change in model appearance (M5) and scheduling detail (S5) while maintaining its cost detail (E5).

Table 2-7: VicoSoftware (2016) Primitives.

	LOD 400	LOD 500
Model Class	M4	M5
Model Diversification	Thickness, type per schedules and additional properties (related to estimating/scheduling)	Thickness, type per schedules and additional properties (related to estimating/scheduling)
Model Geometry	Modeled with exact rectangular	Modeled with exact rectangular

	LOD 400	LOD 500
Model Class	M4	M5
	cross sectional geometry Modeled with exact inclination	cross sectional geometry Modeled with exact inclination
Model Penetrations	Windows, doors and main MEP runs	Windows, doors and all MEP runs
Model Connections	Modeled	Modeled with components
Estimating Class	E5	E5
Estimating Requirements	Cost per unique element, resources level	Cost per unique element, resources level
Scheduling Class	S4	S5
Scheduling Requirements	Production rate from resource hours	Production rate from resource hours

However, this primitive description is not enough to build a detailed BIM model. This is why predefined LODs for each building element have been built which can be attached to a construction project in a standardised way (VicoSoftware, 2016). For example, the model aspect for a wall could be represented as per model diversification (material, element type or thickness), model geometry (exact or approximate measures), penetrations (windows and doors or MEP runs) and connections (see Figure 2-8 and Figure 2-9).

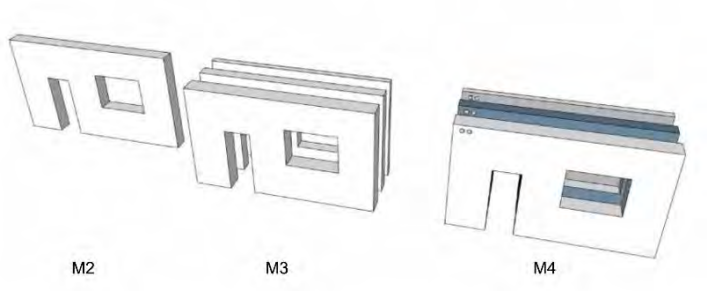


Figure 2-8: MPS graphical LOD sequence.

The LOD covers not only the model but cost and schedule aspects (VicoSoftware, 2016) (see Table 2-8). For example, the LOD 100, used for concept planning is an approximate volume which represents the approximate number of floors and approximate footprint in the case of a whole building or approximate measures in case of a general element. Within the represented example, the measure extracted from the foundation BIM model can be used as an input for estimation calculations when combined with average cost per square unit of measure. Similarly, the LOD 200 could be defined as a schematic type of project design. The approximate locations are specified; however, the exact sizes are still not known. At this level we can specify the type of foundation, so the average cost of that specific element can be calculated as part of the whole foundation substructure. For the LOD 300, the exact sizes and construction methodology are known so we can enrich the cost information with cost items for the required activities. For example, cast in place or reinforcement. As we develop further the model, we can add material take off and labour for the LOD 400 construction model and update the model with actual data versus planned at the LOD 500 as built model.

Table 2-8: Vico Software (2016) example of LOD

LOD	Stage	Item	Unit	Cost unit
LOD 100	Concept planning	A10 Foundation substructure	Sf of building	Average sf cost
LOD 200	Schematic design (approximate locations no exact size)	A1010.01 Continuous footings	Sf foot of element	Unit cost is an average cost

LOD	Stage	Item	Unit	Cost unit
LOD 300	Exact sizes and construction methodology	03.01.10.01 Formwork Reinforcement Cast in place concrete	Add cost items to the activities	
LOD 400	Construction documentation	Carpenter Formwork material	Labour info a material take off	
LOD 500	As built (virtual mock up)	Reinforcement continuous footings Labourer Reinforcement		

Finally, in order to manage the information along the duration of a project, stages are defined (VicoSoftware, 2016). However, instead of traditional phases Vico Software proposes to express stages as a percentage of project progression to acknowledge that there might be different model versions or iterations within the same traditional phase. In the United States, these are measured as a percentage of Schematic Design (SD), Design Development (DD), Construction Documents (CD). For example, if the LOD 100 were required for the substructure at stage 1, it would require the modeler to deliver an LOD 100 at the 50% of the SD completion. This allows the engineer to value engineer the process as the model review frequency is increased.

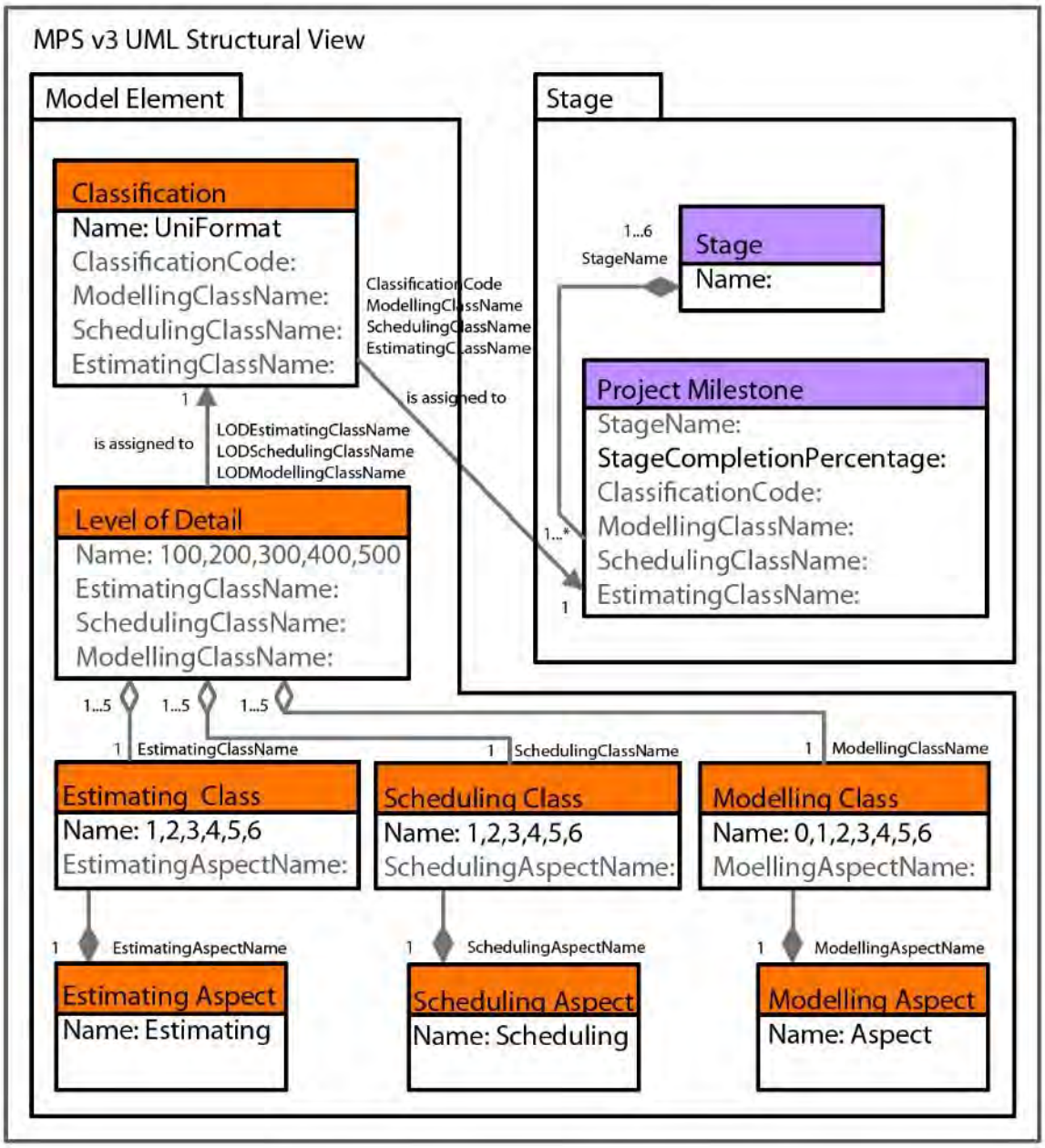


Figure 2-9: VicoSoftware MPS v3 Unified Modeling Language Structural View

AIA Document E202TM – 2008 BIM Protocol Exhibit (Level of Development)

The Vico Software MPS Level of Detail was refined by the American Institute of Architects (AIA). In 2008, the AIA released the AIA Document E202TM – 2008 BIM

Protocol Exhibit (AIA, 2008). This document uses the Vico Software MPS to redefine the Level of Detail concept. The concept name changed to Level of Development and defines the completeness to which a model element is developed. A model element defines a component, system or assembly within a building and these are represented by the Construction Specification Institute's (CSI) UniFormatTM classification system (AIA, 2008). However, the "Guide, Instructions and Commentary to the 2013 AIA Digital Practice Documents" Recommends using a different classification system if required according to the complexity of the classification system, the number of different users, familiarity with the classification and evaluation of the Model use and translation to required software (AIA, 2013c). Masterfomat and Omniclass classification systems are recommended within the guide. The document defines the LOD according to its model content requirements and its authorised uses, which are Construction, Analysis, Cost Estimating Schedule and leave place to define any other uses (AIA, 2008). The Model Element is defined at 5 different progressive detailed levels of completeness which ranges from the LOD 100 to the LOD 500 (see Figure 2-10). For example, the LOD 100 content requirement correspond to an overall building massing (AIA, 2008). Attributes such as area, height, volume, location, and orientation may be represented in 3 dimensions or modelled by any other data. While the most defined LOD, i.e. LOD 500, corresponds to as constructed accurate data, LOD 200 corresponds to approximate data, LOD 300 to accurate data and LOD 400 corresponds to accurate data with complete fabrication, assembly, and detailing information. A similar definition of model progression is made for the uses mentioned before (AIA, 2008).

This information is organised within the Model Element Table, which indicates the LOD and authorised uses to which each of the Model Elements should be developed by

the Model Element Author (MEA) at the end of each project stage (AIA, 2008). This method of organising the information within a project allows for improved model reliance. The user does not infer more information from the model than the one which is specified, and the model element author understand which model requirements are needed beforehand thus avoiding overdesign (AIA, 2008).

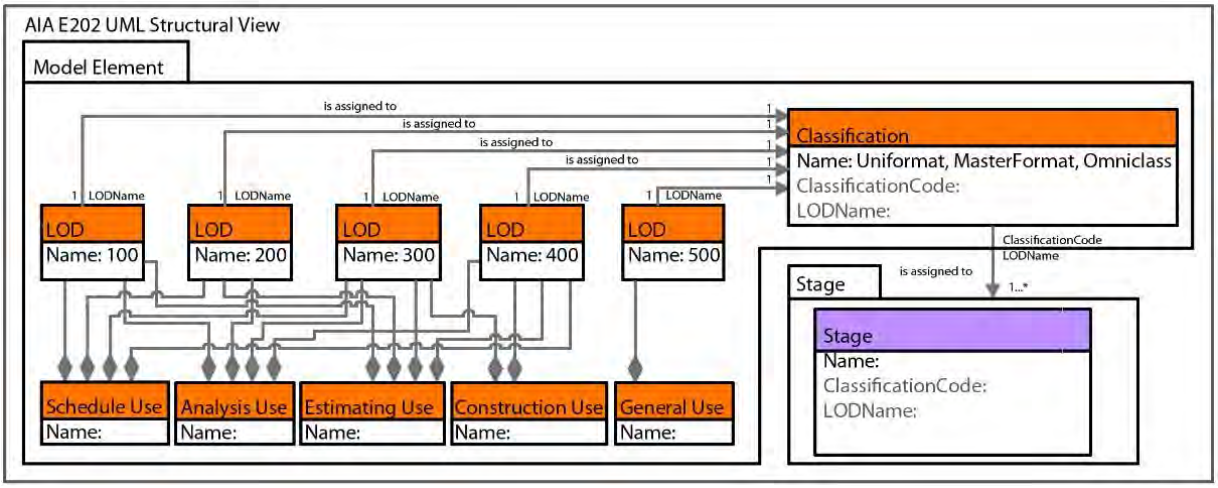


Figure 2-10: AIA E202 Unified Modeling Language Structural View

AIA Document E202TM Related BIM guides

The U.S. Department of Veteran Affairs (VA) Office of Construction & Facilities Management (CFM) which provides engineering consultancy services in support of the U.S army Veterans released the VA BIM Guide in April 2010 (AEC Infosystems Inc., 2010). They devised the Object Element matrix which is a compendium of BIM model attributes for each building element referenced using the OmniClass and Uniformat classification systems, which have evolved in line with the AIA E202 LOD definition (VA CFM, 2010). The attributes are classified according to different BIM uses such as costing requirements, construction logistics or asset management among others. The modeler would choose the

appropriate element and LOD to the required BIM use and would populate its BIM model with the described attributes (see Table 2-9).

Table 2-9: VA use of LOD E202-2008 and description of attributes

LOD E202-2008	Inform action category	Information item	Omniclass Table 49 definition
LOD 200	Physical Properties of BIM Objects & Elements	Length	The shortest distance between the ends on a specified point of measure of the material. Usually differentiated from width by being the longer of the two
LOD 200	Physical Properties of BIM Objects & Elements	width	The shortest distance between the ends on a specified point of measure of the material. Usually differentiated from length by being the shorter of the two.

The State of Ohio BIM protocol published in 2011 by the State Architect's Office also uses the AIA E202 definitions (Ohio DAS, 2011). However, it classifies them according to four initial categories of model development:

I. This model supports project planning through space and volume illustration, adjacencies, and site positioning.

II. This model will include a sufficient level of development to support document and system review, clash detection and coordination, and support an as-built format for owner use after completion. This is the standard model category for Ohio projects.

III. This model will include all the benefits and requirements of the early model categories and will provide sufficient detail to support a detailed model development of systems supporting building occupancy and facility management.

IV. This model will include the benefits and requirements of the earlier model categories, and support highly detailed logistical, scheduling, and estimating efforts.

The different categories arrange the model according to its potential uses as the model progresses. For example, for category I, the model will support project planning, Category II, will support clash detection and coordination, document and system review and will support as built format. This will be the minimal requirement for Ohio Projects submission. Category III will support building occupancy and facility management, whereas category IV will support logistic, scheduling and estimating uses (see Table 2-10).

Table 2-10: State of Ohio LOD

Building System	**Model Category/Level of Development**			
	I	**II**	**III**	**IV**
Substructure	0	300	300	400

Building System	Model Category/Level of Development			
	I	II	III	IV
Structure	100	300	300	400
Electrical	100	200	300	400

The University of Florida has been using the AIA LOD within minor projects as stated within the UF BIM Execution Plan (UF, 2011). The NY guides (NYCDDC, 2012), proposes certain BIM model requirements such as clash detection among other in progression with the LOD similarly to the State of Ohio LOD It proposes certain attributes for building systems LODs.

BIM planning guide for facility owners proposes the use of the AIA E202, VA BIM guide or COBie. E/A Design Division BIM standard Manual (CIC RP, 2013). The Port Authority of NY & NJ and The University of South California USC applies LODs to different design stages on new USC construction projects, major renovations and other projects (USC, 2012, TPA of NY & NJ, 2012).

BIM Planning guide for facility owners v2.0 2013 proposes three levels, A,B and C: Accurate size, general size and Schematic size and location. The last one includes object parameters (CIC RP, 2013).

AIA G202TM – 2013 BIM Protocol Form (Level of Development)

The AIA updated the E202TM – 2008 BIM Protocol Exhibit in 2013. The new protocol was named G202TM – 2013 BIM Protocol Form. The LOD authorised uses were updated to represent coordination issues within a project such as clash detection (AIA,

2013b) (see Figure 2-11). Therefore, a coordination authorised use was added to the list. Table (13) represents a relation between the LOD, the assigned authorised uses and the E202 and G202 documents).

Table 2-11: E202 and G202 comparison of uses per LOD

LOD	100	200	300	400	500
Construction			E202	E202	
Analysis	E202/G202	E202/G202	E202/G202	E202/G202	
Cost Estimating	E202/G202	E202/G202	E202/G202	E202/G202	
Schedule	E202/G202	E202/G202	E202/G202	E202/G202	
Coordination		G202	G202	G202	
General Usage					E202

Other differences between both documents is the way time is organised when a predefined LOD is required. The E202 Model Element Table allows a field for assigning the Level of Development of a model element at the end of one of the typical design stages (AIA, 2008). However, the G202 recognises that an object might develop at different Level of Development within the same stage allowing to add interim project milestones as a percentage of the project stage (AIA, 2013b). Furthermore, it is understood that a Model Element might be modelled at different Levels of Development for different uses at the same project milestone. Thus, a column called notes is added next to the LOD field to clarify this specific instance (see Table 2-12 and Table 2-13).

Table 2-12: AIA 2008 E202 Model Element Table

E202 Model Element Table		Stage		Stage		Stage	
Model Elements using CSI UniFormat™		LOD	MEA	LOD	MEA	LOD	MEA
D50 Electrical	D5010 Electrical Service & Distribution						
	D5020 Lighting and Branch Wiring						
	D5030 Communication & Security						
	D5090 Other Electrical Systems						

Table 2-13: AIA 2013a G202 Model Element Table

G202 Model Element Table		Project Milestone			Project Milestone			Project Milestone		
Model Elements using CSI UniFormat™		LOD	MEA	Notes	LOD	MEA	Notes	LOD	MEA	Notes
D50 Electrical	D5010 Electrical Service & Distribution									
	D5020 Lighting and Branch Wiring									
	D5030 Communication & Security									
	D5090 Other Electrical Systems									

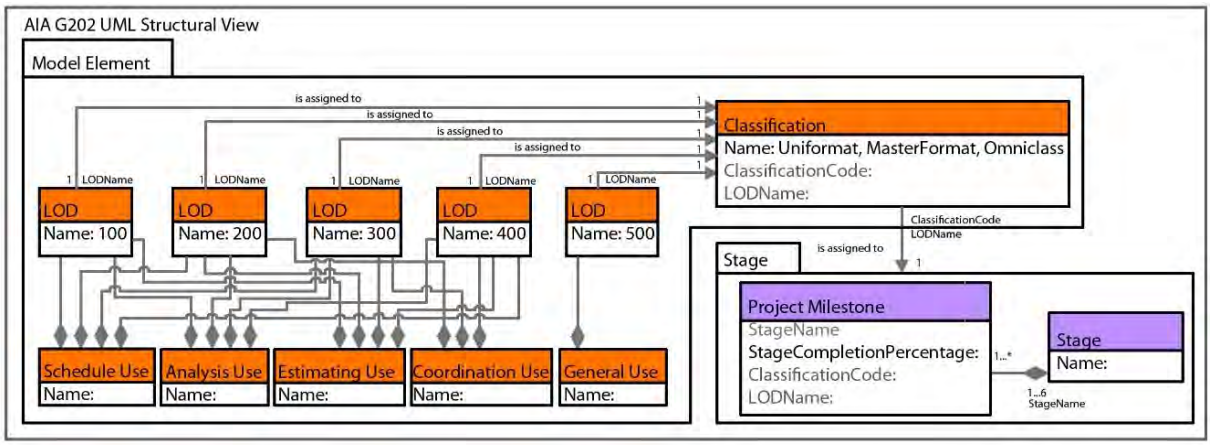


Figure 2-11: AIA G202 Unified Modeling Language Structural View

BIM Forum Level of Development Specification (AIA G202 dependent)

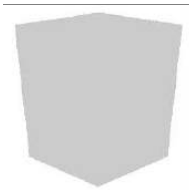
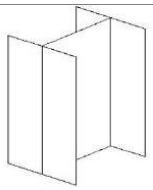
In order to provide illustrations to support the specification of LOD, BIM Forum released four LOD guides since 2013 (see Table 2-14). Each year the guide is reviewed by a group of experts. They have published five LOD guides from 2013 to 2016 including the 2015 and 2016 drafts (BIM Forum, 2013, BIM Forum, 2014, BIM Forum, 2015b, BIM Forum, 2016b). Apart from Model Element illustrations, since the 2015 draft, a Model Element Table and Attributes Tables were added.

The BIM Forum Level of Development Specification uses the AIA G202-2013 Level of Development definitions. However, it provides examples for selected design and construction elements at different Levels of Development using the CSI Uniformat 2010 (CSI, 2012, BIM Forum, 2013). This specification is intended for professionals engaged in BIM element creation. The guide helps these professional to rely on the type of model they are sharing or receiving in terms of usability (BIM Forum, 2013). For example, the working group who created the specification may consider convenient to create models in terms of the BIM use of the model. Model geometry, quantity take-off, 3D coordination

such as clash detection and 3D control and planning are the agreed BIM uses to rely upon within this guide (BIM Forum, 2013). Other uses are satisfied by this guide according to its creators. This guide is intended to be used as a support for a BIM execution plan, this is why the model element author, or the project stage are not prescribed within the Level of Development definition given (BIM Forum, 2013). The prescription of the model element author and the stage are supposed to change from project to project. Furthermore, special advice is given to not develop the whole BIM model at the same Level of Development as it is though that the model systems and products would develop at different paces at different project stages (BIM Forum, 2013). The opposite is considered as design waste in terms of time, cost and human resources.

One of the main LOD differences with the AIA G202-2013 is that a Level of Development in between the 300 and 400 levels is needed to satisfy the coordination BIM use of the model. The guide, instructions and commentary to the 2013 AIA Digital Practice Documents, encourage its use within the G202 (AIA, 2013c). Furthermore, the Level of Development 500 is not prescribed within this guide as this level is intended to be a real description of an as build model. This is after the product has been installed on site (BIM Forum, 2013).

Table 2-14: BIM Forum graphical description of LOD

LOD 100	LOD 200	LOD 300	LOD 350	LOD 400
				

2.3.4 Measurement of BIM Model Progression in Europe

Europe, in the same trend as the United States has approached the definition of the LOD from different perspectives. As of 2017, 16 standards and guides published in English are available from companies, governments, and professional associations (see Table 2-15, Figure 2-12 and Table 2-16). In Europe, LOD is defined as Degree of Detailing, Grade and Level of Detail, Level of Development, Level of Attributing, BIM content levels, Level of Detail and Level of measurement and Level of Definition which is divided into level of model detail and level of information detail.

Table 2-15: BIM model Element Definitions in Europe

Year	Organisation and standard name	Model Element Definition	Inherited from
2006	[Denmark, BIPS] Layer and Object Structures 2006 (Lag- og objektstruktur 2006)	Not in English	
2007	[Denmark, BIPS] 3D Working Method 2006	Degree of Detailing (Information levels)	Not Found
2009	[UK, AEC] BIM Standard v1.0	Grade, Level of Detail (Scale)	Not Found
2012	[Netherlands, Rijksgebouwendienst] Rgd BIM_Standard v1.0.1 EN 1.0	Level of Development	[AIA] 2008
2012	[UK, AEC] BIM Standard v2.0	Grade, Level of Detail (Scale)	Not Found
2012	[UK, BSI] BS 8541-3-2012 Library objects for architecture, engineering and construction	Level of Detail and Level of Measurement	Not Found
2012	[UK, BSI] BS 8541-4-2012	Level of Attributing	Not Found
2012	[Finland, COBIM] Common BIM Requirements 2012	BIM Content Levels	Not Found

Year	Organisation and standard name	Model Element Definition	Inherited from
2013	[Germany, BMVBS] ZukunftBAU	Level of Development	[AIA] 2008, NATSPEC 2013
2013	[UK] PAS 1192-2-2013	Level of Definition (level of model detail + level of information detail)	Not Found
2013	[UK, CIC] Best Practice Guide for Professional Indemnity Insurance When Using BIMs v1	Level of Detail	[UK] PAS 1192-2-2013
2013	[UK, CIC] Building Information Model (BIM) Protocol v1	Level of Detail	[UK] PAS 1192-2-2013
2013	[UK, CIC] Outline Scope of Services for the Role of Information Management v1	Level of Detail	[UK] PAS 1192-2-2013
2014	[UK, BSI] BS1192-4_Collaborative production of information Part 4	COBie	Not Found
2014	[Spain, uBIM] Guía de Usuarios BIM	Level of Development, BIM Content Levels	[AIA] 2008, [Finland, COBIM] 2012
2015	[Belgium, ADEB-VBA] Building Information Modelling – Belgian Guide for the construction Industry	Level of Development	[AGC, AIA, BIM Forum] 2013
2015	[Switzerland, Ernst Basler + Partner] Building Information Modeling	Level of Development	[AGC, AIA, BIM Forum] 2013
2018	BIM Protocol (CIC, 2018)	Level of Definition	[UK] PAS 1192-2-2013
2018	ISO 19650-1:2018 (ISO, 2018a)	Level of Information Need	Not Found
2018	ISO 19650-2:2018 (ISO, 2018b)	Level of Information Need	Not Found
2018	VDI 252 Blatt 5. Data Management (VDI, 2018)	Not in English	
2019	Common InfraBIM Requirements YIV (Building SMART Finland, 2019)	BIM Content Levels	[Finland, COBIM] 2012

Year	Organisation and standard name	Model Element Definition	Inherited from
Under Approval	Building Information Modelling - Level of Information Need - Concepts and principles (CEN, 2019a)	Level of Information Need	Not Found
Preliminary	Building Information Modelling – Level of information need – Part 2: Guidance for application (CEN, 2019b)	Level of Information Need	Not Found
Preliminary	"Building Information Modelling – Level of information need – Part 3: Data Schema" (CEN, 2019c)	Level of Information Need	Not Found

The AIA 2008 serves as the base of definition for five of these standards. In contrast to North America, in Europe, a history of refinement and inheritance of a common native standard does not exist. When a foreign standard was inherited it was refined to adapt its constituents to the country AEC idiosyncrasy.

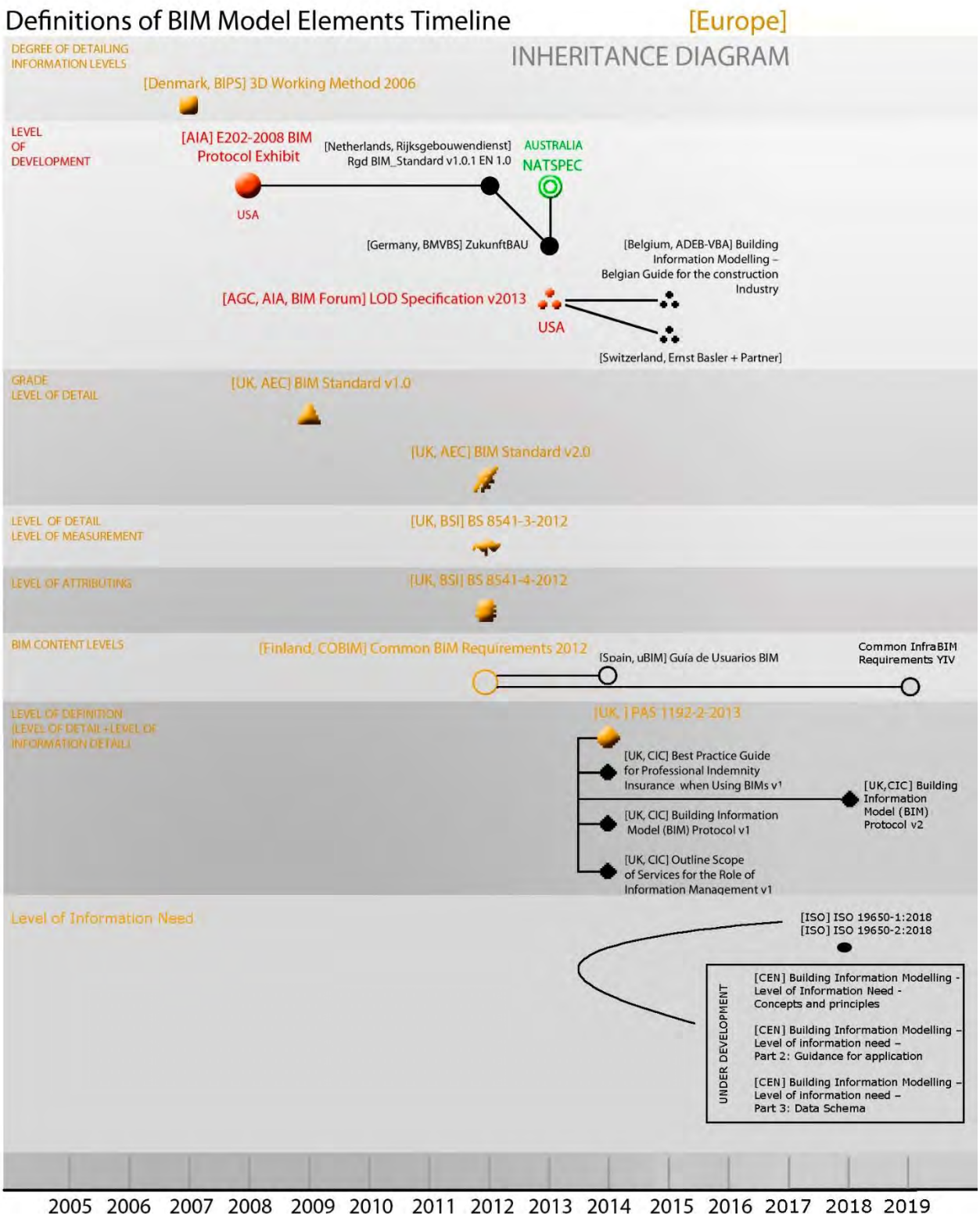


Figure 2-12: Europe Timeline-Inheritance diagram

Table 2-16: Europe LOD features

Year	Organisation and standard name	Classification	Stage and dependency	BIM use	LOD types	Illustrations or attributes
2007	[Denmark, BIPS] 3D Working Method 2006	DBK	End of project stage / Not dependent	Modelling, Estimating, Coordination, Planning, Logistics, Operations Maintenance	0,1,2,3,4,5,6	Attributes
2009	[UK, AEC] BIM Standard v1.0		Not Found	Not Found	Low resolution, medium resolution, high resolution	Illustration
2012	[UK, AEC] BIM Standard v2.0		Not Found	Not Found	0,1,2,3	Illustration
2012	[UK, BSI] BS 8541-3-2012		Not Found	Modelling, Coordination, Visualisation	LOD: Schematic, Coordination, Visualisation LOM: Characteristic, Standard, Method based	Illustration
2012	[UK, BSI] BS 8541-4-2012		Not Found	Not Found	Specification, Assessment, Simulation	Not Found

Year	Organisation and standard name	Classification	Stage and dependency	BIM use	LOD types	Illustrations or attributes
2012	[Finland, COBIM] Common BIM Requirements 2012	Talo2000	End of project stage / Dependent	Collaboration, Communication, Modelling, Energy analysis, Estimation, Planning and Procurement	1,2,3	Not Found
2013	[UK] PAS 1192-2-2013	NRM1, CESMM, Uniclass, NRM3 dependent on stage	End of project stage / Dependent	Design, Analysis, Coordination, Sequencing, Estimating, fabrication, capture of as installed information, operation, maintenance, performance	1: Brief, 2: Concept 3: Definition 4: Design 5: Build and Commission 6: Handover and closeout 7: Operation	Illustration
2014	[UK, BSI] BS1192-4_Collaborative production of information Part 4	Uniclass, CIC, RICS SFCA, RICS NRM	Not Found	Operation and Maintenance	Not Found	Attributes

Denmark_3D Working Method 2006 (Degree of Detailing)

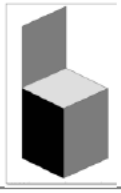
As early as 2006, BIPS published the 3D Working Method 2006 for its use in Denmark. This guide makes a clear distinction between creating drawings and building models to be used within object-based software (Bips, 2007). The LOD is divided into 7 different phases. The guide makes these stages correspond with the Danish DBK classification system project stages but encourages its use within other stages and methods. The degree of detailing is classified per actors or disciplines. For example, only the architects' model is described, whereas other disciplines such as structures, services can be inferred from the given information. Furthermore, the DBK is encouraged to be used to define the building model. Seven different BIM uses (Modelling, estimating, coordination, planning, logistics, operations and maintenance) can be inferred from the information levels descriptions, however, there is no mention of authorised uses. The Layer and Object Structures 2006 published in Danish, provides a guidance on model attributes per level of detail (Bips, 2006).

United Kingdom_ Architectural, Engineering and Construction (AEC) UK BIM Standard V1 and v2

The United Kingdom has made several attempts for defining model element progression specification. In 2009, the *Architectural, Engineering and Construction (AEC) UK BIM Standard* was released and later modified in 2012 (AEC UK, 2009). Fifteen experts from the UK compromising architectural, engineering, and construction authorities, and model content creators collaborated to create a transition from CAD to BIM. The guideline contains references to typical drawing scales for a total of 12 BIM uses such as fabrication,

sequencing, energy analysis among others. The guide only sets three grades of detailing according to graphical information resolution. It recommends creating fit to purpose models in order to ensure the most efficient use of PC processing power. These grades are the following: Low resolution, medium resolution and High resolution which corresponds to different drawing scales.

Table 2-17: AEC UK BIM Standard LOD in relation to scale

"Low resolution" Component grade	**"Medium resolution" Component grade**	**"High resolution" Component grade**
1:500-1:200	1:200-1:50	1:5 or 1:1.
		

The version 2 of the *AEC UK BIM Standard* makes a classification which is similar to its predecessor guide (AEC UK, 2012). Within version 2, there are 4 graphical model representations instead of 3, named: 0 schematic, 1 Concept, 2 Defined and 3 Rendered. However, the most recent guide does not compare drawing scales with BIM objects and expressly breaks the bind between metadata and graphical representation. For example, it explicitly suggests that full manufacturer product metadata such as cost and product specification could be associated to a low-level representation of the product. Furthermore, the level of detail should be managed to fit the intended purpose. Insufficient information level of detail and the model will not be able to be used for its intended use. However, if too much information is put into it, the information can become unmanageable.

United Kingdom_ BS 8541-3:2012

The British Standard Institution (BSI) created the *BS 8541-3:2012 Library objects for architecture, engineering and construction. Shape and measurement - code of practice, 2012* Technical Committee B/555 created a standard that provides a definition for Level of Detail and Level of Measurement (BSI, 2012a). The first term defines the virtual shape representation of an object and the second defines its physical properties (BSI, 2012a). The committee is composed of representatives from architecture, surveying, building services and architectural technologists-chartered institutes. Representatives from universities, computer societies and manufacturing associations are also part of the committee.

The Level of detail is prescribed for specific uses such as coordination, quantity take off and visualisation. This is complemented with the level of measurement definition which defines the measurement detail of the virtual object. Table 2-17 Is coincident with the level of detail described within the *BS 8541-3:2012* standard. Even the graphical appearance is the same as the *AEC UK BIM Standard*, only the description of the model differs. The less accurate representation of the model is called schematic level of detail; it represents the space occupied by the object and connections or relationships with the environment. The medium level of detail is called coordinating level of detail; this level is similar to the AIA 300 LOD and is useful for coordinating disciplines, special allocation and clash detection. The most accurate visualisation level of detail (similar to AIA 300-400) is used to render images or simulate connections. Therefore, the three different levels correspond to different intended uses.

The "Level of measurement" is described by defining three different aspects (BSI, 2012a). The first one is named Characteristic level of measurement and it is related to the object overall dimension and mass. The second is called Standard level of measurement characterised by its main dimensions, volume and areas. Finally, the *Method-based level of measurement* allows for quantity take offs, bill of quantities or to predict the service life of the object and is based on standards such as the *NR", RICS SMM*, the *ICE CESMM4* or *ISO 15686-4* for the estimated service life of the object (BSI, 2012a).

United Kingdom_ BS 8541-4-2012

The BSI also created *BS 8541-4-2012 Library objects for architecture engineering and construction – Part 4: Attributes for specification and assessment – Code of practice.* This guide proposes a definition for level of information called Level of Attributing. This guide recommends using measure naming conventions based on the BS ISO 80000-1. Furthermore, it encourages using IFC property sets, attributes, and units of measure. This allows for internal and external databases consistency. Three levels are proposed: Specification level of attributing (sufficient to select and replace the object), assessment level of attributing (economic and environmental impact attributes) and simulation level of attributing (performance attributes). The standard states that the specification of attributes should considered the intended object BIM uses.

United Kingdom_ PAS 1192-2:2013

In the United Kingdom (UK), the *PAS 1192-2:2013* defines the "Level of Definition" (LOD). The document includes the Level of Model Detail and the Level of Information Detail. The first definition stands for the description of graphical content of models, whereas the second definition, on the contrary, stands for the content description of non-

graphical models (BSI, 2013). This graphical and non-graphical information progresses along the different project stages and is managed by a "Common Data Environment" (CDE), which is defined as the single source of information of the project (BSI, 2013). The CDE requires a project server, an extranet or a file based retrieval to store and manage information and management processes to coordinate the team (BSI, 2013). These processes are defined in the *"BS 1192:2007 Collaborative production of architectural, engineering and construction information – Code of practice"* (BSI, 2007). The different project stages presented in the PAS 1192-2 CDE are called "Levels of Model Detail" and "Levels of Model information" and are consistent with the "CIC scope of services" stage definitions, the "RIBA Plan of work stages" and the "Association of Project Management (APM)" stage definitions (BSI, 2013).

Table 2-18 compares the different project stages defined by different associations and Table 2-19 Describes the "Levels of Model Detail" and "Levels of Model information" defined in the PAS 1192-2 from the brief stage to the in-use stage. Textual definitions define what the model can be relied upon (construction, cost, logistics). Some uses are also suggested such as design, analysis, coordination, sequencing, estimating, fabrication, capture of as installed information, operation, maintenance, performance. However, there is not any reference to attribute information. In the UK, the figure of the Information Manager is legally specified within the UK, CIC Outline Scope of Services for the Role of Information Management (CIC, 2013c). This professional oversees managing the information for a construction project. The information can be managed using the Model Product and Delivery Table defined within the CIC scope of services. Table 2-18 gives a list of BIM uses in order to define the extent which the data could be relied upon. The UK has taken special care about legally binding this document (i.e. if the CIC scope of services

is used, there is a legal requirement to appoint an information manager who will be responsible of checking the accuracy of data). Insurers, then have an overview of the liabilities of the several parties involved within the project (CIC, 2013a).

Table 2-18: RIBA, CIC and APM stages equivalence to PAS 1192 LOD

RIBA Plan of work stages (RIBA, 2013)	CIC Stage Definitions (CIC, 2007)	APM Stage Definitions (CIC, 2013b)	LOD definitions (BSI, 2013)
0 Strategic Definition		0 Strategy	
1 Preparation and Brief	1 Preparation	1 Brief	1 Brief
2 Concept Design	2 Concept	2 Concept	2 Concept
3 Development Design	3 Design development	3 Definition	3 Development Design
4 Technical Design	4 Production information	4 Design	4 Production
5 Construction	5 Manufacture, installation and construction information, and	5 Build & Commission	5 Installation
6 Handover and Close Out	6 Post practical completion.	6 Handover & Close out	6 As Constructed
7 In use		7 Operation and end of cycle	7 In use

Table 2-19: Table A.3- LOD definitions (BSI, 2013)

Brief	At this stage, the graphical model may either receive information from the Asset Information Model (AIM) or not be defined.
Concept	A generic element in the graphical design might only display a massing diagram or a 2D symbol.
Definition	This stage allows a generic representation of the object which contains information enough to select a manufacturer.

Design	At this stage the element should contain the specification attached and should be represented in 3D. This stage defines the Level of Detail required that should show the element space for maintenance installation and replacement and the operational space.
Build and commission	At this stage, the manufacturer´s product should replace any generic object. The Level of Detail will be enough to convey installation and design intent.
Handover and close-out	At this stage the model should contain the necessary information to represent an as-constructed model in content and dimensional accuracy. Moreover, should contain all the manufacturer´s maintenance and operation documentation, final COBie information exchange, health and safety and relevant documentation.
Operation and in-use	At this stage the performance of the project is contrasted against the Employer Information Requirements and the Brief, updating the information if required. Furthermore, the in-use stage requires updating the information with replacement dates and maintenance records.

Finland, COBIM Common BIM Requirements 2012.

In Finland, the Common BIM Requirements 2012 (COBIM) guideline is an initiative of the Technical Committee TK 320 of the private foundation Building Information Foundation RTS. This task group is composed of representatives from software, architecture and engineering companies. Representatives from universities, BuildingSMART and public authorities are also part of the committee (Gravicon, 2012).

This guideline defines 3 BIM content Levels. These levels depend on the BIM use and stage. However, there is not a clear connection between stage and BIM content Levels. On the contrary, BIM uses are defined per each level (Gravicon, 2012). For example, Level 1 requires the model to be used for communication and collaboration. Level 2's most typical use is energy analysis during the pre-design and sketch design phases of the

project. This level is also used for the bidding phase quantity take-offs, while Level 3 describes the construction, scheduling and contractor purchasing.

The guide encourages agreeing the information beforehand using the Architect's Model content requirements table, which uses the Talo 2000 classification, leaving the designer free to sort the BIM content level per stage (Gravicon, 2012). The guide describes that the product naming evolves with the object, for example for Level1 building parts are named using a description of the object, whereas for Level 2, there is a clear naming convention and cost information can be inferred from the model.

2.4 Current processes for the deduction of BIM data

2.4.1 Product Data Templates

In the UK, Product Data Templates (PDTs) are created by the Chartered Institute of Building Services (CIBSE) as a solution to avoid manufacturers completing bespoke data sheets for contractors and designers. These templates are a standardised data repository for every product type (see Table 2-20 for an example).

Table 2-20: Cable Ladder (Lengths) PD Sheet example (CIBSE, 2015c).

Template Category	*Cable Ladder (lengths)*			
Category Description	*System component (length) used for cable support consisting of supporting side members, fixed to each other by means of rungs. Component utilises fittings to*			
Information Category	Parameter Name	Value	Units	Notes
Manufacturer Data				
Specifications	Manufacturer	Legrand Electric Ltd	Text	
Specifications	Manufacturer Website	http://www.legrand.co.uk/home	URL	
Performance Data				
Specifications	Reference	BS EN 61537	Text	Load tests carried out to
Sustainability				
Sustainable Material BREEAM	Embodied Carbon	n/a	kgCO2	Awaiting Industry

The idea behind the PDT is to have a standard form, which can be populated with data from the manufacturer and become a non-graphical description of the product (CIBSE, 2015a). Currently, successful BIM product library management implies the integration of manufacturer's PDTs within the downstream supply chain agent's IS. The following non- linear steps are needed to integrate the PDT within the AEC IS (see Table 2-21 and Figure 2-13):

- **Collect knowledge:** Manufacturer product specification data (explicit Knowledge) is selected to be included within the PDT. The data is organised

into sections, horizontal rows in Table 2-20, which corresponds to predefined BIM uses. The CIBSE oversees the creation of the PDT, which should be elaborated in collaboration with manufacturer's experts for a specific product (CIBSE, 2015a).

- **Record Knowledge:** The PDT vertical value column (Table 2-20) is filled with manufacturing data. While, the previous step consisted on gathering attributes from paper specifications, this stage defines the attributes with parameters (text or numbers). When this process is finished, the PDT becomes a Product Data Sheet (PDS) (CIBSE, 2015a).
- **Store knowledge:** The PDT is stored within the CIBSE website. Manufacturer's PDTs for different construction products are published within the CIBSE website: http://www.cibse.org/knowledge/bim-building-information-modelling/published-pdts. Manufacturers should then download the PDTs from the CIBSE website and complete the value column as shown in Table 2-20. Manufacturers then become responsible for the accuracy and completion of the data, which can be shared with clients from their company websites (CIBSE, 2015a).
- **Share knowledge:** The next phase needed to complete the BIM IS data is to create a Product Data Set (PDS). Designers can download the PDS from the manufacturer's website. Once the PDS is in possession of the designer, the data is sourced and downloaded into the project. This PDS is contained as an Extensible Mark-up Language (XML) spreadsheet which makes the information interoperable and manageable electronically (CIBSE, 2015a).

Table 2-21: PDT Information System implementation description.

	Collect knowledge	Record knowledge	Store knowledge	Share knowledge
PDT knowledge collection process scenario	Data collection: Manufacturer BIM manager and CIBSE experts	XML Excel spreadsheet	Manufacturer Website	Revit model + XML data

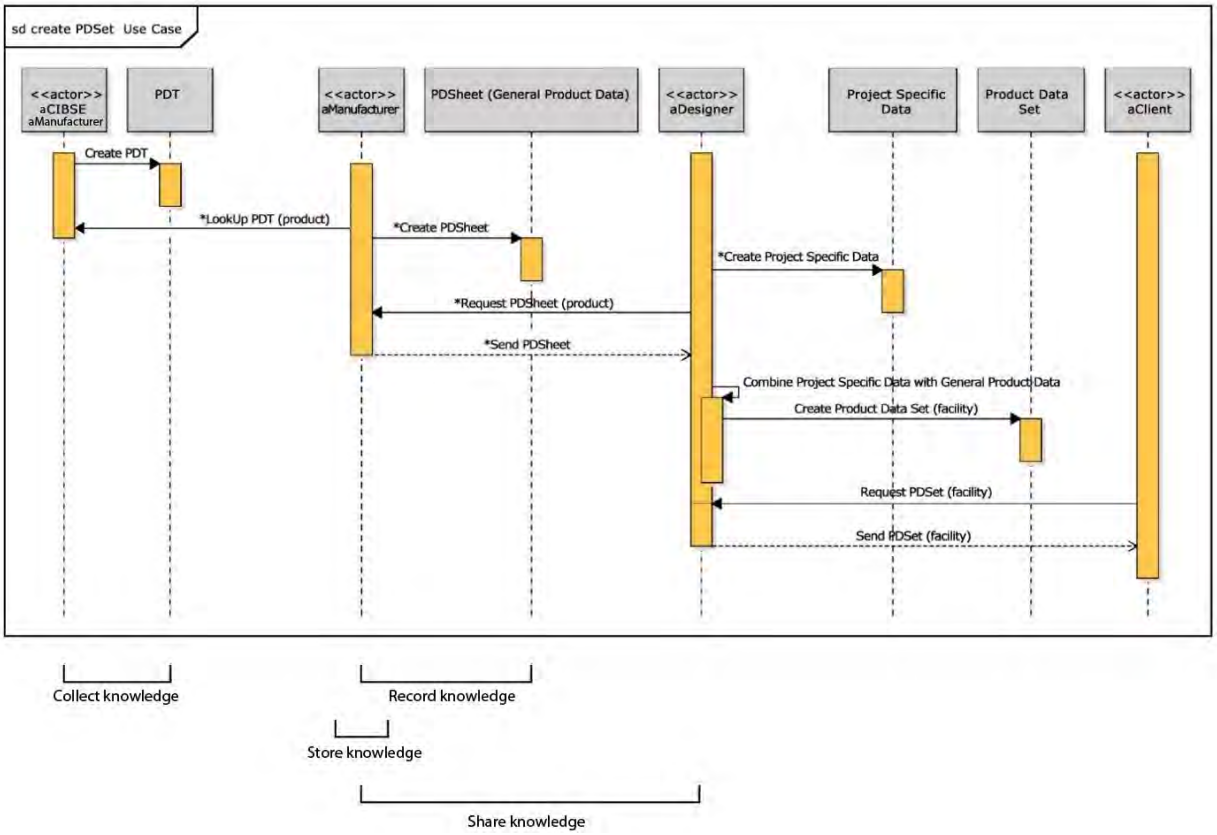


Figure 2-13: Sequence diagram of the PDT integration within the AEC IS.

2.4.2 Information Delivery Manual

While the PDT is a solution based on collecting data from paper product specifications and transcribing them into an electronic XML format, the IDM provides a framework for the creation and maintenance of BIM object data to be included within IS.

According to Berard and Karlshoej (2012), IDM is a business process modelling language based on the BPMN, which consists of the following perspectives (see Figure 2-14): "*process map (behavioural), narratives (organisational), exchange requirements (informational), and narrative business rules (functional)".* Curtis et al. (1992), further explains these dimensions:

- The behavioural perspective represents when the processes are performed (i.e. project stage) or how they are performed (i.e. feedback loops).
- The organisational perspective represents which agents perform the process elements (i.e. engineer, architect, and so forth).
- The information perspective represents the information entities produced by a process (i.e. attributes such as weight or object type).
- Finally, the functional perspective represents what information entities are important for that process (i.e. window width).

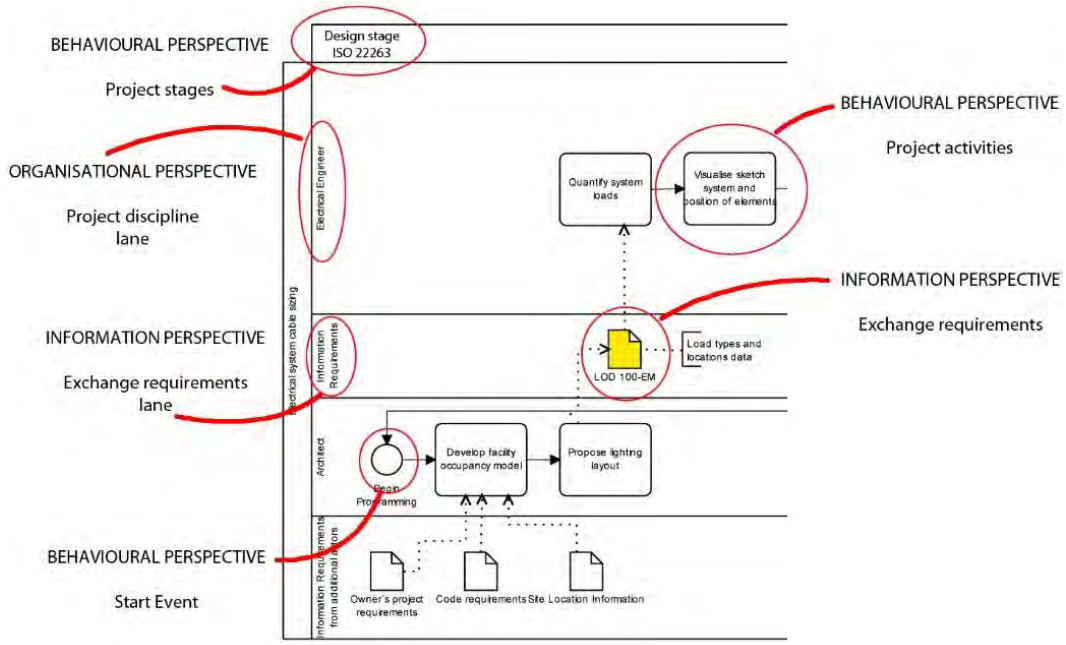


Figure 2-14: IDM BPMN perspectives adapted from Aram et al. (2010).

A review on the BPMN 1.1 conducted by Recker (2010) provides insights about the way BPMN was implemented for process modeling. Three of the perspectives (functional, behavioural and organisational) had scope to improve, while the information perspective was not studied. Similarly, a review carried out by List and Korherr (2006) raised concerns about the implementation of the organisational and informational perspective. Berard and Karlshoej (2012) argues that the IDM language was proposed to overcome the BPMN 1.1 shortcomings.

The IDM is a business process modelling language needed to certify IFC Software (Wix and Karlshøj, 2010). Since the publication of the IDM (ISO, 2010), several business processes have been captured using the IDM specification. For instance, the IDM has been used in a research study to capture precise data and processes for architectural precast concrete (Eastman et al., 2010). MVD, which are subsets of the IFC format are documents used by software developers for IFC implementation within interoperable software (Wix and Karlshøj, 2010). It has been demonstrated that the MVD requires a clear definition of

the IDM Exchange Models (EM), which are information exchanges (see) between tasks and processes (Nawari, 2012). In relation to this fact, authors such as Eastman and Sacks (2010) and Eastman et al. (2010) argue that data sets could be used without the required binding of data to a data structure required for the creation of MVDs, thus easing the IDM development process. Therefore, within the present research, the IDM provides a simple framework (see Table 2-22) needed to capture data from processes to be incorporated within BIM models for Level 2 purposes. For example, the output could be 3D models and XML data. The IDM also sets a starting point from where to develop Level 3 BIM interoperable data.

Wix and Karlshøj (2010) define the steps needed for the creation of data sets and its inclusion within information systems. These steps are summarised in the following point:

- Create knowledge: The process map creation process requires a collaborative team of industry professionals. The process map will represent a business process (from a behavioural and organisational perspective), where the data sets or exchange requirements are identified by industry professionals (information perspective). Finally, if required, business rules (functional perspective) are defined to determine properties or attributes to be asserted or to control its values.

Table 2-22: IDM Information System implementation description.

	Create knowledge	Record knowledge	Store knowledge	Share knowledge
IDM	Data mining	XML Excel	Manufacturer	Revit model + XML

knowledge creation process scenario	using the BPMN: Manufacturer BIM manager, Industry specialist and CIBSE experts	spreadsheet	Website	data

2.5 LOD metrics review

There have been several attempts to define BIM metrics within the literature. The analysis of both model (product) and modelling (process) is the focus of this literature review.

The BIM Cloud Score (BIMCS) roadmap (Du et al., 2014, Liu et al., 2016) was proposed as a cloud-based tool for benchmarking BIM models and processes from end-users. Liu et al. (2016), validated an initial list of categories and metrics. The study proposes Quality, Accuracy, Usefulness and Economy as model categories and Productivity and Effectiveness as modelling categories. A list of 26 metrics was shortlisted. The presence of LOD within the metrics is reduced to the Economy and Productivity categories, which are respectively defined as the most cost and efficient manner to create a model and the speed to which a model is created. Abdirad (2017), analysed a total of 97 references to classify metrics for BIM implementation. The author differentiated between qualitative metrics and criteria-like factors/indicators.

Wood et al. (2014), studied the impact of LOD in cost databases for different structure types with the purpose of having a greater understanding of design decisions on cost. Within this study cost attributes were linked to the model to study cost

performance. Leite et al. (2011), evaluated the modelling effort associated to different LODs. This was measured by recording the modelling time spent and the number of objects as per LOD. The impact of the model´s LOD in the decision-making task that it needed to support was measured using clash detection recall and precision metrics (Leite et al., 2011).

2.6 Research Strategy

2.6.1 Objective 1

Start-up and Diagnosis

This Objective entailed portraying a situation or phenomenon (the implementation of Level 2 BIM and Level 3 BIM within the UK electrical manufacturing industry). Therefore, according to the Robson (2002) purposed based classification of research studies, this was a descriptive case study.

The data collected during this stage is qualitative in nature, as it depicts a highly realistic context (meetings within the BIM4M2 UK manufacturing workgroup), where the parameters of study might change or be flexible as the study develops. This contrasts with quantitative fixed methods where the key parameters to measure or analyse are set from the beginning. Therefore, the data is based on words, descriptions, pictures, diagrams etc., rather than statistical data.

2.6.2 Objective 2

This section has been partially published in the publication number 2 of Section 1.7.

Intervention

A case study is an empirical method aimed at "*investigating contemporary phenomena in their context"* (Benbasat et al., 1987, Robson, 2002, Yin, 2013). This includes trying to understand the phenomena from an interpretive research perspective, from the participants' point of view (Klein and Myers, 1999). The present case study uses a UK manufacturer to investigate the intricacies of the LOD to specify model element data using the IDM BPMN for its inclusion within manufacturers' IS. According to Robson (2002) classification of interpretive studies, this case study is exploratory in nature. The research investigates the role of the manufacturing company BIM manager and looks to seek and generate new insights and ideas to create hypotheses for new research exploratory studies.

Transition

The AR approach used is focused on results and it values participation and the manufacturer's contribution, as it assumes their acceptance of the changes associated. In Information Technology applied to construction, AR has been proved useful for investigating IDM creation (Berard and Karlshoej, 2012). This methodology is used within this study in Section 3.2.2 to investigate how BIM could affect the interaction between manufacturers and the downstream agents of the building environment and consequently change the current reality of the organisation towards another paradigm not yet defined.

2.6.3 Objective 3

This section has been partially published in the publication number 4 of Section 1.7.

Meta-analysis is a recurrent quantitative approach to analyse literature. It is based on statistically significant results. However, Petter et al. (2008) has argued that a meta-analysis only shows correlation between constructs and are not suitable for establishing the boundaries of a theoretical framework. For example, it does not allow to show the direction of causality (i.e the order in which one factor affects the other) because the result is an effect size statistic adjusted for correlation between two variables. On the contrary, the method used to create the preliminary framework in Section 3.2.3 shows the boundaries of the framework and its causal directionality.

2.6.4 Objective 4

According to theory, Runeson and Höst (2008) case studies are suitable for software engineering research. However, it must be noted that the results that they do not generate casual relationships between data as analytical and controlled experiments. It is argued than that a proper methodology must be set to mitigate the problems arising from this bias.

According to Robson (2002), the following methodology is explanatory, as it seeks an explanation for a problem. However, because of the nature of the case study it will not necessarily justify a causal relationship.

2.7 Chapter summary

This chapter reviewed the available literature surrounding BIM Level 2 and Level 3 BIM and its relationship with standards and protocols. A holistic approach to LOD management was presented; however, focus was given to the key areas of implementation

within Level 3 BIM, more specifically the IDM standard. Gaps in the literature are presented as lack of a Level 2 BIM method to create Model Data. The IDM Level 3 BIM standard was presented as a possible solution with limited applicably to the LOD standard. The research methodology is presented in Chapter 3.

CHAPTER 3: RESEARCH METHODOLOGY

3 Research Methodology

3.1 Research Strategy

This section has been partially published in publications number 2 (Objective2) and 4 (Objective 3) of Section 1.7.

The first part of the study (Objective 1) is phenomenological in nature as it requires the researcher to be actively involved in the implementation practices that an electrical manufacturer is carrying out to obtain BIM organisational efficiency within their BIM objects. The research also involves evaluating and critically reflecting on the evidence gathered from interviews, workshops and case studies carried out within the case study organisation (Objective 2). This type of research is referred to as Action Research (AR) and is a method that aims to improve peoples' practical concerns (Gilmore et al., 1986) and acts as a catalyst for aligning people, processes and practices (Jones and Brazzel, 2014). Within this research, AR is used to change a company from an actual State A: "PDT knowledge collection process scenario" to a desired future State B: "IDM knowledge creation process scenario".

AR is implemented in a spiral of steps, each composed of a circular process of "planning, action and fact finding about the result of the action" (Jones and Brazzel, 2014). AR involves data gathering methods and interpretive methods such as interviews, focus

groups, observation, simulations, and surveys among others (Jones and Brazzel, 2014). AR is based on a sequence of stages that can be conceptualised into four steps (Jones and

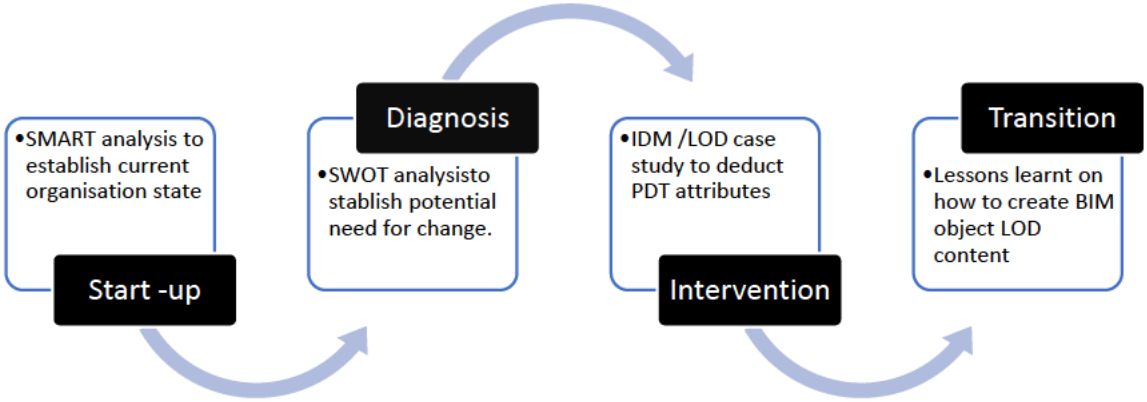


Figure 3-1: Action research stages

Brazzel, 2014): Start-up, Diagnosis, Intervention and Transition, as shown in Figure 3-1.

The second part of the study (Objective 3) is performed to study the LOD concept under the IDM perspectives. Grounded theory is a method that help researchers to construct theory based on inductive reasoning (Charmaz, 2015). The method is qualitative in nature and establishes a systematic approach to data gathering, synthesis, analysis and conceptualisation (Charmaz, 2015). Coding, memo-taking and theoretical sampling methods were used as explained within Charmaz (2015) (see Figure 3-2).

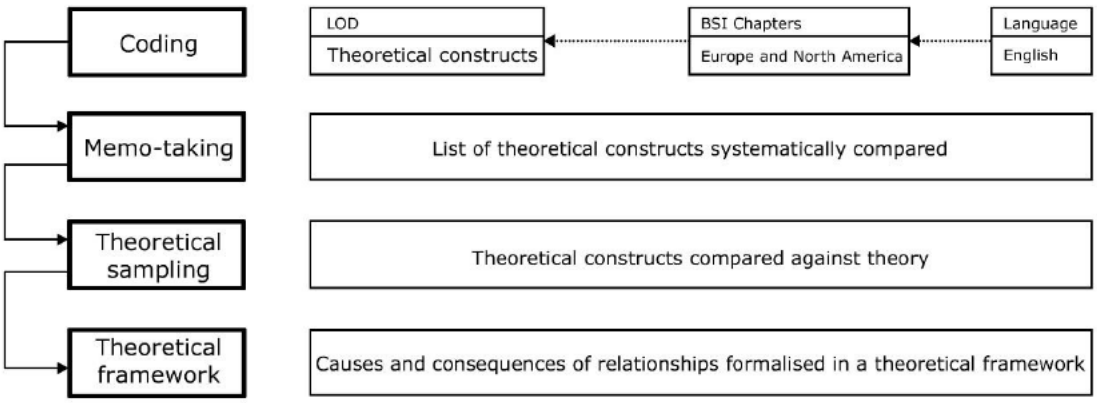


Figure 3-2. Grounded theory methodology modified from Charmaz (2015).

According to Robson (2002), the validation part of the present study is explanatory in nature, as it seeks an explanation of a problem. This is the usage of the LOD in AEC projects. A hypothesis was created using the LOD Grounded Theory Framework. This hypothesis was tested, and the conclusions helped to add to the knowledge of the LOD concept.

3.2 Applied Research Method

The applied research method in this thesis is presented in this section. Figure 3-3 presents the roadmap followed by the researcher to accomplish the objectives from Section 1.5.

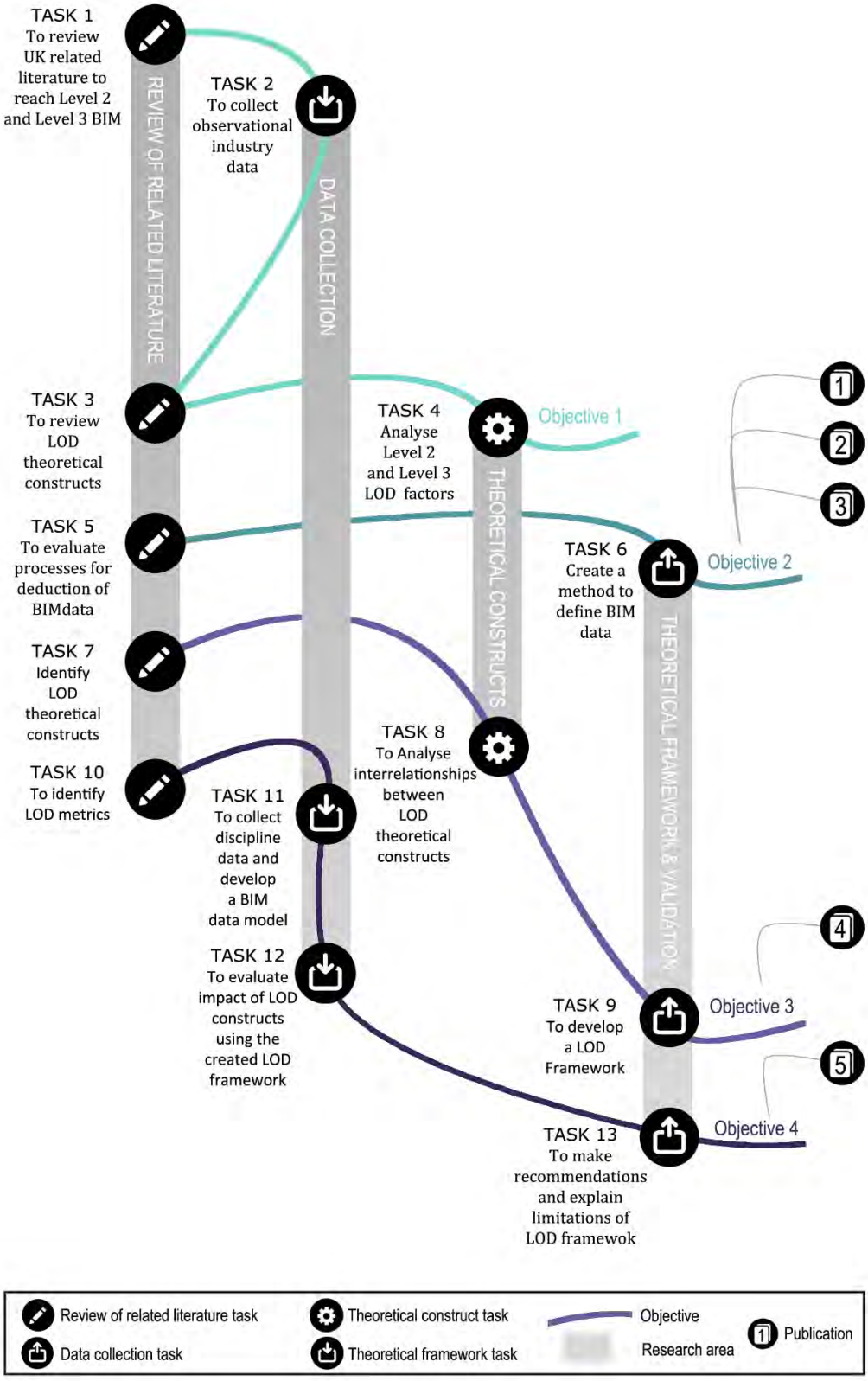


Figure 3-3: Graphical representation of research objectives and task

3.2.1 Objective 1

The first objective of the thesis is exploratory in nature. It established the scope of research through an extensive literature review followed by complementary collection of industry data and an additional review on LOD theoretical constructs that helped to narrow the scope. Finally, Level 2 BIM and Level 3 BIM current implementation factors leading to BIM Model specification were analysed, which prepared the field to perform Objective 2. The tasks for this objective were (see Figure 3-3):

- Task 1: To review UK related literature to reach Level 2 and Level 3 BIM (Chapter 2, Section2.2).
- Task 2: To collect observational industry data related to BIM Model LOD specification (Appendix A and Appendix B).
- Task 3: To review LOD theoretical constructs (Chapter 2, Section 2.3).
- Task 4: To analyse Level 2 and Level 3 factors leading to BIM Model LOD specification (Section 4.1).

The tasks required to accomplish this objective are further explained below:

Task 1

The literature review task consisted of an extensive search of level 2 BIM and Level 3 BIM standards and methods related literature. This was needed as to explore the topic to the extent required to advance in one particular BIM aspect. Output from this task is included in Section 2.2.

The literature review was undertaken by searching Journal articles, Government and public institution standards, reports and guidelines. Also, websites from Government agencies and public institutions that contained information related to BIM implementation were included within the search.

A systematic approach was taken by searching within the following journal databases:

- ASCE library from the American Society of Civil Engineering.
- Scopus from Elsevier.
- Mendeley from Mendeley.
- Compendex from Elsevier.
- IEEE Xplore from IEEE.
- Web of Science from Clarivate Analytics.

The following search engines were used:

- Google from Google.
- Google Scholar from Google.
- FindIt@Bham from the University of Birmingham.

The main specific terms used when searching for resources were the following:

Table 3-1: Search criteria for Task 1.

Level 2	Level 3
LOD	LOD
Interoperability	MVD
Parametric Modelling	IFC
PDT	IFD
PDS	
MPDT	
MIDP	
BIM PAS standards	

The inclusion criterion was meticulously followed to include sources directly related to Level 2 BIM and Level 3 BIM implementation. Also, qualitative and quantitative studies were included. The age of material criterion was different for journal articles and government or public institutions publications. Only journal articles newer than 10 years since publication were included, whereas for government and institution sources, 2 years since the publication was the maximum established. As for the geographical location, only UK standards and guidelines were searched. However, the journal articles included any material published in English.

Task 2

The literature showed the lack of a method to specify information for BIM models (Section 2.4), which indicated the need to complement Task 1 with the collection of observational data from the industry in order to find out current methods to specify BIM Model information not published within the literature in Section 2.4.

To gain a greater understanding of the current industry efforts to manage BIM Model Element data, Legrand Electric Ltd., an electrical manufacturer based in the UK was chosen as in the year 2015 as they were actively involved in UK industry working groups such as BIM4M2 (BIM for Manufacturers and Manufacturing) (See Appendix A for letter of support). The selection of the case study was done based on its unique characteristics as recommended by Benbasat et al. (1987). For example, BIM4M2 tasks involved the elaboration of methods and standards needed to specify BIM model elements graphical and non-graphical information.

The selection of the units (Decisions taken to implement graphical and non-graphical data within BIM models), has been taken based on the need to complement the Section 2.4. findings with observational data" (see Table 3-2).

Table 3-2: Case and Unit of analysis studied within the Start-up stage

Case	Unit of analysis
UK Level 2 and Level 3 implementation within Legrand Electric Ltd.	Decisions taken to implement graphical and non-graphical data within BIM models.

The researcher was invited to a total of 3 meetings were measures to implement Level 2 processes for BIM specification of data were discussed.

- 1st meeting: 16th of February 2015. BIM4M2 meeting (see Appendix A, Table A-0-1).
- 2nd meeting: 25th of February 2015. Legrand Ltd. Internal meeting (see Appendix A, Table A-0-2).

- 3rd meeting: 27th March 2015. BIM4M2 meeting (see Appendix A, Table A-0-3).

The advantage of using observation in meetings is that they provide a real view of the matters discussed in comparison with official versions reproduced on the BIM4M2 website (BIM4M2, 2015) or final meeting minutes. Within this stage, the researcher acts as a mere observer, only taking notes on important matters related to BIM Model data specification.

A tacit agreement was made on not to publish the minutes of the meeting in any journal papers and to keep them only for the thesis reviewers. Within these meetings, as recommended within Robinson et al. (2007), there was a low degree of interaction by the researcher as to not influence the course of the actions. This helped the members to discuss important issues with a low awareness of being observed and allowed the researcher to collect full detailed data on the unit analysed "Decisions taken to implement graphical and non-graphical data within BIM models" (see Table 3-2).The template form used within the meetings contains the following fields: date, organisation studied, codes aligned with the search criteria on Task 1, documents discussed and a final field for the minutes of meeting (See Appendix A and Appendix B tables).

Task 3

Task 3 helped to define better the search criteria in Task 1. After collecting industry data in Task 2, Task 3 consisted of an extensive review of LOD theoretical constructs such as BIM uses, project stages and classification systems and presented in Section 2.3, This was needed as to prepare the field to analyse Level 2 and Level 3 LOD factors in Task 4.

The methods used to review the literature were the same as in Task 1, except for the search criteria used for this stage which is shown in Table 3-3 below:

Table 3-3: Search criteria for Task 3.

LOD
BIM uses
Project stages
Classification systems
LOD
Scale

Within this task any material published in English was included and any other language was excluded from the search criteria.

Task 4

To analyse Task 1, Task 2 and Task 3 in order to describe what is needed to identify factors associated with LOD implementation into BIM Information Systems (IS) to achieve Level 2 and Level 3 purposes (See Section 4.1).

1. First, the Level 2 processes for creating PDTs and associated data attributes was synthetised in 2.4.1.
2. Second, industry guidelines were compared to a current PDT (See Table 1-1) in order to find the gap in data specification.
3. Finally, Level 3 BIM processes for creating BIM model data were investigated in Section 2.4.2.
4. The results of this section were used in Objective 2 to create a novel method to define BIM model element data.

3.2.2 Objective 2

This section has been partially published in the publication number 2 of Section 1.7.

Objective 2 focused on developing a method to define LOD non-graphical information for incorporation within BIM models. This was used in Objective 4, Section 3.2.4 to validate the proposed LOD framework (output of Objective 3, Section 3.2.3).

The outputs of this objective are the conference paper 1 and journal papers 2 and 3 listed in Section 1.5.

The tasks for this objective were (see Figure 3-3):

- Task 5: To evaluate processes for the deduction of BIM data (Sections 2.4.1 and 2.4.2).
- Task 6: To create a method to define BIM data (Section 4.2.3).

The tasks needed to accomplish this objective are further explained below:

Task 5

The "Start-up" stage within this research consists of a SMART analysis, which stands for "Specific, Measurable, Attainable, Realistic and Time sensitive objectives" (Shahin and Mahbod, 2007). A workshop was set up to increase awareness of Legrand Ltd. UK processes to specify BIM Model Data.

The workshop took place on the 3rd of April 2015. The Legrand UK Ltd. BIM manager role for the consecution of the workshop was to reflect on his company´s current practices and fill in the form in Appendix B, Table B-0-1. The results of the workshop are shown in Section 4.2.1.

The second stage is “Diagnosis” and involves establishing whether a change is desirable in the current way the data was being specified.

A SWOT analysis, which acronym stands for “Strengths, Weaknesses, Opportunities and Threads” was performed to investigate the benefits and drawbacks of implementing the BIM Model data specification methods found within the Literature (Sections 2.4.1 and 2.4.2).

The SWOT workshop took place just after the SMART analysis on the 3rd of April 2015. Before the workshop took place, two paradigms were presented to the Legrand UK Ltd. BIM Manager: The paradigm A entailed the use of PDTs (see Section 2.4.1) and the paradigm B was the use of the IDM (see Section 2.4.2). After these were explained, the BIM manager had to critically analyse them as per the SWOT fields described previously. The results of this analysis are shown in Section 4.2.2. The data was recorded in Table B-0-2 and Table B-0-3. This data was analysed in conjunction with the literature review of Chapter 2. i.e selecting a unit of analysis from the SWOT table and comparing it with Chapter 2 literature review.

Task 6

To create a method to define model element data in relation to client’s processes at different LOD’s for its inclusion within manufacturer’s information systems.

Intervention Stage

The “Intervention” stage (Section 4.2.3), helps the company to adapt to the new paradigm “IDM knowledge creation process scenario”. Thus, a case study based on the IDM methodology and LOD was carried out to deduct attributes for the creation of PDTs.

The output from this stage is a process used to generically create attributes for its inclusion within IS (See Section 4.2.3).

Case and subject's selection

The University of Birmingham invited Legrand Electric Ltd. to collaborate with this project in an initial interview. The target company (Legrand Electric LTD.) is a global electrical product manufacturer with presence in nearly 90 countries around the world. A letter of support was created by the Legrand´s marketing director on support of the project where they committed to invest time and to grant access to required data to perform the present research (See Appendix A, Letter of Support).

The selection of the company was arranged according to Benbasat et al. (1987) and Flyvbjerg (2006) recommendations. i.e. the case selected must be revelatory and unique.

The company case study selected is revelatory and unique in the sense that the literature does not document any other approaches to LOD creation from the point of view of manufacturers and product specification data. (See Section 2.4). A process for specifying LOD data within the manufacturing industry is studied in context. Therefore, the chosen working group consists of a manufacturer BIM manager (responsible for BIM strategy, sales, and knowledge about products), who represents Legrand Electric Ltd. UK, an electrical engineer (responsible for electrical process supervision) from the same company and the researcher (IDM and academic monitoring) from the University of Birmingham, UK.

Berard and Karlshoej's (2012) study on the IDM functional behaviour, uses Supply Management Theory to classify manufacturing products. This classification was used within this study to generalise the results and identify any limitations within the product studied. The classification is as follows: Made to stock (e.g. Cable tray or drywall), Made to order (e.g. windows) and Engineered to order (e.g. prefabricated concrete).

Cable trays from the Legrand Electric Ltd. UK Cable Management business unit were studied. Cable trays correspond to classification Made to Stock products. Made to Stock product were selected as per availability and easiness to deduct attributes. This product was studied in conjunction with cables because cable tray BIM models inherit properties from them.

Method employed to generate the case study

The steps followed to create the case study were the following:

1- Selection of Software:

"Autodesk Revit 2015" was the proprietary software platform used to create the case study, as it was found to be the most utilised software in the UK (BIM4M2, 2014). An educational license was obtained from the Autodesk website (Autodesk, 2015b).

2- Use of electrical calculation standards to understand data into context

Cable sizing calculations were carried out by using standards based on 1) "International Electrical Technical Commission" (IEC) *"IEC 60364 international regulation for residential and similar premises"* (AENOR, 2002, AENOR, 2004) and 2) Revit 2015 specific calculation methods (Autodesk, 2015a).

Furthermore, for the Cable tray sizing, the "British Electrotechnical and Allied Manufacturers' Association" (BEAMA) *"Best Practice Guide to Cable Ladder and Cable Tray Systems Including Channel Support Systems and other Associated Supports"* was consulted (BEAMA, 2014).

3- Classification of data according to the recommendation done in "PAS 1192-2 Capex" from the UK.

In order to help researchers replicate the Revit 2015 case study, the research process was based on the UK document, *"PAS 1192-2 Capex"* (BSI, 2013). The data used in the project is classified according to the British Standard 1192:2007 (BSI, 2007) and will be stored for public consultation in the University of Birmingham eRepository (DOI To be confirmed). CD provided with Thesis submission (Data folder name: Objective 2 case study data).

4- Use of suggested method: IDM BPMN.

The process diagram for cable sizing has been depicted using the BPMN (http://www.bpmn.org/) (see Figure 2-3), adopted by buildingSMART and the NIBS (Nawari, 2012).

5- Use of suggested method: Exchange Requirement (ER) linked to LOD.

The connection between processes and the information required at a particular stage of the project was made through ERs. These ERs were named by a prefix, which identified the ER followed by the verb exchange. Then, the subject of the ER was expressed as a noun or phrase followed by further qualification of the exchange (Wix and Karlshøj, 2010) (See Section 4.2.3). Lastly, the data was associated with the *"Specification BIM*

Forum 2015" LOD (See Section 2.3.3) in order to connect graphical and non-graphical information in a comprehensive and understandable manner for manufacturers. i.e: er_exchange_ approximate_geometry_model (LOD 200): Enough to quantify system loads. The results are summarised in Table 4-1 and Table 4-2.

Transition Stage

Finally, the "Transition" stage (Section 4.2.4) validates the output of the process through an accuracy test shown in in Table 4-2, by comparing the current Electrical System information exchange (Sparkie) MVD attributes (East, 2013), created by Building Smart Alliance with the output of the suggested novel method to specify data. This stage explains the value and impact of the new paradigm: "IDM knowledge creation process scenario" for the organisation.

3.2.3 Objective 3

This section has been partially published in the publication number 4 of Section 1.7.

This objective identified the theoretical constructs around the LOD concept and constituted the creation of a framework for LOD implementation for Level 2 and Level 3 BIM purposes. The outputs of this objective are the journal paper 4 listed in, Section 1.7.

The sub-tasks for this objective comprised the following points (see Figure 3-3):

- Task 7: To identify LOD theoretical Constructs.
- Task 8: To analyse relationships between theoretical constructs.
- Task 9: To develop a LOD theoretical framework.

The tasks required to accomplish this objective are further explained:

Task 7

To carry out the coding stage, a total of 41 BIM guidelines and regulations were collected and reviewed from both government and private institutions from 8 different countries from North America and Europe with an interest in BIM implementation (See Section 2.3.3 and Section 2.3.4). The countries analysed were the United States of America, Denmark, United Kingdom, Netherlands, Finland, Germany, Belgium, Switzerland. These countries were selected because their governments had a demonstrated interest in implementing BIM within their industry and because they agreed to implement open interoperable standards in relation to the Building SMART International initiative (BuildingSMART, 2016a).

It must be noted that up to March 2018, 23 different countries had expressed an interest in developing open standards (BuildingSMART, 2016a). However, only public data available in English language was analysed but there is room for other researchers to analyse publications in other languages.

Task 8

To analyse the causes and consequences of the interrelationships between LOD theoretical constructs.

The review of BIM guidelines and Standards in Section 2.3.3 and 2.3.4, Table 2-6 and Table 2-16 helped to focus attention on LOD codes or theoretical constructs. These were, Project Stage, BIM use, LOD, Role, Scale, Classification and Attributes.

During the memo-taking stage the theoretical constructs were systematically compared by selecting the mentioned codes and listing them in tables with the aim to visualise them in the context of their guidelines and standards.

During the last stage called theoretical sampling, the results of the memo-taking stage were compared against the scientific literature review (Section 2.3) to justify net benefits as shown in Section 4.3.2.

Task 9

To develop a comprehensive (only common constructs found within the literature are included) and parsimonious (only high-level constructs are included. i.e. the constructs are not further subdivided) LOD framework for the creation of Level 2 and Level 3 BIM Models that shows the boundaries and causal directionality between theoretical constructs.

In order to performs Task 9, causes and consequences of theoretical relationships were sought and formalised in a theoretical framework as follows:

Petter et al. (2008) methodology was replicated to create a model for IS success for the current study. However, it should be noted that the present study does not base its conclusion on other studies' empirical data as the scientific research on the LOD field constructs is non-existent. On the contrary, a wide range of LOD guidelines exist. Therefore, after a qualitative analysis of the LOD pair of constructs' relationships was carried out, the level of support was summarised as positive, moderate and negative. A value of a 1.0 point was assigned to each of the previous categories, respectively. Then, the total points summed up for each of the relationship's support was divided by the total

of studies. In order to classify the relationship between strong support, moderate support, or negative support, a percentage distribution was proposed. Positive, moderate or negative support was assigned when the percentage of papers with a positive, moderate or negative support respectively result was in the range of 70-100%. These percentages were considered as significant results. A high percentage to measure significant results was chosen, as if we had chosen percentages close to 50-100% or 60-100 %, it would have been easy to assign significant results to a category with a similar significant number of labelled categories. When there were less than 5 guidelines describing the relationship or results in the range of 0-60%, the result was categorised as having insufficient data to draw a conclusion (NA). Similar to Petter et al. (2008) work, this study does not aim to provide a mere quantitative approach (see Chapter 4, Section 4.3.3, Table 4-4), but to suggest net benefits and areas where the LOD construct relationship needs to be researched further. The LOD Grounded Theory framework output of this section can be seen in Section 4.3.3, Figure 4-5.

3.2.4 Objective 4

In order to validate the Grounded Theory Framework and to understand the impact that one of the significant LOD pairwise relationships might have on data specification, the following hypothesis generated using the novel Framework for LOD implementation (Figure 4-5) were tested in Objective 4.

Significant LOD pairwise relationship: Negative support for LOD → Project stage

Hypothesis: A BIM element LOD specified as per the end of a project stage is detrimental for value engineering exercises and is considered a waste of time, cost and

human resources in comparison with a more flexible approach where the LOD might be specified as per project milestones inside the project stage.

The novel Grounded Theory LOD Framework (Figure 4-5) helped to create hypothesis tested for the informational and behavioural perspective of the IDM (Section 2.6.4).

The implication this has for the industry in using a LOD standard is considered and evaluated according to the methodology specified in this section.

The tasks for this objective were (see Figure 3-3):

- Task 10: To identify LOD metrics.
- Task 11: To collect discipline data and develop a BIM data model.
- Task 12: To evaluate impact of LOD constructs using the created LOD framework.
- Task 13: To make recommendations and explain limitations of the LOD framework.

The tasks required to accomplish this objective are further explained:

Task 10

The literature review task consisted of an extensive search of LOD metrics. Output from this task is included in Section 2.5.

The literature review was undertaken by searching Journal articles using the Journal databases search engines in Section 3.2.1.

The main specific terms used when searching for resources were the following:

- BIM Metrics

- LOD Metrics

The inclusion criterion was meticulously followed to include only journal articles newer than 10 years since publication, being this the only constriction.

Task 11

A case study was created, which consisted of a one span composite bridge (Engineered to order products (See Section 3.2.2 for more information).

1. The method used for the creation of LOD data was the novel method created within Objective 2. The steps are indicated in Section 4.2.3.
2. Information workflows were created for both the AIA E202 and AIA G202 standards (see Appendix C, Figure C- 0-1 and Figure C-0-2 respectively).
3. A MPDT (see Chapter 2, Section 2.2.2) was also created summarising the two scenarios as per element classification system (see University of Birmingham eData Repository (DOI to be Confirmed). CD provided with Thesis submission (Data folder name: Objective 4 case study data).
4. The process and data workflow were transcribed to Excel Spreadsheets which worked as the interface to modify the bridge data. This interface was linked to Revit families previously modelled to different LODs through a parametric Dynamo script, which linked the drainage and structure disciplines and modified its geometry. (see University of Birmingham eData Repository (DOI to be Confirmed). CD provided with Thesis submission (Data folder name: Objective 4 case study data).

Task 12

Data gathering procedure:

In order to evaluate impact of LOD constructs using the created LOD framework the following steps were taken:

1. The researcher recorded a video on how the process should be performed following the information workflows in Task 11 Step 2 and did the clash detection exercise where indicated in the required milestone. (see University of Birmingham eData Repository (DOI to be Confirmed) CD provided with Thesis submission (Data folder name: Objective 4 case study data).

   The metrics used in order to help the attendees analyse the quality of the information were the following from Leite et al. (2011).

   - True positives (Identified as a clash and it was really a clash).
   - False negatives (was really a clash but not identified).
   - False positives (identified as a clash but was not a clash).
   - Precision = (Relevant clashes ∩ Retrieved clashes)/ (Relevant Clashes)
   - Recall = (Relevant clashes ∩ Retrieved clashes)/ (Retrieved clashes)

2. The attendants were invited to a workshop where they were given the participant information sheet, consents form and data protection sheets (See Appendix C). The workshop lasted around 60 minutes and was divided into five sections:

   a. 10 minutes Power Point Introduction to LOD coordination for the instance analysed (Model Production & Delivery Table and Business Process Modelling Notation). Also, the video from point 1 on AIA E202 and AIA G202 processes was presented to the attendees.

b. 30 minutes recorded discussion on both approaches. The researcher made open questions related to the cost, time and quality impact of both approaches on the clash detection exercise (See Appendix C, Interviews).
c. 5 minutes qualitative analysis of gathered clash detection metrics.
d. 15 minutes semi-structured qualitative questionnaire on usage of the above LOD standard based on the Recker (2010a) "Technology Acceptance Model" model (See Section 2.6.4). The quantitative side of the questionnaire consisted of a 5 grade Likert scale (See Appendix C, Questionnaire). i.e: 1.Strongly disagree/2. Disagree/3. Neither agree nor disagree/4. Agree/5. Strongly agree.
e. Finally. the attendants had the option to qualitatively explain why they had chosen a particular option from the Likert Scale

Data analysis procedure:

The procedure is further explained below:

The data was anonymised by giving each participant a unique identifier. The Participant numbering was based on the following codes: (Role, Number of participants, Interview number, Participant number): For example: SD512 es equal to a Structural Designer who has partaken in an interview with a total of 5 participants followed by the number of the interview (1), and a sequential number to differentiate participants with the same role (2).

The roles codes used were the following:

- Department Director (D)
- BIM Manager (BM)

- BIM Coordinator (BC)
- Structural Engineer (ST)

The interview schedule is presented below. Participants D511, SD511 and SD512 questionnaires were not received. Therefore, their data was not analysed.

Table 3-4: Interview schedule

Interview 1 (12/02/2019)	**Interview 2 (14/02/2019)**	**Interview 3 (23/02/2019)**	**Interview 4 (01/03/2019)**	**Interview 5 (15/03/2019)**
D511	D221			
BM511			BM341 BM342	BM151
BC511			BC541	
SD511 SD512	SD221	SD131		

The quantitative data from the Questionnaires (See Appendix C, Table C- 0-1) percentages were analysed (Table C-0-2 to Table C-0-7) and the data was contrasted against the qualitative data gathered in Table C-0-8, Table C-0-9 and Table C-0-10 from the Interviews and Questionnaires.

The questionnaire data along with the transcribed recordings (See Appendix C) were coded into themes and sub-themes, which means that part of the text can be given a code representing a certain area or construct. i.e. PU, PEU, ICU, were the themes and the impact of the standard on Waste time, cost, human resources was the sub-theme. That classification helped to arrange the codded data into tables as per each unit of analysis (AIA E202 and AIA G202).

The sub-theme selected (Waste time, cost, human resources) was related to the net benefits in Table 4-5 from Section 4.3.3 to validate the hypothesis from Section 3.2.4.

The themes and sub-themes are listed below:

- Theme 1: Perceived Usefulness
    - Sub-theme: Waste time, cost, human resources.
- Theme 2: Perceived Ease of Use
    - Sub-theme: Waste time, cost, human resources.
- Theme 3: Intention to Continue to Use
    - Sub-theme: Waste time, cost, human resources.

Following Seaman (1999) recommendations for qualitative analysis, internal comparisons and external cross references were carried out in Section 4.4. For example, constant internal comparisons across responses to a theme inside one unit of analysis were carried out. Also, external cross references within the same theme for the other unit of analysis helped to refine the analysis

The quantitative percentages helped to define the responses as positive, negative or neutral. i.e. a high cumulative percentage of responses that agreed or strongly agreed to the questionnaire statement in comparison with a low cumulative percentage of responses that disagreed or strongly disagreed helped to select qualitative responses to be further analysed as explained in the previous paragraph.

Task 13

Finally, in order to make recommendations and to explain limitations of the LOD Framework. The Net Benefits for the behavioural IDM perspective were summarised in

the Section 5.2.4. The deducted information complements the novel LOD Framework Net Benefit Table 4-5. However, there are still limitations that does not make possible to update the causal directionality between constructs of the novel LOD Implementation Framework (Figure 4-5). In order to understand the current limitations, the Robson (2002) validity criteria: Construct Validity, Internal Validity and External Validity was discussed in 5.3.4.

The following methodological strategy was carried out in order to mitigate the possible limitations of the study:

1. Objective, what to achieve?

The validation of the novel theoretical framework created to fulfil Objective 3 (See Section 4.3.3) under the Berard and Karlshoej (2012) behavioural IDM perspective (See Section 2.4.2). To do so Net Benefits of LOD usage in projects are deducted following the method in Section 3.2.4. and shown in Section 5.2.4.

2. The case, what is studied?

The LOD AIA E202 and LOD AIAG202 standard´s behavioural perspective. According to Yin (2013), this is an embedded case study. Karlstrom and Runeson (2005), states that understanding the boundaries of the study is important to be able to generalise the results. For example, in the Section 3.2.4 IDM BPMN LOD process implementation case study, two standards are studied within the same industry (construction design consultancy) from different application domains. One of them is the AIA E202 and the other is the AIA G02. Therefore, the above was considered two units of analysis in an embedded case study where the context is IDM BPMN LOD process within the

construction design consultancy scope and the research goals is to study the AIA E202 and AIA G202 standards impact on the IDM behavioural perspective.

3. Selection based on relevance:

The study group consisted of a Director with experience in BIM, BIM Managers, BIM Coordinators and Structural designers with BIM experience, which constitutes a unit of study within the building and infrastructure design consultancy industry.

The categorisation of BIM Models is based on Berard and Karlshoej (2012)(2012) study on the IDM functional behaviour (See Section 3.2.2). Previously, a cable and cable tray were analysed under the manufacturing unit of analysis (Made to stock products). In order to be able to compare and to also generalise the findings and to study the design phase of the creation of information in projects, Engineered to Order products were selected. This case study is composed of a combination of metallic beams and a concrete slab on the structural design side and outlets and pipe lengths on the drainage design side.

4. Theory, frame of reference:

To help to guide the conclusions of this research and help other researches to put them into context, this study has used an IS theory frame of reference. The frame of reference used is the "Technology Acceptance Model" (TAM) (Recker, 2010a), used to study why users accept and use and IS artefact on a prolonged basis. The constructs analysed in the model are Perceived Usefulness (PU), Perceived Ease of Use (PEU) and Intention to Continue to Use (ICU). Other acceptance frameworks are found in the literature such as the "Expectation Confirmation Model" (ECM). This model includes Satisfaction (S), PU, ICU and Confirmation. which includes a post-adoption satisfaction

artefact (Recker, 2010a), and the "Hybrid model", which combines the previous two models (Recker, 2010a).

The "Technology Acceptance Model" was used as it does not imply the post-adoption satisfaction artefact as a differentiating factor with the other two models.

5. Methods: How to collect and analyse data?

This study relies primarily on qualitative data which is broader in detail but less precise than quantitative data (Runeson and Höst, 2008). Therefore, within this empirical research there is a need to triangulate the data. According to Stake (1995), four types of triangulation has been chosen for compensating this lack of preciseness inherent to qualitative research.

Observer triangulation:

The survey data was collected from different roles such as Director with experience in BIM (1 participant) BIM Manager (4 participants), BIM Coordinator (2 Participants) and engineer with experience in BIM processes (2 participants). A qualitative approach to analyse data was taken, as it was understood that the analysis was aimed at evaluating patterns in data rather than generalising to a larger population. Therefore, we carried out the analysis with a small sample of 12 participants. However, 3 participants who partook in the initial interview did not hand in the questionnaires, so they were excluded from the analysis (See Appendix C Questionnaire forms). The final research group consisted then of a total of 9 participants.

The participants were targeted from the professional social network LinkedIn., Only participants from engineering consultancies bigger than 10,000 workers were

approached as the teams tend to be multidisciplinary. i.e. all Appendix C questionnaires have been filled by professionals belonging to companies with approximately 12000 workers and have worked in projects with a range of 5 to 12 disciplines. This was preferred to random sampling as according to Marshall (1996), it is considered that the error sampling error would be large due to the small sample size (9 participants).

Theory triangulation:

Two different LODs were chosen (AIA E202 and AIA G202) to vary the viewpoint of application of the BPMN.

Methodological triangulation:

Different types of data collection were chosen. First an unstructured interview was carried out followed by a semi-structured questionnaire about the case study thematic (See Section 3.2.4 for more detail).

The population sample to be studied was taken from LinkedIn by searching for BIM Managers, BIM Coordinators and BIM Structural designers both in the UK and the United States.

Table 3-5: Population sample. Numbers taken from LinkedIn on March 2019.

	BIM Manager	BIM Coordinator	BIM Structural Designer	Total
UK	566,435	122,289	1,897	690,621
USA	2,579,693	612,183	7,458	3,199,334
			TOTAL	3,889,955

The Equation 3-1 used to understand whether the number of interviewees (n) was enough to be able to generalise the results has been used in Small (2009) to critically analyse the sample of a small-n interview-based study.

$$n = \frac{Z^2 p(1-p)}{C^2}$$

Equation 3-1: Sample size formula (Small, 2009).

Where Z is the Z value (1.96 for a 95% confidence level); C is the confidence interval, expressed as a decimal (in this case, .05); and p is the accumulated percentage of people who are expected to choose a positive response on the Likert Scale (See Section 3.2.4). We assume .5, the most conservative assumption. (If 51% choose a positive response and 49% a negative response, the room for error is high, so a large sample is needed; if 90% choose a positive response the sample could be smaller).

384.16 participants are needed according to Small (2009) formula. However, as this was not possible due to time restriction, the qualitative data gathered was analysed in the basis of the quantitative questionnaire data, only using the second one to understand the positive or negative attitude towards the response and to be able to critically analyse the qualitative data.

3.3 Chapter summary

A Cable and Cable tray manufacture product, classified as Made to Stock products (See Section 3.2.2), was the first focus of this research due to the availability of a company interested in implementing BIM processes within their business and the need from the

manufacturing industry to generate Product Data Templates (PDTs) to be used by the construction industry within their BIM Information Systems (IS) (See Section 1.3).

As the PDT method does not provide the adequate process to create data (See Section 1.3), a novel method to deduct data for Made to Stock products was created in the context of Level 2 (LOD) and Level 3 (IDM) practices (See Section 2.6.2). The LOD standard was considered as the main unit of analysis to specify product data as it is a common accepted measure of graphical and non-graphical information along the different stages of a project (See Section 2.3). The second row of Figure 1-1: Research Scope, shows that this part of the research scope was RIBA 4 Technical Design, the LOD studied was LOD 400 and the IDM perspective studied was the Informational.

As discussed within the limitations section (See Section 5.3.2), the efficiency of the IDM method to specify data is limited due to the difficulty of gathering data from multiple stakeholders. Therefore, in order to test the generalisation of the method, this was tested during the design phase of a project (RIBA 2 and RIBA 3 stages) using Engineered to Order products and LODs in the range of LOD 200 to LOD 350. The IDM perspective studied was the Behavioural perspective as described in Section 3.2.4. The third row of Figure 1-1: Research Scope represents this part of the research into the whole thesis context.

In order to advance towards the specification of product data according to Level 3 standards and to see whether the method could be used to specify data for Engineered to Order products in a practical design project, the LOD standard was further defined as per its constituents intrinsic constructs which were defined as *BIM Use, LOD, Project Stage, Role, Building Element, Classification, Scale, Attributes, Net Benefits.* (See Section 5.2.3) and were mapped to the Berard and Karlshoej (2012) IDM perspectives: "*process map*

(behavioural), narratives (organisational), exchange requirements (informational), and narrative business rules (functional)" (Section 4.3.1).

To solve the complexity of case study analysis under different LODs, a framework for LOD implementation was created (See Section 3.2.3). This framework can be used to analyse pairwise construct relationships of the LOD standard and to understand net benefits of LOD usage in projects as it has been demonstrated in Section 4.3.3). The output of the Engineered to Order products case study helped to clarify the relationship between LOD and project stage (Behavioural Perspective). It also helped to validate the Grounded Theory LOD framework created in Section 4.3.3

CHAPTER 4: RESEARCH RESULTS

4 Results

This Chapter presents the research undertaken as outlined in Chapter 1, using the methods described in Chapter 3. The key results helped to narrate the conclusions in Chapter 5.

4.1 Objective 1: Level 2 and Level 3 LOD Factors analysis.

The results from this section are shown in the Problem Statement Section 1.3. In summary, the PDT process described in Figure 4-3 and Table 2-21 was not considered a method to create data but was only a mere record of product specifications data. The study of the IDM Level 3 process to create data helped to identify that the LOD process could be studied from the IDM Informational perspective in Objective 2. Table 2-21: PDT Information System implementation description.

4.2 Objective 2: Method to define BIM data

This section has been partially published in the publication number 2 of Section 1.7.

4.2.1 Start-up stage

In order to understand current industry trends towards the implementation of processes for the deduction of data, a SMART analysis was conducted to increase the

researcher understanding of the sponsor´s processes to specify BIM Model data. The workshop methodological procedure is explained in Section 3.2.2, Objective 2. The outcome of this analysis is detailed in Appendix B, Table B-0-1.

The results of this workshop are the following:

- One of the company's objectives is to educate itself in BIM processes relating to data exchanges, which in turn will ensure that Legrand´s products can continue to be specified by their key stakeholders.
- In the case of the UK, the Government strategy requires Level 2 BIM for all public asset procurements (Cabinet Office, 2011). In 2016, the Legrand´s UK cable management business unit agreed to provide 3D models with non-graphical specification attached to them.
- To do so, the company engaged with the CIBSE initiative to provide Level 2 PDTs. These contain product attributes such as the ones found within the paper product specifications.
- Previous processes consisted of providing 2D CAD drawings and paper specifications to their clients, which is known as Level 1 BIM.

The results of the SMART analysis were used to define the diagnosis stage boundary. The boundary can be defined as the sponsor´s data specification processes for Level 2 BIM implementation (See Section 2.4.1).

4.2.2 Diagnosis

This stage was performed to share the understanding of the system involving the project and to decide if there is a potential need for change (Jones and Brazzel, 2014).

Therefore, a SWOT analysis was performed as described within Section 3.2.2, Objective 2. The two paradigms compared in the SWOT analysis are described in Section 2.4.1 (Paradigm A, PDT) and Section 4.2.4. (Paradigm B, IDM). The SWOT analysis workshop outcome can be found in Appendix B, Table B-0-2 and Table B-0-3.

The results of the SWOT analysis are described below:

One of the Paradigm B strengths discussed within the SWOT analysis is the ability to understand better how to structure Legrand´s product data and to understand the potential of the data into context i.e: *"Structured data and self-known of product data potential*". In contrast, Paradigm A, according to Legrand´s BIM Manager entailed a *"Rigid approach to BIM development"* and *"not forward thinking".*

This helped the researcher to investigate further how the data is structured within the industry. As a summary of how data is structured within the literature in Chapter 2, LOD is one of the most cited graphical and non-graphical standards within the literature (Staub-French and Khanzode, 2007, Eastman et al., 2011, Maria-Angeliki et al., 2014, Wood et al., 2014, Han et al., 2015, Hooper, 2015, Wu and Issa, 2015). However, other definitions are available depending on the country or institution which defines it. For example, in the UK, the PAS 1192: 2013 is the guideline used to define the BIM object information referred to as the Level of Definition (BIM4M2, 2014).

1. *As a result, of the analysis it can be said that both concepts contain intrinsic constructs such as stage, LOD number of definitions and BIM use.*

This outcome was further explored in the Section 4.3. In this section only the preliminary results before the literature review on LOD (See Section 2.3) was carried out are presented.

As found within the literature in Chapter 2, the LOD to be included within the definition of a BIM object is a critical criterion for manufacturers (BIM4M2, 2014). Therefore, this concept was analysed in the context of the SWOT analysis.

A common weakness included in the SWOT analysis for both paradigms is the *"lack of knowledge of BIM uses".* Therefore, BIM uses were further explored to understand how to structure data better in Chapter 2. The *"AIA G202-2013, Project Building Information Modelling Protocol Form"* was created by the "American Institute of Architects (AIA) California Council Integrated Project Delivery Task Force". The "AIA *G202-2013''* LOD allows for "Model Element" specification of content requirements and its associated uses. It is divided into five different progressive levels that specify the detail of completeness within the element (AIA, 2013b). This is in line with studied that suggest that the LOD depends on the BIM use or application (Staub-French and Khanzode, 2007, Eastman et al., 2011).

Similarly, the "Specification BIM Forum" in the *"Level of Development Specification 2015"*document (BIM Forum, 2015a), utilises the AIA LOD definitions found in the "AIA *G202-2013".* In contrast to the "AIA *G202-2013'',* it expands the AIA's LOD definition by including a LOD 350 required for coordination between disciplines (BIM Forum, 2015a). Interestingly, the "*G202-2013''* propose several authorised uses such as "Analysis", "Cost", "Estimating" and "schedule", leaving room to assign other uses by the interested stakeholder (AIA, 2013b). While the "*G202-2013''* LOD defines a basic standard, the *"Level*

of Development Specification 2015" document, defines and illustrates LODs by product which help teams to specify deliverables. This specification addresses the definition of components by describing requirements. They can be included in contracts and can also help managers to explain to teams which information should be included in the project at different stages (BIM Forum, 2015a).

2. *Therefore, from the analysis it is understood that BIM uses can be specified by managers and included in contracts and this lesson was considered in Objective 3.*

The SWOT analysis highlighted that there might be opportunities for *"Collaborative engagement with downstream stakeholder".* Within the context of the workshop that meant using the Paradigm B scenario to structure data for different scopes, i.e. maintenance, electrical design, sustainability, which entailed understanding which data was useful at different stages of a client project.

Therefore, the LOD mention to project stages or milestones within the Chapter 2 literature is analysed and summarised.

The "*PAS 1192: 2013"* was created by the British Standards Institution in the UK (BSI, 2013). "*PAS 1192: 2013"* includes BIM models descriptions that are articulated around Levels of Definition. These Levels of Definition, which includes narratives, describe the general information that should be included within BIM models. In contrast to the "*G202-2013'',* the Levels of Definition are linked to project stages, for example the CIC Scope of Services provides a standard classification. The definitions are as follows: Brief, Concept, Design, Definition, Design, Build and Commissioning, Handover and Closeout.

In another example, the "*G202-2013''* authorises 4 BIM uses and allows the user to define others. However, within the *"PAS 1192:2013"* there are no authorised uses Nevertheless, this LOD definition should be used together with the BIM protocol which helps to specify LOD data according to project stages and author, contains a choice of 30 BIM uses (CIC, 2013b).

Some studies relate LODs with project stages with the aim of creating a structured process for sustainability design (Maria-Angeliki et al., 2014) or to satisfy energy analysis needs (Wu and Issa, 2015). These studies mainly relate to the idea of an LOD linked to a project stage such as the "*PAS 1192:2013"*. Conversely, a study on LOD model progression using the AIA LOD concept, states that the LOD should be free of stage bindings (Hooper, 2015).

3. *From the analysis, it is understood that there is a variety of options to specify LOD data as per project stage which basically depend on the standard used.*

Therefore, the opportunity to structure data as per project stage or milestone is explored in Objective 4.

The results above are summarised in Figure B-0-1 that shows the variety of possibilities available depending on the LOD concept studied. Three main constructs (stage, number of definitions and BIM uses scope) define the LOD variances. Within the section "Intervention", the researcher used the *"Level of Development Specification 2015"* definitions as a starting point to match graphical and non-graphical information to generate LODs for different BIM uses. The reasons for using this LOD concept relays on its definition of graphical content according to specific products, its clarity on authorised uses and stage flexibility.

4.2.3 Intervention

The OD Intervention stage is regarded as an "*iterative collaborative process of considering alternatives and clarifying the desired outcome*" (Jones and Brazzel, 2014). After carrying out the Start-up stage (Section 4.2.1) and diagnosis stage (Section 4.2.2) and presenting the results to Legrand´s UK BIM Manager, the desired goal was to provide data that could support the client's life-cycle processes in a reliable and consistent manner. In this line, the process of specifying Level 2 cable and cable tray PDTs by using Level 3 standards such as the IDM was documented.

The workshop methodological procedure is explained in Section 3.2.3, Objective 3. The results of this analysis are detailed below and validated in the transition stage Section 4.2.4.

A case study was carried out which involved deducting information from a client process (cable and cable tray sizing). The generated data exchanges and associated attributes were used to create a PDT for cable and cable tray manufacturer's products which contains attributes necessary for the electrical sizing use at different LODs.

This section focuses on documenting the creation of a LOD for electrical BIM objects. It reviews the IDM specification used to document processes and attributes to advance BIM LOD standard for Made to Stock products. In Chapter 2 it is mentioned that the IDM can capture business processes and the data exchanges associated with them (Chipman et al., 2013). Therefore, in the present research study, the IDM was the basis for data exchange development.

The IDM creation begins with the definition of PMs (see Figure 2-3). In the present research, the PM describes a particular flow of activities within the electrical cable sizing process. PMs are diagrammatically represented as single "pools" and the name of the pool describes the PM. The description and identification of the information from the data involved within the business processes at a particular stage of the project is depicted within ERs. The workflows scenarios and the ERs between the actors "architects" and "electrical engineers", are represented in single "lanes" contained within the PM "Pool"(Wix and Karlshøj, 2010). This is illustrated in the PM shown in Figure 4-2. The process of developing an IDM requires a first step of "process discovering and data mining" (Wix and Karlshøj, 2010). The *"Level of Development Specification 2015"* was used to create the case study. shows the geometric progression of a Cable Tray within this study.

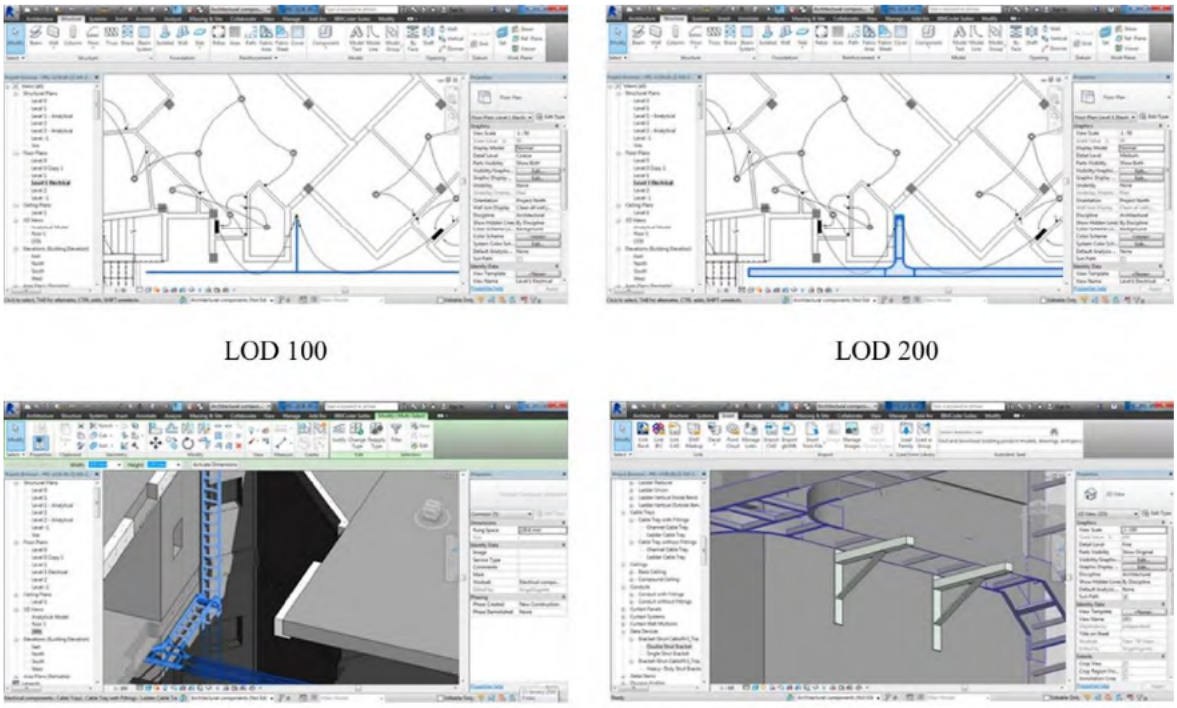


Figure 4-1: Revit Case study- Cable tray system LOD progression.

The process diagram for cable sizing was depicted using the BPMN (http://www.bpmn.org/) (see Figure 4-2), adopted from BuildingSMART and the NIBS (Nawari, 2012).

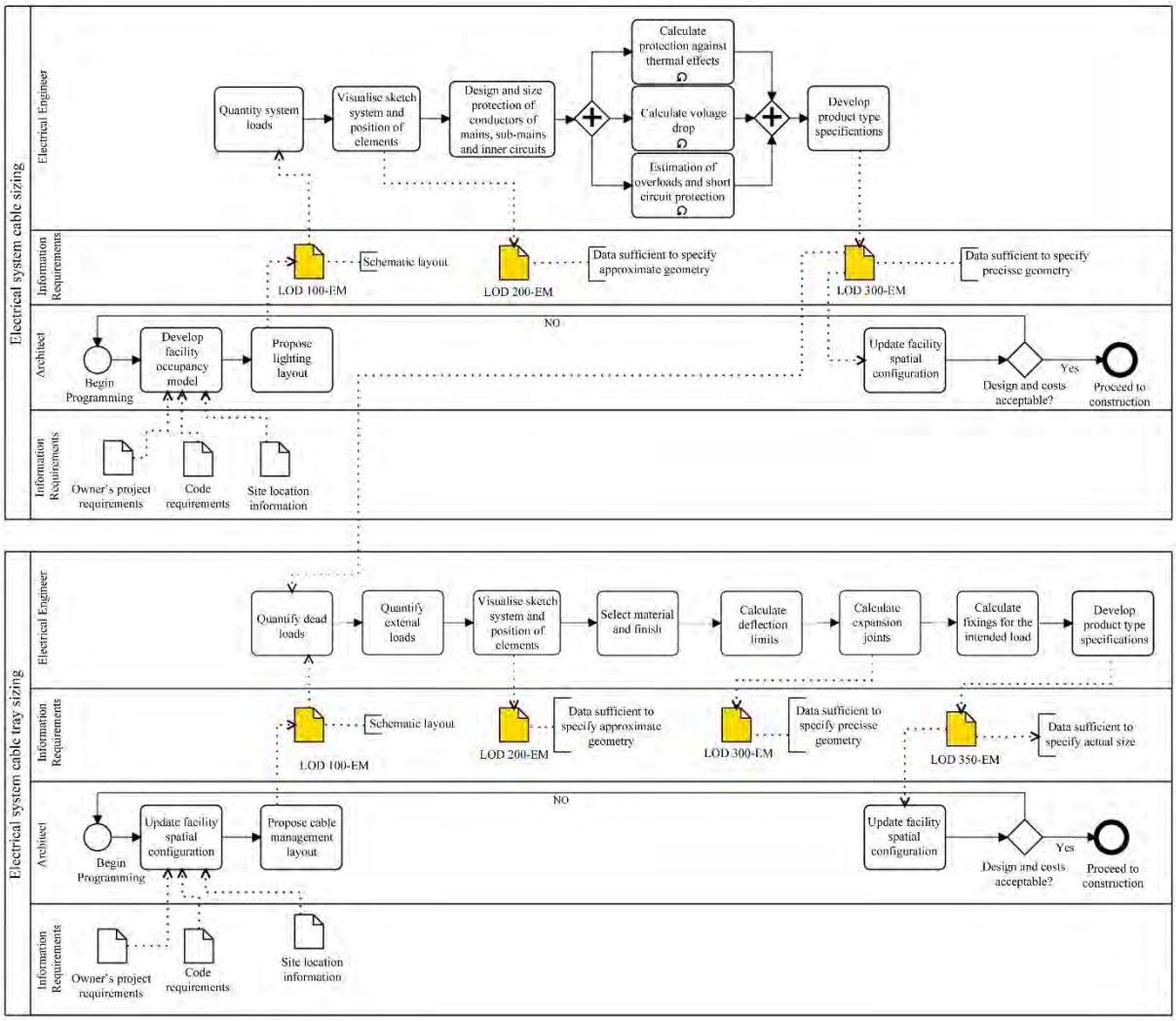


Figure 4-2: PM for cable and cable tray sizing.

The analysis of the "Electrical service and distribution system" sizing and specification, demonstrated that graphical information and non-graphical information

are closely related. Both influence each other in an iterative process which involves calculations and the selection of the appropriate system.

The connection between processes and the information required at a particular stage of the project is made through ERs. These ER are named by a prefix, which identifies the ER followed by the verb exchange. Lastly, the subject of the ER is expressed as a noun or phrase followed by further qualification of the exchange (Wix and Karlshøj, 2010). The ERs utilised in the case study was coordinated with the LOD cable definition from the "Specification BIM Forum Level of Development Specification" (BIM Forum, 2015a). This helped to increase understanding of how BIM model's data progresses depending on its level of geometric development (see Table 4-1).

The ERs deducted from the case study are the following:

For the electrical System Cable sizing PM the following ERs were defined:

- er_exchange_schematic_layout_model (LOD 100): Sufficient to create a schematic model.
- er_exchange_ approximate_geometry_model (LOD 200): Sufficient to quantify system loads.
- er_ exchange_precisse_geometry_model (LOD 300): Sufficient to calculate protection against thermal effects, voltage drops, overloads and short circuit protection.

For the electrical System Cable tray sizing PM the following ER were defined:

- er_exchange_schematic_layout_model (LOD 100): Sufficient to create a schematic model.

- er_exchange_ approximate_geometry_model (LOD 200): Sufficient to calculate dead and imposed loads. Attributes providing from the "Electrical System Cable sizing". "er_exchange_precisse_geometry_model (LOD 300)" are needed, i.e. Cable Weight (kg/m).
- er_ exchange_precisse_geometry_model (LOD 300): Sufficient to select material and finish, to calculate deflection limits and expansion joints.
- er_ exchange_actual_geometry_model (LOD 350): Sufficient to calculate fixings for the intended load.

The ERs were documented using the "*Information Delivery Manual Guide to Components and Development Methods"*. This documentation process is the foundation for IFC and MVD development (Wix and Karlshøj, 2010). As an example, the er_exchange_ approximate_geometry_model (LOD 200) for the cable sizing use is shown in Table 4-1.

Table 4-1. Electrical system cable sizing ER

Name	er_exchange_approximate_geometry_model (LOD 200)
Overview	The scope of this exchange requirement is the exchange of information to enable protection against thermal effects, voltage drop and overload protection calculations. Due to the iterative nature of the calculation process, predefined "Model element" generic attributes can be selected but are not valid to specify elements. Graphical information may be sufficient to specify approximate geometry (i.e. LOD 200).
Information Requirements	Preconditions Electrical system loads will have been estimated. Prior requirement: er_exchange_loads_model (LOD 100) Information Units: Cable Provides relevant information about the cable Attributes or properties that must be exchanged: R= Conductor resistance measured in Ω/m at the service temperature,

	Reactance of the conductor on a frequency of 50Hz measured in Ω/m, Insulation material, γ: Conductivity (values of 48.11 m/mΩ.mm2 for cooper), Conductor material, S: section (mm2), Cable temperature, Iz: Current-carrying capacity of the conductor, Ambient temperature, Impedance (Z)

The creation of BIM object information for the consecution of Objective 2 entailed describing the name of the ER, overview and scope of the requirement and recording the attributes that must be exchanged. The results of this case study are shown in Table 4-2. This table represents the information that two separate Level 2 BIM PDTs should contain for a Cable and Cable tray data exchange for sizing purposes using the PM represented in Figure 4-2.

For the creation of Level 3 standards such as the IFC (See Section 2.2.4), the definition of the data can be further developed by describing "Functional Parts", which requires a detailed technical specification of the exchange. IFC capabilities can be represented using the EXPRESS-G Graphical Form (ISO 10303 Part 11). This notation is used in IFC development because the solution provider or software developer can focus on a specific functional part instead of the full IFC schema (Wix and Karlshøj, 2010). Consequently, the development of the IFC requires a clear definition of the ERs. However, the description of Functional Parts is not necessary for the aim of this study. After deducting the attributes, manufacturers can map them to existing MVDs, for example the SPARKie electrical design MVD. This can improve PDTs interoperability while finding paths for IFC development on an industry basis.

A summary of the results for the Intervention stage is presented below:

1. *The analysis of the "Electrical service and distribution system" sizing and specification, demonstrated that graphical information and non-graphical information are closely related.*
2. *Both graphical and non-graphical information influence each other in an iterative process which involves calculations and the selection of the appropriate system.*
3. *The IDM ER can be link to an LOD definition in order to create a systematic and replicable process to specify BIM Model data.*

The findings suggest the following steps (see Figure 4-4) towards the manufacturer's implementation of the IDM methodology for its inclusion within IS:

a. To select manufacturer product. If the product inherits properties from other products, the inheritance should be studied by creating a related process map. For example, see cable and cable tray PM in Figure 4-2 .
b. To select a BIM use.
c. To select a LOD based on its constituent constructs: stage, actor and number of definitions.
d. To set process map decision points based on product related regulations.
e. To link the chosen LOD with the corresponding set of attributes to create an ER.
f. To record the ER attributes using the "Information Delivery Manual Guide to Components and Development Methods".
g. To include IDM deducted data to PDT (XML format) and find possible mappings to existing IFC data.

h. To select another use for the same product and repeat the process until all the product uses required have been considered.

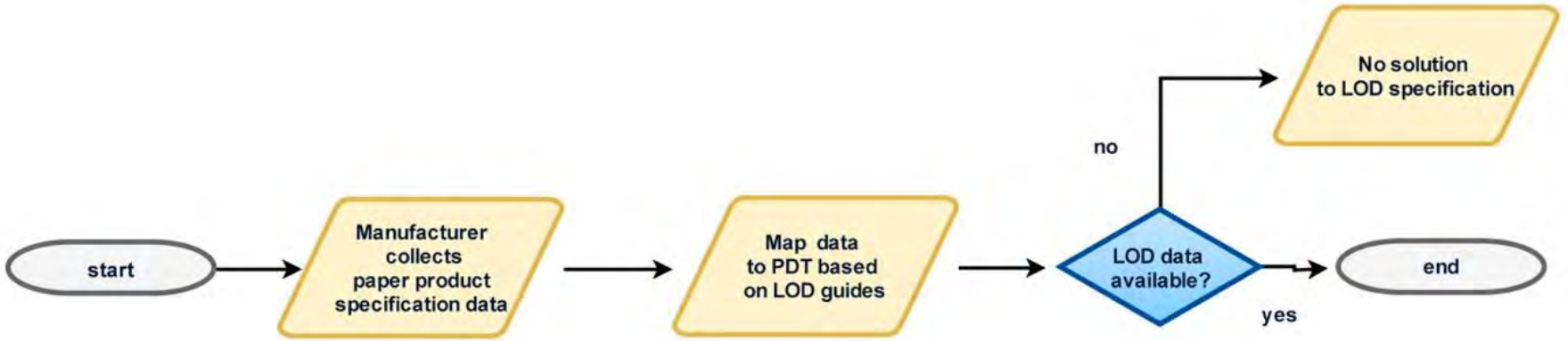


Figure 4-3: Process for PDT LOD data collection.

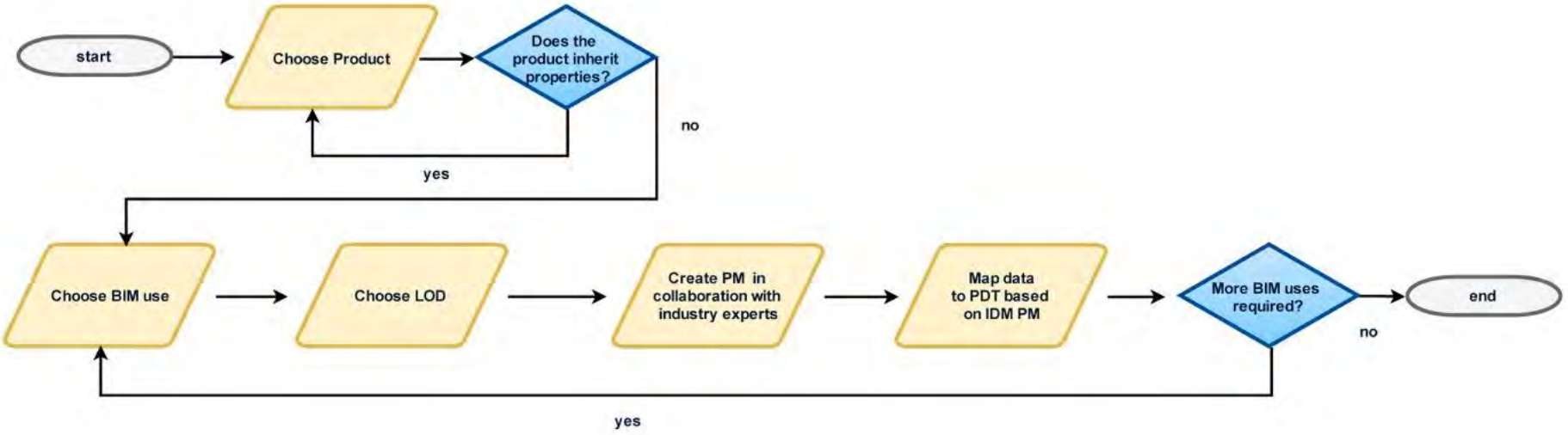


Figure 4-4. Process for IDM LOD data creation.

4.2.4 Transition

This stage was performed to validate the output of the intervention stage and to explain the impact of Paradigm B "IDM knowledge creation process scenario" to Legrand UK. Therefore, a quality test was performed as described in Section 3.2.2, Objective 2. The output of this test is shown in Table 4-2.

Table 4-2. Non-graphical information for Cable and Cable tray PDT.

Sizing use	Cable non-graphical information	SPARKie properties (East, 2013).	Cable tray non-graphical information	SPARKie properties (East, 2013).
LOD 200	R= Conductor resistance measured in Ω/m at the service temperature	×	Z= Section modulus of the cross-section of the beam	×
	X= Reactance of the conductor on a frequency of 50Hz measured in Ω/m	×	l= Length of the beam (m)	×
	γ: Conductivity (values of 48.11 m/mΩ.mm2 for cooper)	×		
	S: section	CrossSectionalArea		

Sizing use	Cable non-graphical information	SPARKie properties (East, 2013).	Cable tray non-graphical information	SPARKie properties (East, 2013).
	(mm2)			
	Iz: Current-carrying capacity of the conductor	CurrentCarryingCapasity		
	Insulation material	InsulationStandardClass		
	Conductor material	Material		
	Cable temperature	MaximumShortCircuitTemperature		
	Ambient temperature			
	Z= Impedance	NetImpedance		
LOD 300	Size (mm)	MaximumCableLength	E= Modulus of Elasticity (N/m2)	×
	Weight (kg/m)	Weight	I= Moment of Inertia (m4)	×
	Single-core or multi-core cable	NumberOfCores	Cable tray material	×
	Installation method	InstallationMethod	Finish thickness (μm)	×
			Finish galvanic series potential difference (Volts)	×
LOD 350			E= Allowable movement expansion joint	×
			K= Coefficient of linear expansion	×

Table 4-2 shows that 10 out of 13 attributes from the Cable product could be mapped to the SPARKie MVD. However, the cable tray attributes needed to design a cable tray were non-existent within the SPARKie MVD.

This exercise was useful for raising concerns on the industry´s need to collaborate towards the creation of structured interoperable data for the definition of BIM objects attributes (i.e. cable tray attributes for design BIM use). The use of attribute guidelines such as those found in Table 1-1 together with PMs Figure 4-2 for specific products and BIM uses, would help to specify manufacturer LOD data.

The results from the intervention stage are presented below:

1. *The replicable approach described in Figure 4-4 allows the BPMN PM to be used as a container of tacit data which can be reviewed for future updates, providing the framework that the attribute guidelines on its own did not provide.*

However, Berard and Karlshoej´s (2012) study advises against the use of IDM BPMN on an industry basis due to its complexity, therefore, restricting its use to a project basis.

2. *Nevertheless, this study has proved that it could be applied on an industry basis for Made to Stock products.*

Although Berard and Karlshoej (2012) suggest that there might be thousands of multiple process maps, Made to Stock products design are based on prescriptive regulations such as the *"IEC 60364 international regulation for residential and similar premises"* used within the intervention stage of the present study. For example, this

regulation contains the processes needed to design an electrical component, shortening the multiplicity of process required to model the IDM.

4.3 Objective 3: Grounded Theory LOD Framework creation

This section has been partially published in the publication number 4 of Section 1.7.

This objective builds on the main findings from Objective 2, which are summarised above in Section 4.2, Objective 2. The theoretical LOD Framework created was built using the grounded theory methodology explained in Section 3.2.3, Objective 3.

4.3.1 Diagnosis

In reviewing the various approaches that standardisation institutions have taken in developing the LOD specification (See Section 2.3.3 and Section 2.3.4), the following observation was emerged in relation to the following Berard and Karlshoej (2012) IDM perspectives: "*process map (behavioural), narratives (organisational), exchange requirements (informational), and narrative business rules (functional)".* The guidelines studied offered some insight which increased our understanding of the LOD phenomena. The most recurrent LOD constructs found within Table 2-5 and Table 2-15 documents organised as per IDM perspectives include:

- Behavioural perspective (process map).
    - BIM use: Kreider and Messner (2013) define BIM uses as a "method of applying Building Information Modelling during a facility´s lifecycle to achieve one or more specific objectives" (Kreider and Messner, 2013).

  - Stage: According to Eadie Eadie et al. (2013), stages can be understood as the project lifecycle phases. For example, “project inception, feasibility, design, construction, handover, operation, maintenance and eventual demolition”.

- Organisational perspective (narratives).
  - Role: In this context, the several stakeholders who are contributing to the development of a BIM project.
  - Building Classification System: The terminology and semantics which need to be utilised within the AEC industry to describe the building entities and processes during the project lifecycle (Ekholm and Häggström, 2011).
- Informational perspective (exchange requirements).
  - Graphical information: The 3D virtual representation of a BIM model
  - Scale: Within the literature context this refers to a specific ratio relative to the actual size of the model.
  - LOD: 3D and associated information progression of a BIM model along the project lifecycle.
- Functional perspective (business rules).
  - Attributes: The explicit information that describes the graphical information as well as the specification and behaviour of an object in relation to the LOD.
- Net benefits: Here, this refers to the extent to which LOD constructs impact on the current use of BIM Information systems.

The previous constructs provide a theoretical base for developing a model for LOD implementation. The relationships between constructs are grouped based on the expected causal relationships between LOD constructs. Examining the literature review using this relationship structure, helps us to understand the reasons behind its adoption or refusal and its impact within the framework. Table 4-3, includes a total of 13 pairs of LOD constructs' relationships analysed within the diagnosis section.

Table 4-3. LOD constructs relationships

Scale	→	BIM Use
Project Stage	→	BIM Use
Project Stage	→	LOD
Role	→	LOD
LOD	→	Attributes
LOD	→	Geometry
LOD	→	Scale
BIM Use	→	Attributes
BIM Use	→	Geometry
BIM Use	→	LOD
Classification	→	Building Elements
Classification	→	Stage
Classification	→	Attributes

4.3.2 LOD Memo Taking and Theoretical Sampling Stages Combined

A systematic pairwise comparison of the constructs listed in Table 4-3 has been carried out as described in Section 3.2.3, Objective 3. The sign "→" in the headers below denote a direction within the relationship.

Scale → BIM Use

The relationship support between Scale and BIM Use within the guidelines is scarce. For instance, the Architectural, Engineering and Construction (AEC) UK BIM Standard (2009) guideline proposes a transition from CAD to BIM (AEC UK, 2009). The UK, AEC BIM Standard v1.0 sets a positive relationship between scale and BIM uses (AEC UK, 2009). The guideline contains references to typical drawing scales for a total of 12 BIM uses such as fabrication, sequencing, energy analysis among others. The guideline proposes that the model scale must be prepared to suit the purpose the project is going to serve. For example, for energy analysis, it sets a preferred scale of 1:200 and a maximum scale of 1:100. This would help to manage detail levels above the maximum recommended. When this happens, the guideline recommends drawing them in 2D while using 3D views as metadata.

Project Stage → BIM Use

An example of a moderate support relationship between project Stage and BIM use is the AIA G202. The AIA G202 finds it useful to define different LODs for different uses at the same project milestone. This is freely assigning the model element per BIM use at a project stage (AIA, 2013b). However, this can result in a fractal effect as the MPSv2 review suggests (VicoSoftware, 2016). The main difference between the AIA G202 and the MPSv3 is that the combination of BIM use, BIM element, LOD on a project stage can be managed at the project level when using the AIA G202 (AIA, 2013b). However, the MPSv3 predefine a rigid set of constructs which in turn will be beneficial to maintain a standardised library of components with attached information (VicoSoftware, 2016), but detrimental for project innovation and flexibility of specification. Therefore, the relationship support can be defined as moderate.

Project Stage → LOD

There are a few standards that encourage using Project Stages linked to the LOD. The Danish 3D working method 2006 degree of Detailing binds the Danish DBK project stages to the LOD classification (Bips, 2007). However, this can be considered moderate support as it also recommends its use within other stages.

Negative support between the Project Stage and LOD relationship is seen in the Vico Software specification (VicoSoftware, 2016), the AIA G202 (AIA, 2013b) or the AIA E202 Model Element Table (AIA, 2008), which recommends LOD management and its specification within a project stage or a percentage of the project stage. In contrast to the Danish DBK, Vico software and the AIA G202 acknowledge that there might be more than one model version per design phase. Thus, enabling the review of the model at various project milestones. Similarly, the BIM forum Level of specification (BIM Forum, 2013, BIM Forum, 2014, BIM Forum, 2015a, BIM Forum, 2016b), assumes that when the BIM model elements and systems are not individually managed, the project incurs significant waste in terms of time, cost and human resources.

On the contrary, the PAS 1192 is a pure example of a positive relationship between LOD and project stages as the LOD is unequivocally coincident with the project stages making easier alignment to UK standard staged submission requirements such as for example the CIC scope of services" stage definitions (BSI, 2013). More recently and in the

same trend, the University of South Florida, encourages aligning design phases or sub-phases to certain LOD definitions (UoSF, 2018).

Role → LOD

There is lack of studies which investigate the Role and LOD relationship. The Danish 3D working method 2006 classifies the degree of detailing by actors i.e. architecture (Bips, 2007). Later, BIM uses would be attached to this definition. This can be considered as a moderate relationship as it is understood that more than one professional might be responsible for common building elements pertaining different roles.

LOD → Attributes

The Vico Software LOD and Attributes relationship can be considered as moderate. Vico Software MPSv3 proposes creating a historical database for the cost and schedule which could be associated with a LOD definition (VicoSoftware, 2016). However, the VICO Software specification does not regulate the attributes and values needed to do such a study.

Examples of strong relationships where attributes have been specified as per LOD include the following: The Veteran Affairs BIM Object Element Matrix provides a list of BIM elements with its correspondent attributes based on the AIA E202 LOD classification (VA CFM, 2010). Other guides such as the NYCDDC BIM guidelines propose required attributes per building system which would be a more generic approach than the previous guideline example (NYCDDC, 2012). The USACE Minimum Model Element Matrix M3 provides a list of attributes based on their own LOD specification which has had little followers within the industry (USACE, 2014). Finally, the BIM Forum Level of

Development 2015 and 2016 recommends a list of attributes based on the AIA G202 LOD specification and is also accompanied by a list of illustrations per model element which leaves little room for human error (BIM Forum, 2015b, BIM Forum, 2016a). Finally, the USF suggest using COBie data in step with the LOD which is closely linked to project stages (UoSF, 2018).

Version 2 of the AEC UK BIM Standard breaks the binding within geometric and non-geometric descriptions of the model (AEC UK, 2012). It recommends that the information is managed for its intended purpose, meaning that there should not be a straight link between Attributes and LOD. Thus, the relationship should be considered as negative.

The BSI also created BS 8541-4-2012 Library objects for architecture engineering and construction – Part 4: Attributes for specification and assessment – Code of practice. This guide proposes a definition for level of information called Level of Attributing. This guideline encourages using the IFC property sets, attributes and units of measure. This allows for internal and external database consistency. Although the guideline encourages using attributes, it does not specify them, therefore the Attribute and LOD relationship could be considered as moderate.

In the United Kingdom (UK), the PAS 1192-2:2013 defines the "Level of Definition" (LOD). The document includes the Level of Model Detail which describes graphical information and the Level of Information Detail. The second, on the contrary stands for the content description of non-graphical models (BSI, 2013). However, there is not any reference to attribute information. Thus, the relationship was considered as moderate.

LOD → Geometry

Vico Software describes how the 3D shape should be represented for different LODs (VicoSoftware, 2016). For example, it describes the type diversification of an object, its geometry, penetrations and connections. However, it does not provide a guide of requirements per object, thus the relationship was considered as moderate.

The BIM Forum Level of Development specification is intended for professionals engaged in BIM element creation. The guide helps these professional to rely on the kind of model they are sharing or receiving in terms of usability (BIM Forum, 2013, BIM Forum, 2014, BIM Forum, 2015a, BIM Forum, 2016b). It provides an image per LOD and a short description of what the image should include as the model progresses. The link between Graphical information and LOD was considered as positive.

LOD → Scale

The UK, AEC BIM Standard v1.0 and v2.0 provides a general example of illustrations per LOD and scale (AEC UK, 2009, AEC UK, 2012). The guidelines recommend creating fit to purpose models to ensure the most efficient use of the PC processing power, therefore the relationship was considered as positive.

BIM use → Attributes

The BSI created the BS 8541-4-2012 Library objects for architecture engineering and construction – Part 4: Attributes for specification and assessment – Code of practice which establishes a positive link between BIM uses and attributes such as the Construction Operation Building information exchange (COBie) MVD attributes (BSI, 2012b).

BIM Use → Geometry

Within the AIA G202 (AIA, 2013b), which is the newest version of the AIA E202 document (AIA, 2008), a coordination use is specified. It must be noticed that the coordination use can only be applied after the model has been detailed enough to allow for clash detection purposes. Therefore, the BIM Forum Level of Development Specification (BIM Forum, 2013, BIM Forum, 2014, BIM Forum, 2015a, BIM Forum, 2016b) introduces a by-step LOD in between the 300 and 400 LOD for coordination purposes. This LOD is called the LOD 350 and its graphical representation is provided to coordinate modelling efforts. The relationship was considered as positive.

BIM Use → LOD

Guidelines provide moderate support for BIM Use and LOD relationship. Some guidelines propose authorised uses which are closely related to the LOD definition. This means that these guidelines are only reliable under the recommended uses. The Vico Software Level of Detail (MPSv1) (VicoSoftware, 2016) defines Geometry (modelling or visualisation), Scheduling and Estimating as reliable data outputs when using their specification. A positive relationship between these two concepts is described: One important lesson learnt from the MPSv1 is that when the LOD is not followed by an authorised use, the specification becomes too general and it is subject to interpretation by the designer (VicoSoftware, 2016). However, a negative example of this relationship is found within the MPSv2. In contrast to MPSv1, this specification defines different levels of model progression per BIM use. When this is defined for each building model element, it creates an iteration problem for model elements, BIM uses (aspects) and levels of definitions (classes), which might be counterproductive for the generalisation of LOD definitions. This problem was illustrated in Section 2.3.3 (see Equation 2-1).

The updated Vico software proposal for the definition of model elements is the MPSv3. Within this specification, the previous problem is acknowledged and the combination of Building element, BIM use and level of model element progression dependent on the BIM use was standardised and its relationships pre-set as a library of definitions. Therefore, a positive relationship between LOD and BIM use was established.

Both the AIA E202 and the AIA G202 documents support the studied relationship (AIA, 2008, AIA, 2013b). The AIA Document E202 defines authorised uses such as construction, analysis, cost estimating and schedule as per LOD. Similarly, in the AIA G202, which is the newest version of the document, a coordination use is added, and a previously defined construction use is subtracted.

A positive relationship between BIM Use and LOD is explained within the State of Ohio BIM Protocol (Ohio DAS, 2011). This guideline uses the AIA E202 to define required uses for building permission purposes as the model progresses. However, it does it independently of project stages. The OSU proposes using the BIM Forum LOD 300 for the clash prevention use. This is overall coordination of the spatial relationship of the model components and systems by the design team. Similarly, the LOD 350 is used for clash detection by the construction team before field installation (TOSU, 2019). This relationship can also be considered as positive.

Differently from the USA, in Europe, narrative descriptions have been created to describe the LOD. For example, the 3D Working Method 2006 in Denmark contains a narrative description of model progression which includes non-authorised uses such as modelling, estimating coordination, planning, logistics, operations and maintenance and fabrication performance (Bips, 2007). Non-authorised uses within this study are uses

which are linked to a very general level of detail giving rise to the authors interpretation. Therefore, the relationship support was considered as moderate.

The *BS 8541-3:2012* establishes a positive relationship between three different levels of detail which attend to different BIM uses each one such as coordination, quantity take off and visualisation (BSI, 2012a). Furthermore, it combines a level of measurement which will set the basis for a detailed definition of the model element and its preparation for quantity take offs purposes. Meaning that for a model element to be used for a specific BIM use, it must be detailed to purpose.

The PAS 1192-2:2013 defines the Level of Definition (LOD) and introduces a narrative for each level of model progression from which the following BIM uses can be deducted (BSI, 2013): Design, Analysis, Coordination, Sequencing, Estimating, fabrication, capture of as installed information, operation, maintenance and performance. This implies a moderate relationship between the LOD and BIM Use relationship. Similarly, the Common BIM Requirements 2012 introduces textual descriptions per level of model progression where certain BIM uses can be deducted from. For example, communication and collaboration, energy analysis, construction, scheduling and contractor purchasing.

Classification → Building Element

There are few initiatives considering the relationship between classification and Building Element categories. Vico software establish a positive relationship between classification and building elements as it uses a classification system to describe a building object in more detail as the project progresses (VicoSoftware, 2016).

Similarly, in Finland, the Common BIM Requirements 2012 encourages agreeing on the information beforehand using the Architect's Model content requirements table which uses the Talo 2000 classification (Gravicon, 2012). This gives the designers the free will to organise the BIM content level per stage. The guide demonstrates that the product naming evolves with the object, for example for Level 1, building parts are named using a description of the object, whereas for Level 2 there is a clear naming convention and cost information can be inferred from the model.

Within the AIA Document E202TM – 2008 BIM Protocol Exhibit (Level of Development) (AIA, 2008), a model element defines a component, system or assembly within a building and these are represented by the Construction Specification Institute (CSI) UniFormatTM classification system. However, the "Guide, Instructions and Commentary to the 2013 AIA Digital Practice Documents" (AIA, 2013c), recommends using a different classification system if required according to the complexity of the classification system, the number of different users, familiarity with the classification and evaluation of the Model use and translation to required software. For example, Masterfomat and Omniclass are recommended. Similarly, The BIM Forum Level of Development Specification uses the AIA G202-2013 Level of Development definitions using the CSI Uniformat 2010 (BIM Forum, 2013, BIM Forum, 2014, BIM Forum, 2015a, BIM Forum, 2016b).

Furthermore, within the Denmark_3D Working Method 2006 (Degree of Detailing), it is encouraged that the DBK national classification is used to define the building model (Bips, 2007).

The PAS 1192 is an example of a regulation that stablishes a link between systems or product with a classification system such as Uniclass and the cost plan (BSI, 2013). The BSI also created the BS 8541-4-2012 Library objects for architecture engineering and construction – Part 4: Attributes for specification and assessment – Code of practice (BSI, 2011). This guide recommends using measure naming conventions based on the BS ISO 80000-1.

Classification → stage

There is a scarcity of guidelines recommending best practice to address the classification stage relationship. However, the PAS 1192-2:2013 suggests using the CIC scope of services" stage definitions (BSI, 2013). However, this was not determinant to evaluate the relationship.

Classification → Attributes

A different trend helps to classify attributes per classification system. For example, the Object Element matrix, which is a compendium of BIM model attributes for each building element is referenced using the OmniClass and Uniformat classification system. The attributes evolve in line with the AIA E202 LOD definition (VA CFM, 2010). The attributes are classified according to different BIM uses such as costing requirements, construction logistics or asset management among others. The model author would choose the appropriate element and LOD for the required BIM use and would populate its BIM model with the described attributes. Therefore, the relationship was considered as positive.

4.3.3 Theoretical Framework

This objective builds on the main findings from the Memo Taking and Theoretical Sampling Stages which are summarised below in Table 4-4 and The table was created using the methodology described in Section 3.2.3, Objective 3.

Table 4-4. Summary of LOD guidelines relationship support.

Relationship	Positive	Moderate	Negative	Result
Scale → BIM Use	(AEC UK, 2009)			NA
Project Stage→ BIM Use	(VicoSoftware, 2016)	(AIA, 2013b)		NA
Project Stage → LOD	(BSI, 2013, UoSF, 2018)	(Bips, 2007)	(VicoSoftware, 2016, AIA, 2008, AIA, 2013b, BIM Forum, 2013, BIM Forum, 2014, BIM Forum, 2015a, BIM Forum, 2016b, BIM Forum, 2017a, BIM Forum, 2018a, BIM Forum, 2019a)	Negative support
Role → LOD		(Bips, 2007)		NA
LOD → Attributes	(VA CFM, 2010, NYCDDC, 2012, USACE, 2014, BIM Forum, 2015b, BIM Forum, 2016a, UoSF, 2018, BIM Forum, 2016b, BIM Forum, 2017b, BIM Forum, 2018b, BIM Forum, 2019b)	(VicoSoftware, 2016, BSI, 2012b, BSI, 2013)	(AEC UK, 2012)	Positive Support
LOD → Geometry	(BIM Forum, 2013, BIM Forum, 2014, BIM Forum, 2015a, BIM Forum, 2016b, AEC UK, 2009, AEC UK, 2012,	(VicoSoftware, 2016, AIA, 2008, AIA, 2013b)		NA

Relationship	Positive	Moderate	Negative	Result
	BIM Forum, 2016a, BIM Forum, 2017a, BIM Forum, 2018a, BIM Forum, 2019a)			
LOD → Scale	(AEC UK, 2009, AEC UK, 2012)			NA
BIM Uses → Attributes	(BSI, 2012b)			NA
BIM Use → Geometry	(AIA, 2013b, AIA, 2013a)			NA
BIM Use → LOD	(VicoSoftware, 2016, AIA, 2008, AIA, 2013b, Ohio DAS, 2011, BSI, 2012a, TOSU, 2019)	(Bips, 2007, BSI, 2013)	(VicoSoftware, 2016)	NA
Classification → Building Elements	(VicoSoftware, 2016, Gravicon, 2012, AIA, 2008, AIA, 2013b, Bips, 2007, BSI, 2012b, BSI, 2013)			Positive support
Classification → Stage	(BSI, 2013)			NA
Classification → Attributes	(VA CFM, 2010)			NA

Figure 4-5 presents a LOD framework which relates LOD constructs' pairwise comparisons and IDM perspectives from section Table 2-2. The framework can be used to determine causal influences in defining Net Benefits arising from its usage in projects.

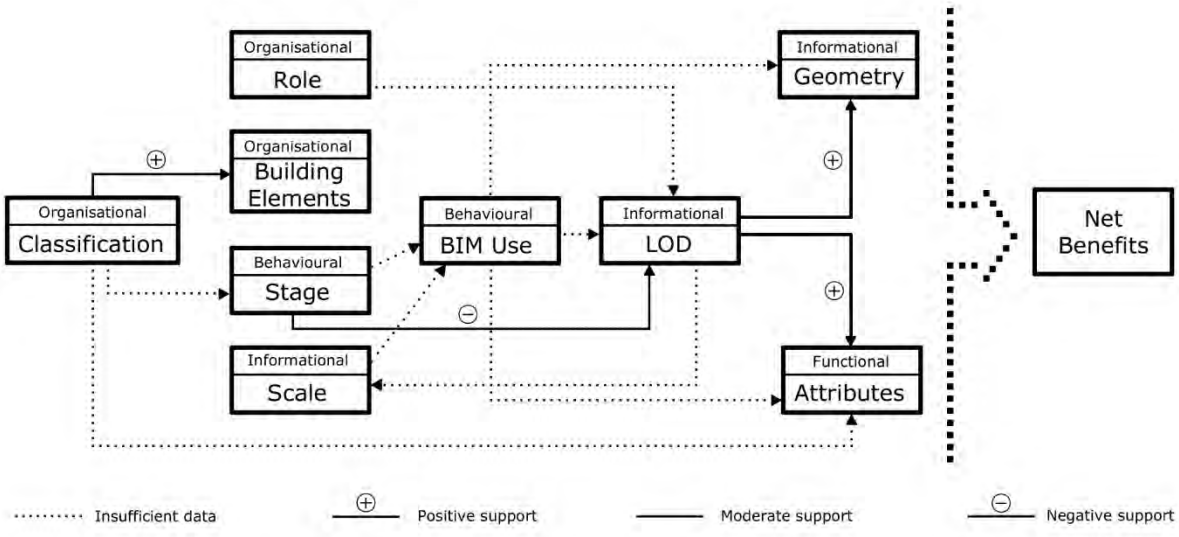


Figure 4-5: BIM LOD Implementation Framework.

The quantitative study shows that there is insufficient data to draw conclusions for most of the unit of analysis (However, there is strong support for the following relationships: Negative support for the LOD → Project stage and Positive support for the Classification → Building Element. There is not sufficient data to establish a direct link between Net Benefits and the studied relationships. However, the net benefits found within the literature has been summarised in Table 4-5 for future case study validations. For example, it would be useful to investigate whether LOD definitions that closely define building elements per classification yield greater reliability of external and internal databases. Similarly, one could also investigate whether the LOD definitions that bind LOD per project stages leads to poor value engineering performance.

Table 4-5. Net benefits associate to pairwise relationship constructs.

Scale	→	BIM Use	+ Transition from CAD to BIM (AEC UK, 2009).
Project Stage	→	BIM Use	-A project stage does not constraint a BIM use as it will affect negatively the freedom of use choice (Kreider and Messner, 2013).

Project Stage	→	LOD	+Alignment to country submission standards (BSI, 2013). -Value engineering (VicoSoftware, 2016). -Waste time, cost, human resources (BIM Forum, 2013)
LOD	→	Attributes	+Attributes validation (Solihin and Eastman, 2015), Historical database link (VicoSoftware, 2016), Avoids waste of time, money and resources during design (BIM Forum, 2015a, BIM Forum, 2016a, BIM Forum, 2017a, BIM Forum, 2018a, BIM Forum, 2019a).
LOD	→	Scale	+ Transition from CAD to BIM (AEC UK, 2009).
BIM Use	→	Attributes	+Attributes validation (Solihin and Eastman, 2015), Historical database link (VicoSoftware, 2016)., Avoids waste of time, money and resources during design (BIM Forum, 2015a, BIM Forum, 2016a, BIM Forum, 2017a, BIM Forum, 2018a, BIM Forum, 2019a).
Classification	→	Building Elements	+Reliability of external and internal databases (VicoSoftware, 2016).
Classification	→	Stage	+Reliability of external and internal databases (VicoSoftware, 2016).
Classification	→	Attributes	+Reliability of external and internal databases (VicoSoftware, 2016).

The Grounded Theory framework presented can be used to generate hypothesis. These hypotheses can be tested, and the conclusions added to quantitative analysis performed reinforcing or weakening the Figure 4-5 relationships between constructs.

4.4 Objective 4: Evaluation of LOD constructs

4.4.1 Perceived Usefulness

AIA E202

To the question PU1, 55.6 % of the participants agreed that the AIA E202 method was useful for coordinating clash detection exercises, while conversely 33.3% disagreed.

The qualitative positive responses are not unified as per any particular theme. For example, BM151Q14 thinks that the AIA E202 is useful as -*"It at least gives clarity of responsibility for each category of element, and an expectation for element maturity"*, while SD221Q14 states that -*"It is useful, but clashes may be detected in further stages leading to repetition of an important amount of the job done*".

BM342Q12 and BM511Q12 reasons for not agreeing on AIA E202 usefulness for coordinating clash detection exercises is similar and can be represented by the BM511Q12 statement -*"The LOD is only defined at the end of the stage, which means it is not controlled throughout the project stage. Clash detection carried out at the end of the project stage will produce more clashes and will require more rework in the design. Which will have a negative impact on time, cost and quality".*

In total there are two statements from a BIM manager and a Structural designer who support the assumption that not coordinating the LOD through the design and only leaving it to the final of the project stage might have a negative impact in terms of rework of the job done after the clash detection exercise.

PU2 had a similar percentage of positive responses to PU1. 55.6 % agreed that the AIA E202 LOD standard was useful for achieving the purpose of the clash detection exercise. The rest of the responses are equally distributed along the remaining four options of the Likert Scale. The positive responses lead to the same conclusion as PU1. However, it is introduced the likelihood of disciplines modelling last minute BC511Q21 or compliance to be too late in process D221Q24.

With regard to PU3, 44.4% agreed that this method was useful for achieving the objectives of the clash detection exercise. This positive figure was reaffirmed with one

additional participant who replied that strongly agreed to the statement. By contrast a 33.3% was doubtful on whether agreeing or disagreeing.

The positive response BM151Q34, highlighted the flexibility of AIA E202 -*"Helps to capture all clashes without risk of change". On the contrary, the neutral response BM342Q33, evidences that it is an unmanaged process, "It´s saying something about the end goal. Nothing about the process".*

AIA G202

To the question PU1, 55.6 % of the participants agreed that the AIA E202 method was useful for coordinating clash detection exercises and seconded by a 44.4% of participants who strongly agreed.

One of the participants answered that more detailed checks could be brought earlier into the design (BC151Q35), to which BC151Q15 added that this would give more time to resolve clashes. BM341 in the response Q15, compared AIA G202 to AIA E202, explaining that AIA G202 would add better context to decision making. SD131 responded in similar trends (SD131Q14).

SD221Q15 added positive attributes -*"Time efficiency and quality".* However, the response was not exemplified. BM511Q14 response might bring more information about the root causes of the positive attributes assigned by SD221Q. LOD defined at set milestones, will produce less clashes, which means less rework in the design. "*This will have a positive impact on time cost and quality".* BC341Q14 was more specific and highlighted that more frequent clash detection exercises may reduce the number of false clashes.

In a similar trend to PU1 44.4 % of respondents to PU2 agreed that it was useful for achieving the purpose of the clash detection exercise. The same percentage applied to participants who strongly agreed to the statement. On the contrary, only 11.1% disagreed.

BM342Q24 emphasised that he would agree only if milestones are well divined and thought through. SD131Q25 fundaments its agreement with the fact that clashes are avoided before they are produced. However, it is remarked that the exercise of bringing different professionals together should be less expensive than the derived cost and time of avoiding the clash.

The only negative response was related to the fact that uncertainty in the process could be mitigated by creating glass boxes which would absorb design tolerances (D221Q22).

Among the respondents to PU3, 44.4% of the participants strongly agreed that this method was useful for achieving the objectives of the clash detection exercise, followed by a 33.3% who agreed and a 22.2% who neither agree or disagree.

Among the qualitative responses it is empathised that the only way to achieve the best solution is by using the AIA G202 (SD131Q34). The standard was seen as a way to find regular clashes as required (BC341Q35). Also, it was said that it could improve certainty of the detail earlier “D221Q33”.

4.4.2 Perceived Ease of Use

AIA E202

To the question PEU 1, 44.4 % of the participants agreed or strongly agreed that the AIA E202 method was easy to coordinate clash detection exercises the way they intended. The same percentage applied to the participants who disagreed or strongly

disagreed. The participants did not give any notable reason to why they agreed with PEU 1, whereas the major reason why this standard might be difficult to use could be the lack of any degree of LOD coordination (SD131Q11, BM342Q12, BM511Q12).

88.9 % agreed that the AIA E202 LOD standard was easy to learn for carrying out clash detection exercises, while 11.1 % neither agree or disagree. Within the qualitative responses, there is a considerable agreement that AIA E202 is easy to learn due to the process being more linear and simpler in terms of target dates to be achieved (BM511Q25, BC151Q25, BC341Q24).

With regards to PU3, 67.7% agreed or strongly agree that this method was easy to coordinate clash detection exercises, while only a 11.1% disagreed. The positive response SD131Q35, highlighted that clashes are easier to be detected.

AIA G202

To the question PEU 1, 55.5 % of the participants agreed or strongly agreed that the AIA G202 method was easy to coordinate clash detection exercises the way they intended. 44.4% of the responses, a very similar percentage, applied to the participants who disagreed or strongly disagreed. The major problem with G202 is the difficulty to know to what LOD each discipline should develop the model at each milestone **SD131Q12.**

55.6 % agreed or strongly agreed that the AIA G202 LOD standard was easy to learn for carrying out clash detection exercises, while 33.3 % disagree. Despite SD221Q24 agreement it is noted that in order to be implemented correctly all teams should become

aware of its importance. This is in line with BM511Q22 that recognised that is would be harder to communicate.

With regards to PU3, 67.7% agreed or strongly agree that this method was easy to coordinate clash detection exercises, while only a 33.3% neither agree nor disagree and nobody disagreed.

Among the positive support, it is said that is easier to focus on certain aspects so more value could be added BM342Q34. SD131Q34, also added that the AIA E202 cannot be considered as a management tool to coordinate disciplines.

4.4.3 Intention to Continue to Use

AIA E202

To the question ICU1, 44.4 % of the participants neither agree nor disagree to continue to use the AIA E202 if they were to retain access, while 33.3 % disagree or strongly disagree. 22.2 %, a fewer percentage agreed or strongly agreed. One user did not find it useful (BM342Q11), a likely cause might be that the management process is not reflective of the design process. (BM511Q11). Some users were doubtful on whether they would retain access or would use the AIA E202 standard. For example, “Granularity of G202 is attractive. Not always our option to choose the system used on a project” BM341Q13. Another user would adopt it if the clash is easy to resolve or is improbable that it makes an impact on redesign.

44.4 % agreed or strongly agreed that they will expect to continue to use the AIA E202 for clash detection coordination, while 33.3 %, slightly less participants, strongly disagreed or just disagreed with the ICU2 statement. One participant argued that not

managing the process along milestones is often the preferred method for large model issues to client (BC341Q24). By contrast, one user stated that it was not very useful (BM342Q21) and same reason as for ICU1 were given not to use it. For example, the process is not reflective of iterative design (BM511Q31).

With regards to ICU3, 55.6% disagreed or strongly disagreed with the idea of using the AIA E202 management method over any other. In contrast, only a 11.1% disagreed.

The reasons for not preferring it were that clash detection should be done frequently (BM511Q31) and again - "*The management process in relation to uncontrolled LOD are not reflective of the iterative design process" (BM511Q31).*

AIA G202

To the question ICU 1, 88.9 % of the participants agreed or strongly agreed that if they retain access to the AIA G202 their intention was to continue to use it. While 33.3% of the participants neither agree nor disagree. The main supporting reason was the following: *"The management process in relation to controlled LOD are reflective of the iterative design process".* BM511Q14

55.6 % agreed or strongly agreed with the idea that they will expect to continue to use the AIA G202 for clash detection coordination. 44.4% of responses, a slightly superior percentage disagreed or strongly disagreed. BM151 in the comment BM151Q24 positively agreed and manifested its expectations to continue to use it if client and project requirements allow it. On the contrary, BC151Q22 thought that clients´ would not see benefits for themselves and this might affect its future use.

With regards to ICU3, 66.6% agreed or strongly agree that they prefer to use the AIA G202 management method over other clash detection exercises, while only a 11.1% disagreed. One of them stated that it avoided unnecessary work by allowing clashes to be detected during design (BM151Q34). On the other hand, BM511Q34, stated that the management process is reflective of the iterative design process.

4.5 Chapter summary

The analysis of Level 2 BIM and Level 3 BIM brought up that the PDT was not an appropriate method to create data. Findings from Objective 1 identified the IDM BPMN as a modelling language to be used to create data. The Action Research Start-up stage, Diagnosis, Intervention and Transition in Objective 2 helped to understand that the IDM ER can be link to an LOD definition in order to create a systematic and replicable process to specify BIM Model data. This was tested with Made to Stock products; however, it was found that in order to understand better the process of BIM Model data specification and to be able to generalise the findings, the LOD concept, independently of the standard and type of product needed to be further explored. For that reason, Objective 3 explored further the LOD concept. A novel BIM Implementation LOD Framework was created with aim to create a tool that could generate hypothesis to explore the relationships between pairs of LOD constructs. Results from the validation of the LOD Implementation Framework were presented and further analysed in the conclusions section,

CHAPTER 5: CONCLUSIONS

5 Conclusions

5.1 Introduction

5.2 Key research conclusions

Manufacturers have difficulty in specifying BIM objects' data using the LOD (BIM4M2, 2014), which requires an in depth understanding of product content requirements (attributes) and BIM uses (ie. Facilities Management) (Van Kolck et al., 2012). Currently, Level of Development (LOD) data specification is not feasible as the method used to populate BIM objects with manufacturer data is based on compiling data from paper product specifications or LOD attributes guidelines which are not precise in terms of scope (BIM use) and content (attributes). UK manufacturers need to be capable of modelling business processes for their products using the LOD standard for data specification. The present research outlined the development of a novel approach to deduct parameters associated with the LOD (IDM informational perspective). It also provided a framework for LOD implementation which was used to study the impact of the IDM behavioural perspective.

5.2.1 Objective 1: Level 2 and Level 3 LOD Factors conclusions

The PDT developed by CIBSE is not completely suitable for modelling LOD data associated with BIM Models due to the lack of a method to associate LOD data with BIM processes (Refer to PDT process in Table 2-21 and IDM process in Table 2-22). Therefore, the IDM process was thought to be able to help understanding the procedural aspects of data specification, which was further explored in Objective 2.

5.2.2 Objective 2: Method to define BIM data conclusions

This section has been partially published in the publication number 2 of Section 1.7.

The Wix and Karlshøj's (2010) IDM BPMN method from BuildingSmart International was used within the present study to create manufacturer Made to Stock product data.

1. *A systematic method to create LOD data has been tested and validated. The method has been able to detect more fit to purpose attributes than previous attempts to specify data (See Section 4.2).*

The "Intervention" stage of the present research study showed that the IDM could be used as a starting point for agreeing on the definition of the BIM object data.

2. *It was demonstrated that the BMPN is able to capture data exchanges at certain LODs (See Chapter 4, Section 4.2.4).*

However, the research group suggested that the IDM BPMN would require improvements in order for the LOD to be implemented within its structure.

Working on their case study on building product data, Berard and Karlshoej (2012) suggested that data resulting from the IDM process should be free of IFC bindings (i.e. data should be exchanged as IFC, Revit files or unstructured documents).

3. *The present study agrees that manufacturers would benefit from a less complex process of data creation.*

Furthermore, we suggest that manufacturers can effectively incorporate IFC attributes to the interoperable XML format at Level 2 BIM for its inclusion within proprietary software BIM models.

The case study working group agreed that data value will increase as long as it could be used within proprietary software for data exchanges. That in turn will allow clients to include manufacturer data within contracts. Therefore, this study suggests that the mapping of the deducted IDM data to existent MVD should be a task of manufacturers, leaving the task of transcribing free binding data to IFC format to software developers as suggested by Berard and Karlshoej (2012).

4. From the manufacturers point of view, the BIM object should incorporate attributes defined within a current MVD or those created using the IDM BPMN for its future inclusion within a MVD.

For example, the results highlighted in Section 4.2.4, Objective 2 show that for the case study working group, it is more important to advance on interoperability of attributes rather than incorporate attributes from manufacturer paper specification which in turn might not be useful for data exchanges.

Despite having an industry known BuildingSmart International IDM guideline, Wix and Karlshøj (2010) and Lee et al. (2016) studies draw attention to the lack of a common standard for defining Exchange Objects (See Section 1.4).

5. *The present study proved that the LOD could be implemented within the BPMN for the definition of Exchange Models.*

However, the working group found that the Wix and Karlshøj (2010) and IDM guideline has some shortcomings within the Behavioural (project stages), and informational (attributes) perspective when implementing the LOD to define Exchange Requirements.

6. *The information perspective requires a clear definition of the Exchange Models to deduct attributes consistently along process maps.*

Eastman et al. (2010) highlighted the difference between Exchange Models and Exchange Objects. Exchange Objects are not documented within the IDM guide and are defined as building blocks for defining Exchange Models. While the Exchange Models identifies the information set exchanged, the Exchange Objects are atomic definitions of the information sets that are to be exchanged. The Exchange Object definition might vary depending on the level of detail of the exchange object defined as per stage. While, Eastman et al. (2010), Exchange object definition process requires preparing the field for MVD development, thus overcomplicating the IDM development (i.e. defining functional semantics, relations and property sets for each exchange object), the present study proposes that it is kept relevant to property exchanges.

7. *It is suggested that a simple method free of IFC bindings is beneficial to end users such as manufacturers as their interest remains only on defining consistent attributes agreed on across the industry.*

Recker (2010b) analysed the BPMN use and found that the BPMN 1.1 needed an approach to specify Pool and Lane meaning. Recker (2010b) proposes workarounds such as restricting the meaning of the BPMN Pool and Lane constructs. While Berard and Karlshoej (2012) argue that the IDM language was proposed to overcome the BPMN 1.1 shortcomings, the present study has found that an effort needs to be made on defining Exchange requirements in future releases. For example:

8. *Within the method described in the Transition Stage, Section 4.2.4, it is recommended keeping the Exchange Requirements relevant to a standardised LOD.*

For example, the AIA E202 or the PAS 1192 provides a standard way to express Exchange Models in a consistent manner. However, while the geometric information is well defined within the AIA E202, the PAS 1192 uses a more generic approach. Similarly, in both cases, the detail of the LOD non-graphical data (BIM object attributes) is either non-existent or insufficient to define exchanges. Therefore, a common industry solution should be given to define Exchange Requirements in a consistent way if the IDM aims to be deployed in an industry basis. As seen within the Diagnosis Stage, Chapter 4, Section 4.2.3, the selection of the LOD should take the following intrinsic constructs into account: stage, number of definitions and actors. The wide range of options could affect the behavioural perspective of the BPMN.

The behavioural perspective is well addressed within the BuildingSmart International IDM guideline (Wix and Karlshøj, 2010). In line with Recker (2010b)

recommendations, the meaning of project stages was restricted. For example, to clarify project stages meaning, the IDM guide utilises a list of stages based on the Generic Process protocol (Wix and Karlshøj, 2010).

9. *In order to reduce required PMs and for its ease of use on an industry basis, this study proposes keeping the PMs free of stage bindings.*

For example, the design of a product could take place during the design stage, construction or during the maintenance stage (Kreider and Messner, 2013). Trying to map LODs Exchange Requirement to project stages might overstrain the data specification process and require mapping more processes than required to find a general solution. Furthermore, Hooper (2015) study on LOD model progression states that the LOD should not be restricted to project stages. For example, a cable tray LOD 100 might be specified during the design stage or during the construction stage. It is up to the project specifier to organise the data as the project progresses (CICRG, 2010). Therefore, the IDM BPMN should be free of stage links when specifying LOD data on an industry basis. To accomplish this, the PM created should be specific enough to include only the product studied, related products (i.e. inherited attributes) and a defined BIM use.

5.2.3 Objective 3: Theoretical LOD Framework conclusions

This section has been partially published in the publication number 4 of Section 1.7.

A grounded theory methodology has been carried out to create a framework for LOD implementation within the IDM. The following observations arise from the review of the LOD literature from a historical perspective and from the analysis of the LOD constructs pairs of relationships for the IDM industry adoption:

1. *The theoretical constructs that conform the framework can be classified as follows: BIM Use, Lod, Project Stage, Role, Building Element, Classification, Scale, Attributes, Net Benefits.*

By studying the interrelations between pairs of constructs, it has been possible to suggest Net benefits from LOD implementation such as:

2. *Increased Model Reliability, Enhanced Value Engineering, Enhanced Attribute Validation, Reliability of External and Internal Databases, e- Submission, Lean Design Among Others Such as Risk, Cost and Schedule Prediction.*

It is obvious that there is no consensus on the best approach to combine LOD constructs for it use on a global and industry basis. There are many approaches to LOD project management depending on the country approach to BIM and year of publication. For example, some countries might recommend using IFC attributes such as the UK with its BS1192-4 (2014), while other guidelines might recommend a gradual transition from CAD to BIM identifying BIM uses, LOD and Scales together within the same specification. For example, the Architectural, Engineering and Construction (AEC) UK BIM Standard (2009).

3. *The present research shows that there are many dependent variables from which the LOD researcher can choose*

It can be argued that selection of a LOD specification entails selecting the best approach to its intended context of use. Therefore, there is not a better approach which could be recommended from the LOD framework (see Figure 4-5) and associated Net Benefits in Table 4-5. However, the review of the LOD pairs of constructs has helped to

determine that some constructs might work better under certain context than others. The research is limited to the literature available and some guidelines' recommendations lack of scientific criteria. Therefore, some consolidation of the previous variables should be done in order to create a basis for future research.

4. *The critical comparison of the described pair of relationships could weaken or strength the relationship based on the Net Benefits of the approach compared.*

Measures to LOD implementation success has never been suggested within the literature. It is acknowledged that it might be difficult to isolate the impact of one construct on the overall LOD performance within a project. However, the study of the previous pairs of relationships has helped the researchers to suggest the Net benefits shown in Table 4-5. The measures of Net benefits have been classified per pair of constructs and negative (-) and positive (+) impact on LOD performance. For example, a project stage closely linked to a LOD definition might lead to poor value engineering performance.

It should be noticed that the LOD is composed of multiple relationships that might give place to use more than just a pair of constructs when creating a LOD specification. Therefore, the measure of the benefits should consider hypothesis that test multiple pair of constructs to assess the overall impact of the option chosen.

5. *BIM validation requires a consensus on the LOD standard used on an industry basis which requires the use of the IDM*

At this stage, there is insufficient scientific data to measure the strength of the relationships. Furthermore, the presented results are illustrative in the sense that it is aimed for other researchers to test hypothesis based on the LOD framework. Therefore,

more work was needed to stablish qualitative or quantitative studies which could measure in terms of positive support or negative support the proposed pair of relationships. For example, visual inspection of the framework shows that, although there are not enough studies to evaluate the strength of the proposed relationships, there is consistent support for the following relationships net benefits and measures to be evaluated in future research: LOD → Project stage and Classification → Building Element.

In addition, more studies are needed at the project level and industry level. The proposed framework prepares the field for industry adoption of the LOD standard, linking its intrinsic constructs (Section 4.3) to the IDM perspectives in Table 2-2. This in turn will help to understand the managerial performance of LOD standards in Level 2 BIM and Level 3 BIM projects.

5.2.4 Objective 4: Validation of the LOD Framework conclusions

Perceived Usefulness

The cumulative percentage of people who positively agreed or strongly agreed for the AIA G202 PU1 statement was of the 100%, considerably higher than the 55.6% of people who agreed for the AIA E202 PU1. A possible explanation of that variation according to the qualitative response's analysis in () is that although both the AIA E202 and the G202 does give clarity in terms of responsibility of each element category and expectation of element maturity, the AIA E202 might lead to repetition of the job done due to detecting the clash at later stages. Also, the strong agreement with the AIA G202 standard method was due to its capacity of assigning LODs as per defined milestones

which would add better context to decision making. For example, bringing more detailed checks earlier in the design might mitigate clashes avoiding rework.

On the other hand, none of the AIA G202 PU1 had a negative opinion over the overall usefulness of the standard, while 33.3 percent, on the other hand disagreed with the AIA E202 PU1 statement. The qualitative reason for disagreeing with AIA E202 was that is not a method that controls the LOD process along the stage, this would produce more clashes at the end of the design process and more rework after clashes have been detected, which will impact time, cost and quality.

The cumulative percentage of people who positively agreed for the AIA G202 PU2 statement was of the 88.8%, similar to the 66.7% of people who positively agreed or strongly agreed for the AIA E202 PU2. This might be explained by the concern of disciplines modelling last minute or compliance to be too late in process if the AIA E202 is used. However, recommendations to use the G202 were introduced. It was recommended that the milestones set along the project stage should be well defined and its definition should be informed.

The cumulative percentage of people who positively agreed for the AIA G202 PU3 statement was of the 55.5%, similar to the 66.7% of people who positively agreed or strongly agreed for the AIA E202 PU2. The AIA G202 was seen as a way to find regular clashes as required while the AIA E202 would help to capture clashes without risk of change in the design process.

Perceived Ease of Use

The cumulative percentage of people who positively agreed or strongly agreed for the AIA G202 PEU 1 statement was of the 55.6%, slightly higher than the 44.4% of people who agreed or strongly for the AIA E202 PEU 1. However, 44.4% of the participants for both the AIA E202 and the AIA G202 found difficult to use the standards as they intended to.

Contradictorily, it was found that one of the reasons for finding difficult the AIA E202 in comparison with AIA G202 was the lack of any degree of coordination on the first, while the need to gather LOD information for coordination at milestone might complicate the use of the second.

The cumulative percentage of people who positively agreed for the AIA E202 PEU2 statement was of the 88.9%, notably higher than the 44.4% of people who positively agreed or strongly agreed for the AIA E202 PEU2. The major reason why the AIA G202 percentage is lower might be because is harder to communicate due to be more complex.

The cumulative percentage of people who positively agreed for both the AIA G202 and AIA E202 PEU3 statement was of the 66.7%, AIA G202 was found easy to focus on certain aspects, while the AIA E202 was not recommended as a coordination tool.

Intention to Continue to Use

The cumulative percentage of people who positively agreed or strongly agreed for the AIA E202 ICU 1 statement was of the 22.2%, considerably lesser than the 88.9% of people who agreed or strongly agreed for the AIA G202 PEU 1. A probable cause might be a management process is not reflective of the design process does not bring opportunities to add value.

The cumulative percentage of people who positively agreed for the AIA E202 PEU2 statement was of the 88.9%, notably higher than the 44.4% of people who positively agreed or strongly agreed for the AIA E202 PEU2. The major reason why the AIA G202 percentage is lower might be because is harder to communicate due to be more complex.

Regarding ICU2, the cumulative percentage of people who positively agreed or strongly agreed for the AIA E202 was 44.4% and for the AIA G202 was 55.6%. By contrast, 33.3% disagreed or strongly disagreed for the AIA E202 and 44.4% for the AIA G202. Even percentages are very similar for both standards, it can be said that the reasons for having high percentages on both sides to the spectrum for AIA G202 might be willingness to personally use it as benefit is seen bot low expectancies of using it as the client might not see the value.

With regards to ICU3, 55.6% disagreed or strongly disagreed with the idea of using the AIA E202 management method over any other. In contrast, only a 11.1% disagreed with the idea of using the AIA G202. The main reason might be the value seen on an iterative process reflective of the design which allows to detect unnecessary clashes and avoid redesign.

Net benefits

The hypothesis generated in Section 3.2.4 using the Framework for LOD Implementation (Figure 4-5) was answered below:

The net benefits that explain the Perceived Usefulness of a LOD closely bound to a design stage (i.e. the AIA E202) are:

- No context to decision making (Negative).

- Detrimental to clash mitigation (Negative).
- Capture clashes without risk of change in the design process (Positive).

The net benefits that explain the Perceived Ease of Use of a LOD closely bound to a design stage (i.e. the AIA E202) are:

- Lack of coordination with design (Negative).
- Easy to understand and communicate (Positive).

The net benefits that explain the Intention to Continue to Use an LOD closely bound to a design stage (i.e. the AIA E202) are:

- Not reflective of the design process (Negative).
- Neglects opportunities to add value (Negative).
- Does not allow to detect unnecessary clashes increasing redesign (Negative).

The conclusions above complement the Net Benefit Table 4-5 and is adding to the practical knowledge of implementing LOD standards in projects, which will be of benefit to BIM Managers. 6 out of the 8 Net benefits were regarded as negative, while only 2 were positive. Therefore, it can be said that the LOD/stage relationship in Figure 4-5 can be regarded as negative. Nonetheless, the finding lack of external validity as discussed in Section 5.3.4.

5.3 Limitations and Recommendations

5.3.1 Objective 1: Level 2 and Level 3 LOD Factors

To compensate for the lack of preciseness of the qualitative empirical research carried out in Objective 1, triangulation is recommended (Runeson and Höst, 2008). This is approaching from different angles the phenomena to be studied (Stake, 1995), thus the most recommended approach is the methodological triangulation where qualitative data is triangulated with quantitative statistical data. However, this part of the study tries to understand the intricacies of the implementation of the Level 2 and Level 3 BIM maturity within the context of the manufacturing industry. More specifically within the BIM4M2 working group. Therefore, another kind of triangulation is required. Within this kind of research, (descriptive/interpretative) case study, collecting the same data at different occasion to compare its progress was more adequate. This kind of design is called data source triangulation (Stake, 1995). This approach has been taken because during this stage of research, the researcher is a mere observer of a process. This helped the researcher to narrow the scope of the research and set the research gap within this study.

5.3.2 Objective 2: Method to define BIM data

This section has been partially published in the publication number 2 of Section 1.7.

The present research does have some limitations to consider. First, the unit of analysis was discretised to Made to Stock products (Cable tray and cables) and the electrical design BIM Use. However, future research should investigate the same and other BIM uses using a wider sample of companies (For example, sustainability or construction BIM uses within the PDT shown in Table 2-20). Also, these uses should be applied to the

study of other products in the context of the Berard and Karlshoej's (2012) clasification of Supply Management products. For example, Made to stock (e.g. Cable tray or drywall), Made to order (e.g. windows) and Engineered to order (e.g. prefabricated concrete). This was discussed in the methodology section 3.2.2 and introduction chapter where the scope was defined (section 1.2).

This will help identify paths for further research and help to generalise the findings from this study. Furthermore, the effectiveness of specifying BIM object's data from IDMs is limited due to the difficulty in gathering data for specific processes from multiple stakeholders. This has already been addressed by Berard and Karlshoej (2012). It is acknowledged that the IDM should adapt its constituents to different LOD definitions complicating data gathering processes. In future studies, it would be interesting therefore to explain the impact of the LOD constructs such as BIM use, stage, role or number of definitions on the IDM perspectives. The previous should be addressed for the findings to be extendable to other companies. Nevertheless, this exploratory study represented an initial attempt to standardise manufacturer's non-geometrical information for BIM data exchanges within Level 2 processes.

5.3.3 Objective 3: Theoretical LOD Framework

This section has been partially published in the publication number 4 of Section 1.7.

A qualitative documentary analysis was used to carry on the code phase of grounded theory in Objective 3. Therefore, only relevant LOD documents were examined to create the framework. Notwithstanding, the researchers encourage to complement this inductive reasoning with a future abductive stage. This is testing the framework hypothesis and creating both qualitative and quantitative results (for example meta-

analysis) which will modify this preliminary framework. This will only be possible when the industry has reached an adoption and maturity stage favourable enough to gather high quality quantities of meta data.

5.3.4 Objective 4: Validation of the theoretical LOD Framework

According to Robson (2002), there are 3 aspects that limits the methodological research strategy taken in Chapter 3, Section 2.6.4. These are Construct Validity, Internal Validity and External Validity

1. Construct validity. There is a risk that the interview questions are not interpreted in the same way by the researcher and the workshop attendant. In order to mitigate this risk, the data has been triangulated by recording their thought about the research question (See Appendix C, Transcripts), gathering quantitative data with respect to their perception as a user and confirming it with qualitative data on why they had selected a specific quantitative response from the Likert Scale (See Appendix C, Questionnaire). However, still the conclusions must be read taking into account that the researcher cannot control this aspect of the research.
2. Internal validity: The Grounded Theory Framework created in Objective 3 has helped to select a unit of analysis which is the influence of Project Stage in LOD. In case studies, there is a risk that the investigated factor is affected by a third factor. In order to mitigate the risk, the study was narrowed to study the clash detection use. This was thought to avoid respondent to talk about other factors that might tangentially influence the conclusions of the analysis.

3. The findings are only generalisable for Engineered to Order products; however, causal directionality between LOD constructs was not possible to be studied using the Section 3.2.4 methodology. Therefore, in future studies it is recommended to complement case studies such as the one performed within this thesis with large surveys such as the one performed by Recker (2010a) in its study *Explaining usage of process modeling grammars: Comparing three theoretical models in the study of two grammars.* In order to be able to generalise the results a minimum of 384.16 participants are needed according to Small (2009) formula presented in 3.2.4.

5.4 Chapter summary

Contrary to similar studies such as that of Berard and Karlshoej (2012) on the IDM BPMN functional perspective, the findings from the present case study has shown that the IDM could be applied on an industry basis if the product range is carefully selected and the BIM use can be supported with process prescriptive regulations. For example, we propose the use of Made to Stock products for the design BIM Use using the *"IEC 60364 international regulation for residential and similar premises"* (AENOR, 2002, AENOR, 2004).

Although it might be argued that it would be difficult to reach a common agreement on the process maps needed to define LOD attributes, this study found that as far as process prescriptive regulations are used, the process map variability is reduced. Only the company studied counts with more than 2000 Made to Stock products which gives a measure of the scale of the solution. In order for the IDM to be applied on an industry basis, manufacturers should keep the IDM BPMN simple. This should be free of IFC

bindings which would make the IDM methodology less complex to implement. However, this should not exempt the manufacturer from mapping the deducted attributes to existing MVDs and recording them within XML format which in turn can be easily exported to any proprietary software format. This is valuable for manufacturers as their BIM object data will increase in interoperability and consequently will be included within contracts when used in projects. It was also demonstrated that a common effort could help to find gaps within current MVDs thus finding paths for IFC extension.

This study also demonstrated that the BPMN is able to capture data exchanges at certain LODs. However, both the informational and the behavioural perspective of the IDM BPMN should be improved if the LOD aims to be implemented on an industry basis. The BPMN can easily modify its structure to accommodate the LOD, for example an Exchange Requirement can be identified as a LOD BIM object (see Figure 4-2). The selection of a LOD standard is recommended to avoid inconsistencies when defining exchange requirements within the PMs. However, the LOD varies in terms of its intrinsic constructs (stage, number of definitions and actors) depending on the institution which defines it. Regardless of the LOD chosen, this study recommends keeping the LOD chosen free of stage bindings, this will in turn ease the complexity of process maps needed to define the data exchanges.

The theoretical constructs introduced within this thesis: BIM Use, Lod, Project Stage, Role, Building Element, Classification, Scale, Attributes, Net Benefits; and the LOD Framework for LOD implementation described should be considered a useful tool that hypothesis for future research development. I.e. LOD defined as per project stage is detrimental for project cost, time and quality. This hypothesis was tested in Objective 4

for Engineered to Order products and the results showed a higher number of negative Net benefits for the LOD/Stage relationship. This cumulative knowledge can be used in order to select the most fit to purpose LOD when linking it to Exchange Requirements.

In summary the present research provides a comprehensive view of the LOD constructs' impact on project performance, this has been demonstrated within Objective 4. Second, it compiles a broad range of research and guidelines which tend to be dispersed and makes it coherent for its holistic study. Third, the present study can be studied as a cumulative framework, where new research on the constructs can be added therefore allowing researchers to point towards directions where further work is needed.

APPENDICES

Appendix A

Letter of Support

Dr. Darshan Ruikar
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Edgbaston
Birmingham
B15 2TT

5th January 2015

Research Project: BIM maturity implementation strategy: a critical approach for manufacturers.

Legrand is the world's leading manufacturer of wiring devices and cable management systems. In the UK, Legrand has developed a customer focused structure which harnesses the power of its market leading specialist brands, including Bticino, Electrak and Zucchini, to deliver innovative, integrated solutions for every phase of construction. Legrand is committed to offering innovative solutions that meet regulatory requirements whilst controlling our processes to limit risk and cut down on waste. For many years now, Legrand has worked with its customers and partners to ensure profitable, lasting and responsible growth in its operations. This is how we meet the environmental, business and social challenges facing the world today and tomorrow. Our aim is to offer innovative sustainable solutions to our users, to act ethically towards society, and to make a commitment to and with the Group's 36,000 employees. All the while limiting our impact on the environment
We are committed to working closely with the UK knowledge base. We see the UK Universities as global leaders in driving forward research in this area.

The UK Government have mandated BIM (Building Information Model) on all Government projects to Level 2 by 2016. This has put unprecedented emphasis on suppliers and supplier produced information. We would like to support this research project as it aims to raise clarity on the data requirements in supplier produced product models to fulfil the UK Government objectives to achieve Level 2 BIM. We are keen to be participating and support the project because we recognise the importance to develop new capability in the UK to address the requirements imposed on the UK construction industry and thus the associated manufacturing industry to achieve BIM maturity.

Design and products developed to Level 2 BIM standards contain both graphical and non-graphical information. Currently in the UK there are standards to define the level of building design and graphical requirements necessary to be represented in the BIM model at different design stage and the associated level of detail in BIM (e.g. RIBA Plan of Works). However these standards and related process primarily focused on design work streams (e.g. architecture, structures) and not on the manufactured component parts (e.g. Mechanical and Electrical parts) that are represented in the BIM. Development of models for these parts requires an extra effort from manufacturers to meet the Level 2 BIM requirements for 2016. The research project investigates these requirements and proposes the development of product libraries to different Level of Development (LOD) BIM scenarios. Working with the research project Legrand would like to develop a standardised process and associated product model/s containing non-graphical data that is complaint to Level 2 and possibly Level 3 BIM.

The research will investigate the development of a product development strategy (within the BIM LOD framework). It will guide Mechanical, Electrical and Public Health (MEP) component

manufacturers with the development of structured data for product models to achieve Level 2 and Level 3 BIM standards. Such an approach will give the MEP Manufacturing industry the process for model development required to create a coordinated BIM strategy; this can also act as a driver to organisational efficiency. The findings from the research will add to the knowledge and understanding of Level 2 and Level 3 BIM and its application within the MEP Manufacturing industry. We see the outcomes of this project to be of national importance as the project will provide the foundation for the UK construction component manufacturers to exploit the commercial opportunity surrounding the topic.

The collaboration on this project presents Legrand the opportunity to engage with experts from the University of Birmingham. We want to be able to provide practical industry experience, scenarios and data to achieve research outcomes as well as advancing the UK knowledge base to maintain the UK pioneering position in this research area. We see significant opportunities for this research in the UK and some specific export markets, which are heavily influenced by UK standards and specification eg. the Middle East.

For a project of this size, Legrand would contribute £80,000 (10 days of time per year at the cost of £1000/day over 3 years and £50,000 of data) resource and data and expect to add £0.5 million business value through exploitation of new services to customers with greater margins, repeat work through improved customer satisfaction and enter new markets. We would expect to t be involved with the development and validation of LOD model be produced as part of the project. As part of our commitment we will also contribute to technical papers and industry articles, where we are part of the dissemination of the knowledge and will participate in communication activity.

This research project is a well-placed, timely and a clearly developed proposal, prepared at a time where we are seeing significant investment in manufacturing and the Government priorities focused on the development of the high end-engineering sector.

My colleagues and I look forward to supporting you on this project.

Yours sincerely

Mark Evans
Marketing Director
Legrand Electric Limited.

Case Study Logs

Table A-0-1- 16 of February case study log.

BIM4M2 PDTs	16 Feb.
Codes	PDT, PDS.
Documents	-(company name)'s PDT/PDTs real use guidelines (confidential content) -PDT timeline from the Chartered Institute of Building Services -PDS Sheets (Cable ladder Lengths & Cable Ladder Fittings)
Minutes	The structure of the PDT rows varies depending on the building element The rows contain electrical design data, maintenance data among others

Table A-0-2- 25 of February case study log.

Legrand Group BIM follow up	25 Feb.
Codes	Australia Product templates
Documents	Revit Plugin: http://www.bimmepaus.com.au/software.html
Minutes	The Australia's product templates cannot be compared with the UK initiative.

Table A-0-3- 27 of March case study log.

BEAMA WG40 BIM	27 Mar.
Codes	Level 3 BIM, IFC/COBie mapping, Open BIM
Documents	New Level 3 BIM website: http://digital-built-britain.com/

	The IFC/COBie Report 2012 Open BIM Focus (IFC/COBie Trial 2013) BuildinSMART UK website: http://www.buildingsmart.org.uk/ BIM4M2 survey on BIM use y manufacturers
Minutes	-Building Smart UK and Ireland are running IFC/COBie trials -BIM4M2 is going to look at the mapping of the PDT to the COBie -The shared PDF "The IFC/COBie Report 2012" gives reasons to implement open standards and inform about the barriers of implementation. they talk about the benefits of using IFC and COBie together but do not mandate the use of a specific work flow. They state that *"innovation should not be stifled by mandating a process to achieve the required data"* (page 15) -Open standards are needed to implement Level 3 BIM ("The IFC/COBie Report 2012" page 6). - It's clear that BuildingSMART UK are looking at developing both IFC & COBie together. I think Patrick was unsure if BuildingSMART were supporting COBie. Perhaps just the UK chapter are doing this...I don't know for sure.

Appendix B

SMART Analysis

Table B-0-1- SMART analysis

Name: BM Position: BIM Manager/Legrand Electric LTD	
Specific	The UK Government requires collaborative 3D BIM on its projects by 2016, with all project and asset information, documentation and data being electronic.
Measurable	Structured (manufacturer) data supplied in accordance with PAS 1192-2 Specification for information management in the cap-ex construction phase.
Achievable	PDT's in conjunction with CIBSE, BIM4 Communities, CPA, BEAMA & other trade or industry bodies or organisations need to be created to support collaborative data sharing. This is to be considered a key task. 3D objects (graphical) is secondary to the provision of data.
Realistic	The creation of industry PDT's is problematical due to the large number of PDT's required and the fairly low understanding of PDT's within the wider manufacturing community. Working groups have been formed to accelerate the programme but the process remains slow. Legrand UK have authored PDT's in support of its business and have also decided to create libraries of 3D intelligent objects.
Time-scaled	The target for structured data in the public sector is 2016 – for the PDT's which Legrand have authored, this is achievable. For the wider work on PDT's, this is largely going to be difficult.

SWOT Analysis

Table B-0-2- SWOT analysis – Strengths and weaknesses

STRENGHTS	WEAKNESSES
PARADIGM A Structured data without the need of bespoken questionnaires (PDT) Common platform with competitor collaboration Compliance with UK requirement for Level 2 BIM Platform from which Level 3 BIM can be investigated	PARADIGM A Rigid approach to BIM development Competitors engaging with voice but not with action Not forward thinking
PARADIGM B Structured data and self-know of product data potential Opportunity to review our internal processes Utiliise our data to its full capacity International BIM approach can be fully realised Possible to link BIM to our manufacturing processes Creation of new employment opportunities – career progression	PARADIGM B Lack of Level 3 Knowledge (technical aspects needed) Lack of technical understanding
COMMON Statement of support for public projects Integration with ETIM (procurement classification) Capability to supply Level 2 BIM compliant formats (PDT and COBie)	COMMON Lack of technical expertise Uncertainty over the non-graphical information required (LOD) High range of products and cost of implementation Lack of knowledge on BIM uses

Table B-0-3: SWOT analysis – Opportunities and Threats

OPPORTUNITIES	THREATS
PARADIGM A	PARADIGM A
Collaborative engagement with downstream stakeholders (synergies)	Long term results might or not cover benefits
Software developers can create product supportive tools	Limited long-term outlook
Quality control of data supplied MVD checks (inclusion in contracts)	Competitors will replicate our work
Become and early adopter of Level 3 processes	
Become an expert in BIM processes and advice clients on information needs	
Become an early adopter	
Be seen as leaders in our industry	
Build new relationships or strengthen existing ones	
Opportunity to internally structure our data better	
PARADIGM B	PARADIGM B
Become an early adopter	Competitors releasing Level 3products before than us
Be seen as leaders in our industry	Competitors gaining advantage due to being more ‘agile’
Join industry leading working groups / bodies	Cost to invest or set up internal department
Build new relationships or strengthen existing ones	Time to dedicate to investigation
Opportunity to internally structure our data better	Lack of technical knowledge
SMART manufacturing	
COMMON	COMMON
Understand better our client’s specification demands	Exclusion from procurement of technologically advanced public projects
Integration with client procurement processes	Competitors creating alliances with software developers.

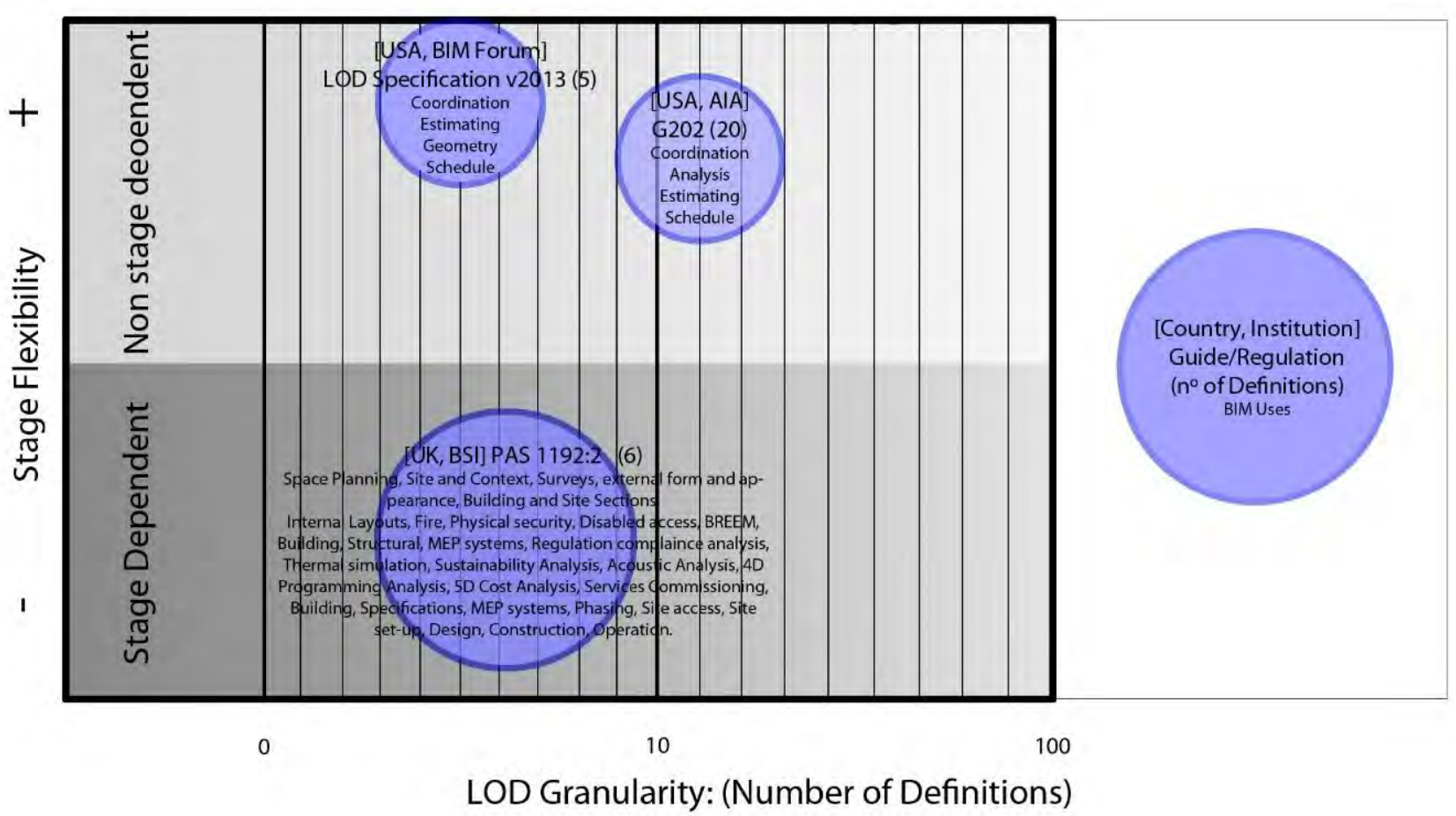


Figure B-0-1. LOD Stage dependency compared

Appendix C

Participant Information Sheet

Dear Participant,

I would like to invite you to take part in a research study. Before you decide you need to understand why the research is being done and what it would involve for you. Please take time to read the following information carefully. Ask questions if anything you read is not clear or would like more information. Take time to decide whether or not to take part.

You have been invited to take part in a PhD research study exploring the impact of different LOD definitions on design programme and clash detection.

All participants identity will be anonymised, and a journal paper will be submitted to the research journal Automation in Construction. All results from the paper will also be made available to those who partake.

The workshop will last for 1 hour and will be divided into 5 parts:

10 minutes Introduction to LOD coordination for the instance analysed (Model Production & Delivery Table and Business Process Modelling Notation).

30 Minutes discussion on given approaches and unstructured recorded interview.

5 minutes analysis of gathered clash detection metrics.

15 minutes qualitative questionnaire on usage of the above LOD standards.

Role

You have been contacted as you are an engineer with experience on design programme, a BIM coordinator or a BIM Manager.

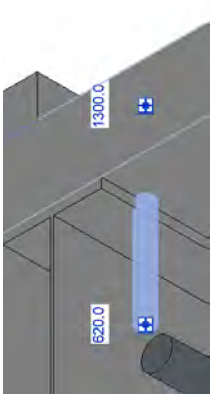
During the workshop you will be asked to:

Discuss the coordination of disciplines pre - clash detection workshop for the AIA G202 option.

Highlight clashes between the structural model and drainage model.

The metrics to be used will be the following

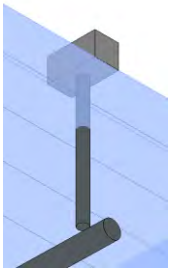
True positives (Identified as a clash and it was really a clash).



i.e Girder (LOD 300) and pipe (LOD 200)

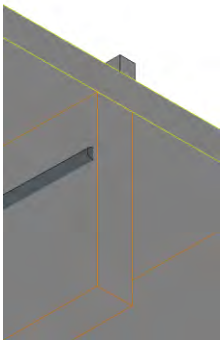
High LOD involved

False negatives (was really a clash but not identified).


i.e rebar (LOD 200) and pipe (LOD 200)

Software not able to do interference check between elements

False positives (identified as a clash but was not a clash).

 i.e Girder (LOD 200) and pipe (LOD 200)

Low Level of Development elements involved

Precision = (Relevant clashes ∩ Retrieved clashes)/(Relevant Clashes)

Recall = (Relevant clashes ∩ Retrieved clashes)/(Retrieved clashes)

Precision and recall must be close to 100% for the clash detection exercise to be reliant.

You will be also asked to discuss, cost and time associated to both options.

Your data

For the purpose of enhancing the accuracy of the qualitative analysis of the data from our interview session, with your consent I will record the audio of the session. Also, with your permission, I may include selective quotes from the transcription to illustrate point of my thesis and any resulting publications. These will be anonymised, and great care taken to ensure that any quotes cannot be attributed to you as an employee of your current organisation.

Consents Form

Role:

Years of experience:

Company size:

Type of projects involved:

Average No. of disciplines per project:

Contact email address:

Participant identification:

Title of project: Explaining LOD constructs usage: Comparing two LOD standards as per clash detection use.

Contact details:

1. I agree to take part in the above research. I have read through the Participant Information and I understand what my role will be in this research, and all my questions have been answered to my satisfaction. ☐
2. I understand that in order to withdraw from participation I must complete the slip at the bottom and return it to the researcher. ☐
3. I have been informed that the confidentiality of the information I provide will be safeguarded. ☐

4. I am free to ask any question at any time before and during the study. ☐
5. I have been provided with participant information. ☐
6. I understand that I am under no obligation to complete the study once it has commenced and can stop it at any time. ☐
7. I would like to receive a copy of the results of the workshop. ☐

Data Protection

I agree to the University processing personal data, which have supplied. I agree to the processing of such data for any purposes connected with the Research Project as outlined to me.

Signed…….. Date……

Withdrawal Form

Name of participant:

I wish to withdraw my data from the study titled: Explaining LOD constructs usage: Comparing two LOD standards as per clash detection use. That is being carried out by Angel Gigante Barrera

Signed…….. Date……

Questionnaire

AIA E202 management method

Perceived usefulness

Overall, I find AIA E202 management method useful for coordinating clash detection exercises

1.Strongly disagree/2. Disagree/3. Neither agree nor disagree/4. Agree/5. Strongly agree

Why?

I find AIA E202 management method useful for achieving the purpose of my clash detection exercises

1.Strongly disagree/2. Disagree/3. Neither agree nor disagree/4. Agree/5. Strongly agree

Why?

I find AIA E202 management method helps me in meeting my clash detection objectives

1.Strongly disagree/2. Disagree/3. Neither agree nor disagree/4. Agree/5. Strongly agree

Why?

Perceived ease of use

I find easy to coordinate clash detection exercises in the way I intended using the AIA E202 management method

1.Strongly disagree/2. Disagree/3. Neither agree nor disagree/4. Agree/5. Strongly agree

Why? Because there is not any degree of coordination.

I find learning AIA E202 management method for clash coordination exercises is easy.

1.Strongly disagree/2. Disagree/3. Neither agree nor disagree/4. Agree/5. Strongly agree

Why?

I find coordinating clash detection workshops using the AIA E202 management method is easy

1.Strongly disagree/2. Disagree/3. Neither agree nor disagree/4. Agree/5. Strongly agree

Why?

Intention to continue to use

If I retain access to the AIA E202 management method my intention would be to continue to use it for clash detection coordination.

1.Strongly disagree/2. Disagree/3. Neither agree nor disagree/4. Agree/5. Strongly agree

Why?

In the future, I expect I will continue to use AIA E202 management method for clash detection coordination.

1.Strongly disagree/2. Disagree/3. Neither agree nor disagree/4. Agree/5. Strongly agree

Why?

I prefer to continue to use AIA E202 management method for clash detection coordination over other standard management methods.

1.Strongly disagree/2. Disagree/3. Neither agree nor disagree/4. Agree/5. Strongly agree

Why?

AIA G202 management method

Overall, I find AIA G202 management method useful for coordinating clash detection exercises.

1.Strongly disagree/2. Disagree/3. Neither agree nor disagree/4. Agree/5. Strongly agree

Why?

I find AIA G202 management method useful for achieving the purpose of my clash detection exercises.

1.Strongly disagree/2. Disagree/3. Neither agree nor disagree/4. Agree/5. Strongly agree

Why?

I find AIA G202 management method helps me in meeting my clash detection objectives.

1.Strongly disagree/2. Disagree/3. Neither agree nor disagree/4. Agree/5. Strongly agree

Why?

Perceived ease of use

I find easy to coordinate clash detection exercises in the way I intended using the AIA G202 management method

1.Strongly disagree/2. Disagree/3. Neither agree nor disagree/4. Agree/5. Strongly agree

Why?

I find learning AIA G202 management method for clash coordination exercises is easy.

1.Strongly disagree/2. Disagree/3. Neither agree nor disagree/4. Agree/5. Strongly agree

Why?

I find coordinating clash detection workshops using the AIA G202 management method is easy.

1.Strongly disagree/2. Disagree/3. Neither agree nor disagree/4. Agree/5. Strongly agree

Why?

Intention to continue to use

If I retain access to the AIA G202 management method my intention would be to continue to use it for clash detection coordination.

1.Strongly disagree/2. Disagree/3. Neither agree nor disagree/4. Agree/5. Strongly agree

Why?

In the future, I expect I will continue to use AIA G202 management method for clash detection coordination.

1.Strongly disagree/2. Disagree/3. Neither agree nor disagree/4. Agree/5. Strongly agree

Why?

I prefer to continue to use AIA G202 management method for clash detection coordination over other standard management methods.

1.Strongly disagree/2. Disagree/3. Neither agree nor disagree/4. Agree/5. Strongly agree

Why

AIA E202 Workflow

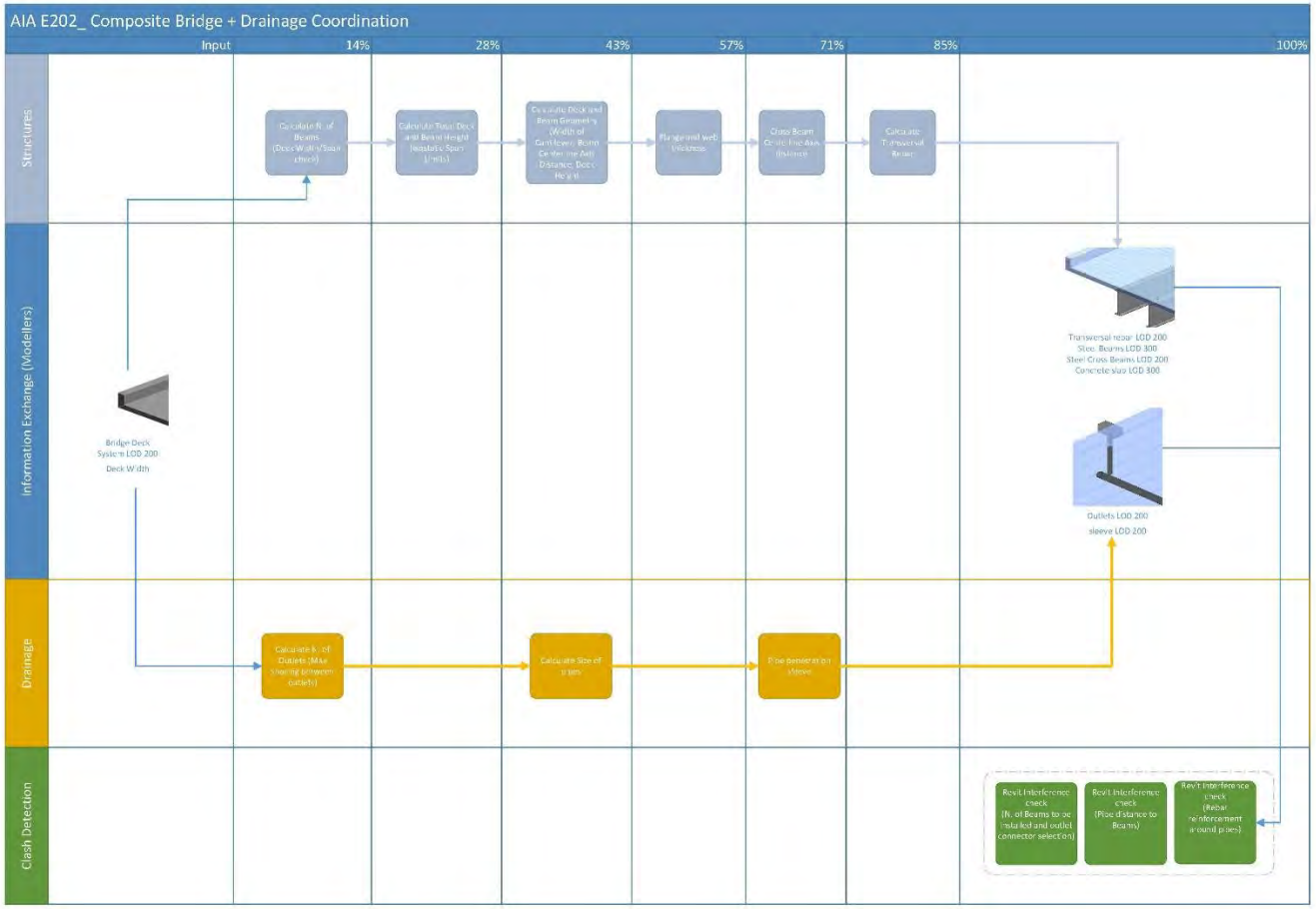


Figure C- 0-1: AIA E202 workflow.

AIA G202 Workflow

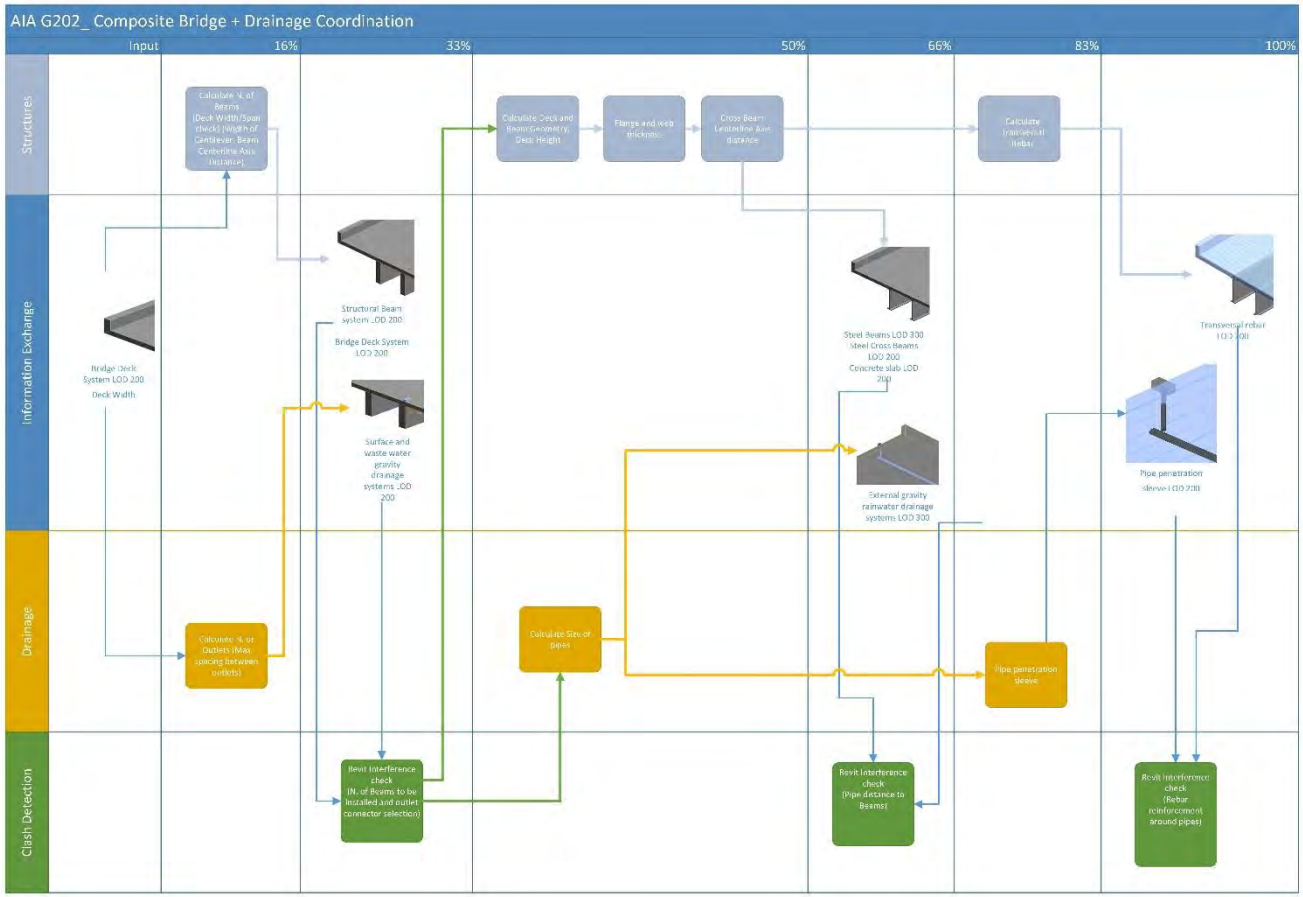


Figure C-0-2: AIA G202 workflow

Interview 1 (BM511 and BC511)

First Part

BM511: [00:12:23] Ok so, so doing the level of detail and sort of level of information at each stage gate is a lot simpler for…it's a lot simpler for other people to understand…people that will be sort of doing the modelling as such but then the problem with that is that we tend to have to issue at the same time like the quantity schedule and things like that… so actually having the level of detail and level of information mature between the stage gate means that we can have…erm ..makes it easier for like quantities and other disciplines which tend to be forgotten about. It's not the core discipline it's not the bridges, high ways, rail…but there needs to sort of be a cut-off date and I think that's where ...really the level of detail needs to be part of the programme and not just the MIDP, the MIDP is not enough I don't think, well not the MIDP the master…

Researcher: [00:12:23] The MPDT?

BM511: [00:12:23] The MPDT, that's the one.

Researcher: [00:12:23] So… ok…so do you think it's that… if that has to be part of the programme what kind of roles do you think will be needed? Do you think that we'll need somebody who has experience enough to coordinate different disciplines… somebody who knows a little bit of everything but who is…like imagine…erm…the design...? I mean we have the information manager, but the information manager is not going to plan our task. We have the lead designers, they can plan them, but they plan them as per discipline…do you know what I mean?... there should there be somebody coordinating them and putting that information into a programme for example?

BM511: [00:12:23] Personally, I think it should sort of come down to the BIM manager. I think it should be their responsibility but I… if people were to get in a room and you have the Lead designer, the BIM coordinator for each discipline and then you have the BIM manager and project manager doing the programme…erm… you'd get it done in an hour or two…cause everyone could just say alright …you sort of start with what deliverables do you have then everybody just sort of says say how early they are going to need certain things cause what will happen is you'll say…alright we need the rail alignment a week before we can freeze our bridge and then the civils team will be like alright well we need the bridge a week early before we can freeze ours and then straight away you've then got your sort of almost your hierarchy erm…and that's sort of what you need….and you sort of need to...everything sort of needs a bit of a relationship, so the bridge is driven by like the rail alignment and that places them where highways place the rail in between the piers and such… sorry the highway between the piers and such and I think that's what should be done…. and the model production delivery table should actually sort of be almost merged into the programme…along with the MIDP as well I think…I think you could create one massive programme that you'd split it down so that you can see sort of like the Gantt chart…then if you were to click on bridges you then see all the deliverables they're going to do and what point it needs to be frozen so their model needs to be done two weeks before the actual issue date which would then give everybody else time to process their…

Researcher: [00:12:23] It would be something like a creating Gantt chart and a critical path…. Kind of that?

BM511: [00:12:23] Sort of…yeah

Researcher: [00:12:23] Sort of?... alright

BM511: [00:12:23] … but then I suppose it´s kind of then…it's kind of coming back to…you are kind of putting in stage gates…just earlier than the actual ones the client wants. You'll…you know you might put in three weeks early, but each discipline will have different stage gates…erm… and then how you manage it all... well that's going to be a bit of nightmare….

Researcher: [00:12:23] It's going to be difficult?

BM511: [00:12:23] Yeah…but I suppose that's what the BIM manager is there for…

Researcher: [00:12:23] Ok….yeah….not bad…so what I think…how do you think...because you design differently from the people at buildings because you a using this software programming…how do you think trying to micro manage things a little bit more will affect your interactions with structural designers?...I mean imagine that they have to give you some kind of information at certain points and you'll have to create a script and you have to modify the geometry of the model based on that information given by the structural designer…do you think he will help you…to have that in mind in the programme? and I'm going to put you an example. Imagine that the client has asked you to do a… quantity take of a model at a lower stage…so let's say that you need to quantify…. imagine that you have 100 beams in the model, they are made of concrete and then you have some rebar inside…at that point of time probably you don't need to know where to

place the rebar but you need to know the density…so you need to know…I mean you can quantify it because you have that density of metal as part of the concrete…but you don't know anything else… but that might be an input from the structural designers in order to start creating that quantity take off at early stages…so what I mean is…if… that information can probably be managed and at different stages you may need more detailed information about the rebar or less detailed information about the river…and accordingly you might create scripts which are different because in the scripts you take families and you can take attributes and you put values… so that might help to…to understand how you have to create your script at different stages...or how you….imagine that you create templates where they just put…the structural designers.. put information into the templates…and it's kind of a baseline information needed at different stages…I don't know it's just an idea... how do you think….do you think that might be useful starting coordinating that flow of information in detail knowing which attributes to put into…

BM511: [00:12:23] Personally, I think that's the goal …I think we are not really there yet… just because of sort of old legacy…sort of ways of working…. but really what that has been is putting info into the model erm…we're just trying to improve our models at the minute and then we've got to process now how we would do that. We've just not done it. But I think it's kind of coming together within (company name) now because it's all about what actual data do we need to add…I mean that's the big question and we've started looking into that and listing it as part of like the UK infrastructure…erm.. but it would help if clients had a bit more knowledge in it because you know… we kind of push…like if there were to say to a project manager ok we need to add all this information into a model and they say well what does the client want then you're like this…then they're like well why are we doing the rest let's not bother…so it kind of always comes down to

client requirements so unless you can prove that there is some value in having that information there… say for analysis or something like that it won't get put in a lot of the time…it depends on how willing the people doing the modelling or the structural designers are…

Researcher: [00:12:23] So, do you think that probably using…or if we compare both using the G2002 trying to put milestones will help you to create models within the scope of the client requirements…do you know what I mean?… trying to…

BM511: [00:12:23] Erm…yeah…so if you start splitting it down a bit more I think it wouldn't necessarily …I think because the client requirements you'd get...if on each stage gate you just put in you know…between say DAL 1 DAL 2 …the model should go up to this level of maturity…. ermm…whereas if you do the stage gates in between its more for internally and (company name) …alright so this stage gate if we had this information it would then help the costing team because they'd know what material it is as such so I feel like this one is more client based…so literally alright here's the stuff as you want it whereas the other one is better for (company name) and their digital vision erm…because internally we have models…maturing slowly but in a managed way so that everyone is aware of what they an almost use them for…so that is usually the biggest problem...people don't want to use our models because they don't know how accurate it is...so you know…

Researcher: [00:12:23] Ok then…we can stop and do the questionnaire…

BM511: [00:12:23] Ok…cool.

Researcher: [00:12:23] Ok cool, thank you very much.

Second part

BM511: [00:00:01]: If you try and resolve clashes in that meeting, you could be there for hours discussing where it goes. Whereas if you say in this meeting, we found this Clash (.) this discipline, this discipline, speak about that, before the next meeting and resolve it. Yeah that…that bit takes two to five seconds. Whereas if they have to resolve the clash. First of all, getting the right people in there, to resolve the clash is hard and they could discuss that for 15 minutes.

Researcher: [00:00:34] Okay. So, if you were to resolve a clash, you will need not only the technician but the lead designers in there? Kind of...there would have to be more people and It would be long. It would be a long meeting.

BM511: [00:00:48] Interviewee (G): Oh, yeah.

BM511: [00:00:50] Interviewee (G): We tried one on HS2 before and yeah, we were going to do the whole route of phase one and we spent about 40 minutes on one bridge and we were like, yeah, this isn't going to work.

Researcher: [00:01:11] It's going to take forever.

BM511: [00:01:12] Yeah. So yeah, so I kind of agree with this being easier (Making reference to AIA E202) I don't think you get as much usefulness out of the Clash detection, but by doing It over signing it... I strongly agree that that's better. I think.

Researcher: [00:01:45] Ease of Use…

BM511: [00:01:46] Ease of use… is then I'd say this is a lot easier, but I think it's also clearer. I feel like this other…the other… erm sort of standard… if it became more

widely used... and more people understood it, then I'm sure it'd be a lot easier to use but I think to manage it would be quite a challenge.

Researcher: [00:02:18] Probably requires experience as a group, not individual experience.

BM511: [00:02:19] Yes, so…but yeah so agree…

Researcher: [00:02:33] What do you think (name)?

BC511: [00:02:35] yeah…yeah….

Researcher: [00:02:37] So from your point of view (name) if you were to have kind of (..) because you are creating a script, right?

BC511: [00:02:58] Yeah

Researcher: [00:02:59] So if we held that in between stages, you have a clear program on which are the objectives of that model. So let's say we are going to use this model for this reason when you are probably I don't know, probably using the model now, to….erm… place it into a context you the origin…placing families. But if you were to have other uses such as quantity take off or any other, do you think that you will be able to use your scripts with different purposes…. different objectives. I mean it's a general question…I don't know…I know it may be difficult to answer but…

BC511: [00:03:47] That's kind of the idea of scripts…to be able to tweak them to be able to do different things…so in terms of clash detection…the whole…automating design and modelling bridges is so….the intentions aren't actually an issue because you can just change the simple framework to the whole thing…or it will remodel itself so it's not as much undertaking as it usually would be when you have to remodel the entire thing.

Researcher: [00:04:10] Do you think that when creating scripts because you are now working at bridges but imagine that you were to have…imagine that there was somebody like you at drainage and you were able to talk to each other…would you be able to start creating a script that flexes both systems…that are able to…

BC511: [00:04:35] you could do…

Researcher: [00:04:36] Do you know what I mean?

BC511: [00:04:37] Yeah…yeah…

Researcher: [00:04:38] and try to start probably avoiding the clashes or mitigating something that you are not able to see when you work separately.

BC511: [00:04:40] Yeah, you can input the same parameters and use…so use the parameters from drainage planted from Bridges and you can input them into a model and then you can have the model regenerate itself over and over again, with slightly different parameters until it finds a solution where nothing clashes…that's definitely possible. Something that Amsterdam is doing currently is they were… their model… they were giving bounds to their parameters and the model would just shift itself until it finds a place I suppose where it just works for everything. It's definitely possible if you were to join forces with another team. You can create a script which will mitigate the clashes in the first place.

Researcher: [00:05:40] yeah…ok thank you.

BM511: [00:06:59] This is a hard one to answer the 'Do I find coordinating Clash detection workshop using the blah blah blah…easy. Its kind of is but I think it's just

because it's been done so much now because this is very similar to the one we currently use…sort of you know at the end…

Researcher: [00:07:18] So, this might be like saying during these stages we are going to create frequent meetings so weekly every two weeks. So that's what it is. You work and you get there probably easy…

BM511: [00:07:36] Yeah, I sort of agree because it's just set days…

BM511: [00:08:06] I suppose, yeah… continue to use it…to obtain access (fills out another question) yeah…and that kind of ties in with this one in the future I'd probably say yes. They're both just two kind of requirement.

Researcher: [00:09:15] One question (name) do you think that if we were to have a…well these are just ideas…Imagine that there are some kind of erm…lessons learned from clash detection exercises, which can be transcribed into certain points and you can take them and start writing your scripts based on what might happen usually when coordinating drainage and structures? For example, you might find that usually will have these kinds of problems. Probably we will have to root the device through the pedestrian, through all the side or at some point we might have a problem because the diameter is very big. It doesn't fit within that pedestrian way and we have to put it somewhere else. I don't know you start taking lessons that might happen quite commonly. Do you think that will help to create better scripts?

BM511: [00:10:23] yeah…

Researcher: [00:10:26] if I mean, it might not all of that information be used because it may be difficult, but studies are saying we're always having the same kind of

problems and it can be transcribed into design intent somehow within my script and start creating better scripts along the years probably because it would be like a long-term goal.

BC151 [00:10:49] Yeah. That just comes down to data at the end of the day because if you've got a load of data on our projects move forward with different scripts then you can tweak the scripts to common… common problems.

Researcher: [00:11:26]: So…which one of both do you think will help better, to…or will fit within that concept? which of these two standards?... Micromanaging it, trying to create that hierarchy of information both graphical and non-graphical. Creating baseline information for different LOD's?

BC151: [00:11:42] I kind of want to see what both are similar because they're both…we get the same information out of them…which is a clash. Yeah, so the kind of doesn't really…for the Long Haul..so just forgetting about one project. Yeah, including all projects …I don't think it matters when you get that information out as long as you get the information out

BM151: [00:12:16] and then on the other hand having it earlier…because I think that's the benefit of the G202 is it have that you'd have that information earlier so could at least benefit. This project whereas with the other management system It would only benefit future projects. Yes. I think the big problem with it is everything tends to be very last minute because a lot of disciplines weren't actually modeling 3D until the very last minute…. yeah…because of how long it would take them to amend. So it's hard to do Clash detection within a 3D virtual design review environment with that. But yeah…but if you sort of thinking about machine learning artificial intelligence …it shouldn't really matter what way you pull out. It's just the data in the end, isn't it?

BC151: [00:13:16] I suppose the other side is if people are doing it slowly over the course of the project there is a chance that they might just not do it whereas if it's all done in one…like right at the end, although it's last minute, I think there is less room for people to forget things whereas If they've got to do it continually, I think there is potentially more of a chance people will forget to do it as they don't see it as important in that point in time. Although I suppose that on the flip side of that...there is more chance people will forget to do it if they are doing it all in one go.

BM511: [00:13:55] So for me… this management system, the G202. How would the clash reviews we use be run. Would it be still be every say two weeks?

Researcher: [00:14:01] Erm it doesn't really need to be done with a frequency but with an aim and objectives in mind. So, you have your aim you may say well we only want to clash, circulate or assign action or we may say we want to get there and we want to analyze the geometry and assign actions based on what we can avoid or mitigate in the future. So in order to get there, we have to set up the hierarchy of information….input output input output and get there with an objective in mind. So you probably don't design everything. You design just only certain parts, certain families, at certain LODs. Because one of the things which is going to help you to analyze that problem.

BM511: [00:14:56] So would it be kind of erm…so we talked about having sort of internal stage gates. So you have like dell1 to dell2 but you'd have internal one…so rail issue now and then I suppose…you wouldn't really…would you check that…but maybe and then…alright…bridges issue the next week right and then we do a review whether rail and bridges work together, that's fine. Yeah, then the next is sort of highways and Civil,

then we'll check them. So... the clash sections do get bigger, but they are easily managed because some more is ticked off in a way. Yeah, we're already ticked off rail and bridge…

Researcher: [00:15:36] you don't probably have to redo work because you went there with a purpose in mind. The problem I see is that what happens if after one month the alignment changes and you have done a lot of work that was unnecessary. But I don't know. I mean, just….

BM511: [00:15:43] Yes, the alignment changes is a lot. But I suppose you sort of iterate through the process again so the alignment would change… so you check the clash of the bridge and then you find out what needs to be amended… then the bridge changes and then you clash detect everything that sort of interacts with the bridge…so the highway and Civils. So it's kind of… in a way you have disciplines that work more advanced than others in a way…and then it kind of catches up and they kind of …they jump back to the ends then they jump back in a way….yeah

Researcher: [00:16:44] everything has throwbacks

BM511: [00:16:48] Interviewee (G): Yeah I think it's a nice idea, yeah.

Researcher: [00:16:51] It might depend on projects. If they have a residential building there's no alignment which means there's no… there are no really big changes… it may depend on the type of project. You can use one management method or the other.

BM511: [00:17:10] For infrastructure I suppose some alignments can move and then the project is going into a completely different place.

Researcher: [00:17:18] Yeah, so thinking about MEP and architecture. A room is a room and you have to calculate your staff based on the volume of the room. So first

comes architecture then comes MEP. So kind of…I don't know …or probably...there's something I've been thinking about as well. ..having different CDEs common data environments and not able to…something I've been reading, but I don't know how it works. I think it's called…you know that you have IFC and BF..

BM511: [00:17:39] BCF, the mark up format…

Researcher: [00:17:41] Does that help to communicate better in an iterative way as you are working?....I don't know I haven't used it…

BM511: [00:18:14] It's more of like a… transfer format. That's what it is. So if someone works in Revit and someone works in micro station, I can export my bridge to IFC. They can export their highway alignment to IFC.

Researcher: [00:18:32] plus the markups?

BM511: [00:16:32] Well, yes, and then that will help run the clash detection because everything is sort of in a similar format that anything can open. So the idea is that…because you've got the problem of like erm…so if you do something in Micro Station, you have to convert it to AutoCAD to then read it in Revit and… there's a bit of a process there…but then if you just convert it to IFC …everyone converts to IFC, everyone can open it and then with the BCF format, it's more of its like that but for mark ups for different software…. So It will make it easier to sort of run analysis and to be able to use machine learning on it. So and you could say all right. Well, you know, you will input the BCF format…you can pull it a part so you can that a common problem tends to be MEP and architecture always clashing with each other and then it tends to be with architectures, floor slabs and stuff like that so then you look at why and then you can say all right. Well,

maybe we need to look at having the floor slabs more detail earlier. That's where the BCF format would help but…. it takes…. you tend to find that the project will just use one review file BCF…I don't know , I don't find it's that useful. Because if someone uses say Technobim site and someone uses Navisworks...then it's useful but we tend to say we're on a project, we are using Navisworks. So unless someone else is going to set up and manage ...because you don't want to be managing two review models really… you'll kind of want to just have one. So…

Researcher: [00:20:18] What I was thinking is that the software that you use may…I mean imagine that we are all working in Revit, we can communicate to each other and do interference checks inside Revit instead of having to export the Navisworks because you are working in different software. So instead of having formal ones you can communicate in an iterative way.

BM511: [00:20:43] Yeah, I think we prefer doing it outside of the software. One because it is a bit more flexible and this kind of software built for crash section like I know Revit can do it but Navisworks does it a bit quicker visually as well It can make it look a bit better… kind of… and it's easier to use for start because the whole idea is well… even with clash detections but after the APM Clash detections, when we get the package that file I create a copy sort of and then I send it round to guy and Chris and they can go in and have a look at and it tends to be the only time they'll see in 3d everything put together.

BM511: [00:21:23] Okay, so I think yeah, I'd still separate out even if everyone's using the same software, I'd still separate it out anything but then depending on what software you use depends on what software you use depends on what software you'll do

the Clash detection with. So I'll have to have a bit of a think about that I think….so I'm trying to think how I would manage a clash detection for that…

BM511: [00:22:31] (looking through questions) I'm kind of in two minds about this one. Because I think this kind of…I kind of find this one a bit more good practice but then in theory trying to implement it puts a lot of….erm….everyone in the team needs to be aware of it almost. Whereas with the other one it's kind of like a BIM manager just tells someone ..so like this date have it like this and this date you've got to have this and this date you've got to have this.

Researcher: [00:23:09] You will need to have a better communication Channel rather than an Excel spreadsheet with the MIDP. You need to have something else that coordinates teams, So I think that's where ease of use not so much…yeah so...I don't know…

BM511: [00:26:28] (reading through questions)…I like the idea so I probably agree but then I don't know whether clients will because it benefits (company) internally a bit better but…I prefer…I'd like to give it a go….

Interview 2 (D221 and SD221)

Researcher: [00:38:34] Would you be able to challenge that coordination of disciplines, information workflow to avoid clashes? In terms of time money and quality? Can you find a solution to coordinate that disciplines with the end in mind of a clash detection exercise? Trying to mitigate clashes, trying to save modelling time, trying to…

SD221: [00:39:59] I am going to think out loud. May be, for example one we have done the deck at an initial stage we are going to find also the number of beams. Once we do this, we can define which could be the critical bridge design parameters that can affect the drainage system. For example, one could be changing the number of beams. One could be the need of using transversal beams on the bridge. One could be the need of… I don´t know… define certain parameters. So, at this stage you define the drainage, which one is going to fit your model. So, as far… and then you continue… at further stages the drainage team is going to continue doing the design, adjusting pipe diameter, adjusting a bit the slope or whatever. As far as there are not changes on those critical parameters of the bridge you are going to continue doing independent models. So that if there are not changes in the transversal beams or number of general beams, you think that you may adapt your final model with not very big change so your result will be close to the one... So, while there are not big changes, you can still be doing a two weeks meeting.

Researcher: [00:42:02] So, that will be for example, the number of beams, the flange width, the cantilever and distance between beams.

SD221: [00:42:23] Or not even the flange width. You can say ok, a critical parameter… if at that stage of the project the flange width it happens that is going to be thinner than certain dimension… let´s say 40 cm you have to give a shout because we have to reduce our models, because we have found that our type has to be at least 3 cm of diameter. But if you are not going to come below than the flange width everything is fine. Or maybe, another critical parameter might be… if you change your alignment in more than 20 mm on the vertical you are going to give me a call. If not, I don´t need to know anything because I am going to design with certain tolerances my drainage, so my results are still valid for those changes.

Researcher: [00:43:30] Just to clarify, I think that I found something that it might be important. So, there might be standard factors. So, you might think that you can create your coordination between disciplines but suddenly the alignment might change.

SD221: [00:44:03] So, you can have a matrix, where whenever there is a change you fill it and you will see which discipline you have to give a shout to in order to let them know that this change is important for them. Maybe a change on the, for example a decision like ballast or slab viaduct, this is a change that is not affecting drainage. So, if you do a change you don´t even need to call them.

Researcher: [00:44:37] So there are critical factors that affect other disciplines. Do you think this is practical on a project? (name of D221).

D221: [00:44:46] It´s interesting. Looking at that, this is reflecting a piece of work I am doing at the moment, which will be going out to (name of a company) and defined risk management and principles are there. You are doing it from the deck and drainage. So, for me this is fine (Pointing at E202 diagram) for the principles of risk management.

The more complex the more disciplines you get involved are almost applicated early in a project what clash detection do you want with the frequencies. That will allow people´s knowledge, experiences, the five years experienced, the twenty years' experience to come to the for to say, no there is still a risk of changing the deck. That will carry on until 50% during design so we might want to do an extra check. So it´s almost in having a stage on here that stablishes the frequency of clash detections. So, I welcome periodic. Are they beneficial financially? Yes, because you are moving the design forth, it will be more assurance avoiding rework. How you quantify that, that is almost impossible is like me doing my risk staff on safety and I have safe somebody´s life, that I haven´t done but it will be death. That is a measure, but it didn´t. How can I put that? So, these are more thought, the more you do. So were I am going with this is on design risk management we have identified basically two threads. specific issues, specific threads, specific risk that have been identified or required while the discipline designers are doing a normal design and I have defined that in a document that is been the design influx but they don´t need to know all the risk, they don´t need to know all the challenges. Because they are coming and going all the time as people make design decisions. Ok I am going to put that way around when the door opens, that will open towards the street, no I am not going to do that, I am going to open it around the corner. They are doing it. You don´t need to record it. They are doing a discipline decision. Is part of your job. So, you are doing it. However, there are then unique risk that have been identified that need to be incorporated. So, these two are constantly exchanging. All of the sudden, the designer in this normal writing of risk he will say, this is of such elevation it needs to be moved over to the other side. This specific risk we only need to be aware of. So, I move for periodic clash detection. For me is taking away

uncertainties and removing risk and is adding assurance. But I think that they should be on an informed frequency.

Researcher: [00:47:50] Ok, they should be periodic, and they should be informed.

D221: [00: 47:54] My other issue I´ve got with the comment I wrote in here is that you are vert engineeringly structural orientated. This is a clash, yes or no.

It might hear it before. Why don't you have clash boxes around things. So for instance, at the very early stage when you are doing the basic check, yes we know that the gas pipe is going to have a penetration through the flange? They don´t know, it can carry on moving forth. But let´s say that the drainage is a 100-mil diameter. Why don´t you model it on a 120 mil. Allowing it a tolerance, flexibility, slight movement so a 150 mil. It is all very well to say I am going to run a drainage on there but what happens if it can´t get the drills on to get the fixings? So, the clash detection doesn´t pick up constructability and maintainability review. So, the clash detections are totally engineering and mathematical?

Researcher: [00:49:01] Do you think that should be brought to early stages? Introducing volumes…

D221: [00:49:05] Yes, you could do. I´ve talked about and we didn´t do it. We have talked about putting glass boxes around pile caps so you might think a meter bigger? Put a glass box on. Is the drainage running through it? Ok, I am not gonna change anything. No, but I can make an informed decision there. So is construction technique controlled. The designer… I can´t anything about it, the contractor, you do, I can´t do anything about it. But now under constructing, we know we have a problem. So, you could. It also the

bridge moves, it flexes, drainages move, thermal, seasonal. You could put at this stage you could exaggerate certain things to give you tolerance.

Researcher: [00:49:56] What you just said is that for example, if the structure is going to flex with time. That can be a tolerance for example.

D221: [00:50:00] But you are mathematically perfect. That is the problem.

Researcher: [00:50:15] Cannot you anticipate that in ten years the structure is going to deflect.

D221: [00:50:20] Things move, thermal expansions, contractions.

SD221: [00:47:27] The thing is as he said to work with tolerance and as far you don´t modify any of those critical parameters with this tolerance you can absorb little changes. For example, I don´t really mind if the beam instead of…there are still 5 beams, but I don´t really mind if it is placed 10 mm. on the right because I have designed with tolerance, but if instead of 5 is 6 beams, there is an important change that hasn´t been defined as critical since the beginning and then we have to inform because the tolerance is not absorbing those changes.

D221: [00:51:09] When you get integrated detail, it might be prudent that in early clash detections you have a little glass box around that part that is slightly greater diameter so instead of a 100 mil, you are putting 120. It will be taken out latter on as things are finalised more defined, more determined. But you know is a small clash detection, is 5 mil is 6 mil. With a 120 we can absorb that. Just give us assurance. It´s just a view! It´s just a view! And we now put clash boxes around lifting. You know around lifting zones, hazard areas.

Researcher: [00:52:11] Do you think there should be new roles? At the moment, there are BIM managers, BIM coordinators, but all of them have different backgrounds. The background of that person who identify that tolerances, what should be model. This is more technical than just.

SD221: [00:52:40] There you can speak with the drainage team and tell them ok, tell me which are the important changes that affect your design, ok and he tell you… I need to know exactly what the beams are passing because I am going to attach my drainage to the beams. So because I need to know this, I need to know whenever a beam is moving to one side or the other 50 mm. whenever there is a change on the beam size, whenever there is a change on the alignment. Is not the BIM coordinator, the BIM coordinator is going to coordinate certain things but different things are going to settle which are the critical… he doesn´t need to know everything.

D221: [00:53:29] It doesn´t need to be a unique role that is necessarily digital. We are having that discussion at the moment. It´s people who can look at a drawing or a model and look at it through a different t set of eyes. A set of risk and uncertainty eyes. What about maintainability. You put a gully next to there is between two and a half meters across. Who is going to check it, how are we going to get to it? Spaghetti junction designed where you cannot change the bearings. It´s probably beyond your scope, but my view is it supports periodic clash detection. With better parameters around, what are doing those, is an informed criterion.

Interview 3 (SD131)

Researcher: [00:00:01] Well now I would like you to please compare the two American Institute of Architects E202 standards and the American Institute of Architects G202 standards in terms of quality, time and cost when applied to a project. So, what I would like is to be able to incorporate your experience to my research. Then, once the examples are exposed, I would like you to analyse, for example, what would be the benefits of incorporating certain milestones when managing information between the stages of the project and how you would see it applied to your profession

Researcher: [00:01:27] For example in the past how you have interacted with the BIM modelers. What has been the way to give them information as a professional that calculates structures?

SD131: [00:01:51] At the end we only gave them directly ... We calculated all that structural calculation and all the geometry, and we gave him that information so that they could model the geometry.

Researcher: [00:02:07] What kind of information did you give them and in what format?

SD131: [00:02:12] No, no ... It was all oral communication

Researcher: [00:02:17] ¿At some point have you had to develop a list of elements and attributes for each element?

SD131: [00:02:32] When the client asked us to make a budget.

SD131: [00:02:41] Yes, we were asked that certain elements had some minimum information for them to be able to establish a cost.

Researcher: [00:02:53] So, that information you gave them, was somehow standard? Was ... Was it managed by you? Did it have any coherence? any meaning? was it managed in any way? did it serve any purpose?

SD131: [00:03:10] We were given a list of the minimum level of information that each item must have.

Researcher: [00:03:19] A minimum level of information so these elements could be costed?

SD131: [00:03:23] Exactly, so that a cost exercise could be done.

Researcher: [00:03:28] Do you remember the LOD of those elements?

SD131: [00:03:37] The LOD of each element was different. Not all elements had the same LOD. Depending… for example, the foundations of the footing of the bridge foundations had a lower LOD.

Researcher: [00:03:57] To be able to coordinate with other disciplines? Because for example, what you are explaining to me is for structures but, do you imagine that it must also be done for drainage? If you think that within a project it would be good that this information was represented and not only visually a diagram, but also for example an Excel spreadsheet or some other format ... If you think it´s important that to demonstrate, to transmit intention… in some way to convey a purpose or an intention (..) that each person in the project could understand what kind of information has to ... What to give... To the other part of the team. If that obviously should be reflected in some document that will help you coordinate and facilitate your work?

SD131: [00:05:52] We worked independently, each discipline worked independently. Then never ... We did not have information, if another discipline affected our design or not. So, I think it would be interesting to have more information of the other disciplines but at a very low level of project development so that it does not change what we have to do our input does not suppose ... That supposes a ... if we want to make a change that is at the beginning. Because of course, if we work and then they tell us that we have to change some aspect of our work because there is a ... For another discipline that needs another requirement, then we will be like losing

Researcher: [00:06:57] what you want to say is that in any case if there is any transfer of information between disciplines that information should be provided at an early stage of design and preferably there should not be changes in that information because if there were changes ...

SD131: [00:07:23] If there are changes there are costs.

Researcher: [00:07:24] There are costs because you would have to redo your work.

Researcher: [00:07:31] So if we handle information in a structured way, what you want to say is that maybe that plan could not be carried out because there could be some unforeseen element that would undo that planning, therefore it would not be easy to plan the hierarchical coordination between disciplines.

SD131: [00:08:12] I do not follow you very much ...

Researcher: [00:08:13] I'm going to paraphrase myself.

Researcher: [00:08:18] If as an information manager I provide you with an Excel sheet where the columns could have milestones within the project stage… those milestones could correspond to critical decision points. For example, at this moment I have to design the reinforcement of the structure but at the same time I need to know where are located the drainage points that are going to pass through the slab. That is the only important thing to make a decision.

Researcher: [00:08:57] If I had put that in a register so that you could coordinate ... Do you think it would help? Or do you think that as the design process can lead to certain uncertainties…?

SD131: [00:09:22] I think it would be helpful at the beginning, the first stage of the design because if you gave it the final in the final stages it does not help you. Then you would have to fix the design.

SD131: [00:09:46] The time has passed and they are demanding you to finish ... you are not going to waste all the work and maybe you're moving forward but adopting a solution, you cannot go back, we should design another way, we have not already designed this way, now we have this problem (.) We solve it in another way that would not have been solved if we had seen that problem at the beginning. Therefore, I am always interested to have it at the beginning.

Researcher: [00:10:14] Okay, and you think that if that information were given to you at the beginning it could be a time and cost saving when it comes to modeling compared to designing yourself on your own, designing the equipment of drainage on your own and dump information to a federated model every two weeks without coordinating among you?

SD131: [00:10:45] Well I think the cost is difficult to know if it has a cost or not. What I would avoid is problems.

Researcher: [00:10:55] And you think it would be difficult to quantify the benefit in terms of cost over the decisions you could make in that exercise, for example ...

SD131: [00:11:07] I think they would take ... It would be the design would be more effective or a more effective solution but very difficult that it would have had ... many times what is done is an independent design when a study is made all the disciplines are brought together and if there is any ... something that does not fit, what is done is adopting a solution from there. It would have been different if this inference had been made before, so for me what interests me is minimal information. What would be interesting is that in each discipline would have to be established a minimum information needed by the other so that your design is not affected.

Researcher: [00:12:05] Okay.

SD131: [00:12:07] I think it would be interesting.

Researcher: [00:12:10] Is interesting to study the point of view (..) Well, what do you think ...

SD131: [00:12:19] So I think that for example the LOD had to be determined by the need of each discipline guided by the others at the early stages of the project.

Researcher: [00:12:36] You think it would vary with the type of project? Are there projects where it would be easier to have that minimal information or projects where it would be more difficult?

SD131: [00:12:44] Complicated. I do not know.

SD131: [00:12:52] I do not believe because if you set a ... before you start any discipline to work ... It was planned to establish as a milestone. That is to say, we have to define a minimum geometry of a minimum of information so that we do not affect other disciplines regardless of how big the project is or not.

Researcher: [00:13:23] And do you think it would take a specific role or quality for a person to be able to visualize that coordination of information? Someone with some specific experience or ...

SD131: [00:13:42] If it's established in advance, no.

Researcher: [00:13:46] So you think that it is established in advance, it is established in advance by the disciplines. Do you think that it is important that someone has an overview of the different disciplines to know what is ...?

SD131: [00:14:03] Maybe, each type of project would be interesting to dump at that level of minimum information of each discipline so that it does not affect another or that which you demand to another discipline so that it does not affect yours because at the bottom of the same minimum data that you need that your design does not affect ... It is not affected by the other discipline are the minimum data that the other needs so that its design does not affect yours and vice versa.

SD131: [00:14:34] That's better, it can vary for each project, but, if someone comes with someone with experience ... in this project there can be this kind of problems. If each discipline, we put a minimum level of information and geometry that they have to put because we know that at that level of detail and no more, we can detect errors or problems

... It depends on what type ... For each type of project we assign to each discipline a minimum level of information so that the others are not affected. Each discipline develops its part independently and there comes a time when we can already do it. Now we all agree at an early stage and from there we already make decisions and we continue with the design knowing that we have done an exercise of trying to avoid interdisciplinary problems

Researcher: [00:15:33] Even though you think that... You think that this process could be standardized through templates where the information is dumped ... Through coordination between different software ...

SD131: [00:15:55] It could be standardized to be flexible.

SD131: [00:16:00] What kind of flexibility?

SD131: [00:16:02] Flexibility in the requirement of geometry information of each element ... you cannot define it because each project is different.

SD131: [00:16:15] So, you can set a minimum LOD for each one to do an exercise for example ... We're going to do an exercise at an early level where important decisions are made ... I mean let's see what it costs, then maybe depending on what type of project you may have to have a minimum information or another that would be different. It's very different ... there has to be flexibility. I mean, you cannot demand what kind of information you need for that project or what kind of information you need to try to avoid interdisciplinary problems. What you have to say is that in advance you have to be

according to the project… you have to establish what minimum need, then we would standardise how to do it but we do not say what level you have to have.

Researcher: [00:17:16] For example, when we talk about modeling, we talk about attributes and values. An attribute can be a coefficient of thermal transmission and a value can be a number ... You are talking about that type of information you are talking about another type of information as hypothesis ... As technical requirements ... What kind of information do you talk about? you talk about some inputs ... Can you give some concrete example based on your experience?

Well for example, a problem that we had with the example that you put before was that you had to lay a pipe in the area of the footpath and it was established that it would have to be inside the sidewalk but as the pipe that had to be laid was bigger than the sidewalk on the sidewalk, it was decided to put it inside the beams, of course, because there was already a problem because that slab had to be redesigned. So, if you knew beforehand before designing anyone and I do not need you to tell me I do not want you to design the entire beam all the way down. I just want to know the diameter. Then I know where to put it or not.

Researcher: [00:19:37] If any drawback could be assigned to the AIA G202 method? What would be?

SD131: [00:19:47] The method of disciples speaking to make decisions, to progress and avoid conflicts throughout the project. A drawback may be that all decisions are taken, and all disciplines are changing their designs depending on the other and at the end of the project can happen that a discipline maybe due to an external element or

contract or by an external element of the client or any other issue... Maybe this discipline is removed in the project, is no longer necessary or has been decided not ...

SD131: [00:20:25] Maybe, for example, a railway project that was going to be electrified, right? Then everything has been conditioned to have to be electrified, but in the end, it is decided that it is not going to be electrified or that it is not going to be done ... Or that there is not going to be drainage here, it goes the other way or not. It is necessary or not that ... Then it has conditioned all the design of the discipline but in the end, they do not have or do not have any value but has conditioned the whole design. Maybe it has had a greater cost because to accommodate your discipline you had to adopt a better solution, maybe a little more expensive or more complicated but in the end, it was not necessary and it can be a drawback. Because maybe there is a problem if you do not do any interdisciplinary meeting throughout the project only at the end you find a problem, but it can give an easier solution than the one it would have been given adapting everything.

Researcher: [00:21:39] Thank you very much.

Researcher: [00:21:42] Can I ask you some questions also related to your experience with the different types of contracts that may be in the construction? Do you think it could have any influence on the implementation of this methodology? I mean, these two types of methodology always trying to compare one with the other?

SD131: [00:22:05] For example, in the methodology that establishes milestones? Maybe if you are doing a design and built in which your design is linked with the contractor because you are together in the project. Maybe there is a stage or milestone that should be the price, because to present the BIM and put it in that project you need

the cost of what you are going to build. So maybe a milestone should be, we are designing but there had to be a milestone in a moment where with this minimum information we need to be able to get a price because it is needed by the contractor and we work together shoulder to shoulder... in a design and built we need to work shoulder to shoulder with the contractor. However, another type of contract that is not a design and built. If the design is independent of the contractor, it would not be necessary to establish a design milestone because we already design in the most efficient way or in the way that the client wants and then the contractor must see if it costs the contractor more or less.

Researcher: [00:23:26] One question, do you think that in a design and built it would be appropriate… in addition to marking milestones where a price is established, within that coordination of disciplines try to handle the LOD trying to adopt future solutions that can happen during the period of construction and logistics ... Try to bring such risks to the project as scaffolding, as storage areas ...

SD131: [00:24:03] Well… if you go hand in hand with the contractor, maybe it's a good moment ... At some point in design it would be nice to try to put that contractor's need or that input from the contractor in and design to tell you… It is not that I need this tolerance to be able to build and I need a certain support to put the beam here then if you have more relationship with the contractor it would be better to make another milestone of constructive needs where to sit and see that constructive need and a longer plan in the design.

Researcher: [00:24:42] Thank you very much.

Interview 4 (BM341, BM342 and BC541)

BM342: [00:00:03] The states of the designer. So, if a certain calculation has been done you can introduce a certain check.

BM342: [00:00:09] I think that might be valuable. So We come back to here.

BM342: [00:00:21] But that's something different I think than what you've been explaining.

BM341: [00:00:25] Yes. I mean there is no other angle and it's something that came up in conversation with an engineer yesterday and that is elemental LOD rather than model LOD. And the problem we have at the moment. You tend to work on a model LOD. So, I think well some people do. We don't. We have an MPDT that breaks it down to say beams will be 200 columns will be 200 foundations will be 300 or whatever... They wanted to take it even more granular than that and say These beams are already two hundred and these beams are only 300. Therefore, you can pass them on to the fabricator.

BC341: [00:01:03] I think that works for especially for large scale project doesn't it where you are vulnerable most construction is that is alongside design in as well as we often find. Yeah but I guess in a typical building you would try and generate a model to a specific date. I think we normally would think of you. You did get it to a certain level of detail then and then and then issued a model.

BM341: [00:01:25] I think it's a call it's a factor of stage and scale at stage three which would just be a consistent day across the building stage for us the contracts it comes

on board. They want to hurry things through to fabrication of course. So, you might do it also like you were saying for a big job you might zone the job and phase it.

BC341: [00:01:47] I think we see a lot. I mean you might you might see a steel frame like you said LOD 2 or 300, but you'll see slabs maybe still a LOD 200 even at stage 4. Yeah. It all depends isn't it so. I guess I guess the benefit might be and goes to just look at I guess if you go through what you're trying to get out of this again in a lot of detail I guess what you're looking at here and that might be useful is is it worth you asking us the specific questions you have got.

BC341: [00:02:24] We're not trying to railroad you all know and understand...

Researcher: [00:02:39] I mean it's not that I'm trying to defend something I need your critical thought. So that can be incorporated as limitations to the project. So, it's not bad that you actually. Give your your honest opinion. It's not a problem. So, let's try to. OK so if we go to the questionnaire. I would like to compare that just on that. So, the first one. So, what I am gonna try to do to make it more specific.

Researcher: [00:03:25] I mean to put this in here and the actual is in there. So I'm going to be asking you a question about usefulness of the two standards. So by comparing both of them in terms of cost and quantity... Here I don't really know whether you see so If you try to compare both. Do you have you find any benefit from using one over the other. On saving modelling time. I mean if you're micromanaging that information workflow...would you save time? Would you avoid modellers to over the sign or to under design? Or just nothing will happen?

BM341: [00:04:39] That that workflow is something that you've created? Yeah.

Researcher: [00:04:43] You're gonna create another one.

BM341: [00:04:45] Because I'm trying to understand that still the difference between E and G and it seems to me the only difference is that one sentence that changes it from stages to milestones is that the only fundamental difference?

Researcher: [00:04:59] That is the fundamental difference what they have seen is that milestones can be used to actually guide their model to a certain point where it can be analyzed for certain purpose. Milestones are useful because we do have conversations with people, contractors and others about LOD and MPDTs and we might put 200 at RIBA 3 or 300 at RIBA 4 and they don't know when during RIBA 4 columns reach 300 or beams reach 300 or slabs reach 300. We just say to them it's all 300 by the end of RIBA 4. And that's not very useful. So, the granularity of G202 might be useful because you could then allocate different points in time at which your foundations your columns your beams and so on reach the LOD required for that stage.

Researcher: [00:05:54] So I'm going to put you a scenario, do you think it will be useful to incorporate construction and logistics assumptions if it came the case where that team is starting to give input into into the design? And you might want to.... Allocate I don´t know a scaffolding as a volume. And start taking decisions according to, this is going to be the construction sequence, or this is going to be the construction constrictions and I want to incorporate that earlier on the project.

BM341: [00:06:35] Well I guess whether or not the information is available.

Researcher: [00:06:39] Yeah. So, the question is. Do you think it will help to save money afterwards, during construction. If you start incorporating that elements early on making an informed decision rather than just saying... Look we're going to finish everything at a low the 200 at the end of the project stage. But we haven't really been incorporating elements that maybe three hundred and fifty or even more detail earlier.

BM342: [00:07:24] I think there is definitely fail you in what you're doing here you're saying that certain elements are on a higher LOD at in search of stage and then do a check. I think there's value in that that you because they are so important so setting basically the rules for the design at such a high level because they are big the beam for example in this example over here, they have a big impact on the location of the pipes. So, you want to have them. At LOD300 before the pipes. That makes perfect sense. So that's if I understood your concept right and E 202 you have a final result were both the bridge and the pipes are at already 300 in the same moment almost and you going for a real check in between right. So, the G202 definitely definitely has a big advantage that you can check the LOD300 bridge against a LOD 200 pipe.

BC341: [00:08:28] That will save time. Yeah.

Researcher: [00:08:33] But it would be difficult to manage that? For example, it would be difficult. I mean if you start micromanaging things that way do you think that you would find more useful having something like. A guide like this that the stars say in this LOD you have to incorporate rebar. You have to incorporate expansion joints and as well having an Excel table with information.That might be incorporated into the model?

BM341: [00:09:09] That guide is currently a problem for us (BIM LOD Specification 2017) because what it doesn't take into account is capability and we we struggle because we were asked to do 350 increasingly. But the stuff there that's not within our scope to do we still own the model at the point at which it's 350 has been asked for and we we can't do those things that we were either not capable or it's not within our scope it is a contractor task. And so the the models structure has to be factored into this you know it might be if you've got pre-cast concrete we need to take the precursor concrete and separate that into a tend model to give to the pre cast concrete subcontracts while we carry on developing the in situ stuff because we're not doing the panelisation or something that. And I think going back to I mean I agree with what you've said but I think we have to factor in scope all the time. With this we have to be mindful that we don't over deliver.

Researcher: [00:10:18] OK.

BC341: [00:10:19] I think I think one of the concepts I'm sure let's get my head round at the minute is I guess I think personally we do the G2 to solve almost that as part of our day to day role. As I say as a technician I would often every now and then you are at your clash detecting all the time whereas E202 is what we would do as a formal class detection if that makes sense. So yeah, I guess I'm struggling to find the G202 to to be a formal to compare the two. I can see why you see almost why you're trying to do it but I still I feel like the problem is is you almost do both subconsciously.

BM341: [00:11:01] I think I agree.I do agree with you Lou. I think where I'm get into with this is if you think of the MPDT and the rows of the different types of elements and the columns of the Reapers stages I guess what we're saying is rather than the

columns being read the stage is likely to go to milestones like G202 so you might have a collection of columns that represent stage 4 rather than one column and those columns might be weeks through Stage 4 and it might be the architect needs to get ceilings too. Yeah. LOD 300 by stage 4 week three so that by stage four week five the MEP guy can position his lights in the ceilings. Right. Okay so I think he's breaking the columns down to be more detailed.

Researcher: [00:11:49] Yes that's what it is. That's what it is.

BM341: [00:11:54] Makes the MPDT bigger. Really.

Researcher: [00:11:57] Exactly. Exactly so. So for example one conclusion might be well it might be a good idea but it's not practical because we are not going to be able to prepare or the flow of information on time. It will take a lot of time to do it. It might be a manageable I don't know. It's up to you now.

BM342: [00:12:19] Yeah. The challenge will be to set the rule right most milestones that are actually really valuable to the project. Yeah. And then not going to be really pretty.

BM341: [00:12:28] Isn't that what the MIDP already does? Aren't we supposed to combine we haven't traditionally combined the MPDT with the MIDP? And I think we were supposed to combine them so that you knew that yellow the MPDT, the ceilings would be LOD 300 at stage some point during stage 4 and the MIDP told you when the ceiling information would be released.

Researcher: [00:13:00] The MIDP they would tell you they're the actual model or drawing, I mean the combination of elements.

BM341: [00:13:09] The MIDP would cover all sorts of information exchange. Okay. And if you look at the most recent CIC beam protocol version 2 they seem to have done away with the MPDT and they talk about the design responsibility matrix which effectively is a kind of look at I think it's a combination of the MIDP and the MPDT to try and achieve this granularity.

Researcher: [00:13:37] Okay. And we'll have to take a look at that because I am not using the MIDP at the moment okay. Yeah. Thank you. Thank you. Thank you for that. It's something we're going to be looking at.

BM341: [00:13:51] I think it sounds like we were all agreeing on the G202 approach though. Yeah yeah. Okay then. Well thank you very much if you don't have anything else. Anything else to say. I can't give you 10 minutes to fill in the questionnaire and give it back to me. Is that possible? You.

BM342: [00:14:34] So I was just wondering one more thing you were talking about clash checks. For me clash checks are something that's been done five years ago. If I'm checking models now, it's more than a clash check. It's also something about is the right information in the model. Are there the right dimensions used as the, there maybe even a distance between components? Did you did you consider this in this whole thing as well. I mean I think it can be far more advanced than what you're saying here.

Researcher: [00:15:07] Okay so what you mean is that you use it to take critical decisions.

BM342: [00:15:11] Yeah. But also check quality and if and you know do more than check checking if something physically clashes with something.

Researcher: [00:15:21] Quality of vs the quality of the quality of the geometry much more than just saying there is geometry that's touching each other or hitting each...

Researcher: [00:15:36] OK.

BC341: [00:15:36] Yeah but I agree I think it follows the same concept as well doesn't it. And you can you can you can check that data milestones or you can check it. Exactly. I think you'd be good. I think I'd go to incorporate both into the into those workflows.

Interview 5 (BM151)

Researcher: [00:12:23] Well yeah. Yep, yep, yep. You can type it if you want. And I will follow up. So, my question are these questions (Pointing at power Point). What you think about over modelling under modelling, rework, number of coordination meetings. I mean who would be involved in creating a more detailed informational flow. Would that be a problem? Since like this and we have a lot to talk about quality. Yeah. So that's a discussion.

BM151: [00:13:00] When we're talking you know it's it's always there gonna be related to the stage on the milestone for how much I want your model is there. Is there a specific stage of the project that you're looking at or is it just it through throughout the project? What, what is appropriate for each stage and milestone.

Researcher: [00:13:19] Okay actually in this one I only did a preliminary design because this is my knowledge doesn't go further than that. So, I mean, I was able to have these Excel spreadsheets and take those numbers put it into Dynamo and I had a flexed the structure. So, what I am analyzing here is just preliminary design, concept design but it will be the same approach for a more detailed design. Okay. To be honest I mean I think that it can be that all the implications can be transferred to RIBA Stage 3. Okay so, if you want to, we can just go question by question.

BM151: [00:15:12] (Perceive Usefulness, AIA E202) OK well let's disagree. Yeah. Well say... The LOD that has been modeled is not to find that specific project milestones is only defined for the end of the project stage. Therefore, class detection is not gonna be too

useful through the project stage as the LOD is not gonna be... There's no time when you're going to receive that LOD data in order to undertake the class detection.

Researcher: [00:15:54] So yeah sadly that's what it is. So that way just the way would be the form would be something like we do a class action every two weeks. I mean which is similar to what we are doing isn't it.

BM151: [00:16:12] Yeah. Yeah, we do byweekly rather than at the end of the stage.

Researcher: [00:16:18] Yeah. Oh yeah. Yeah. Yes. But exactly I mean that would be one way of doing it. Probably not at the end of the stage. That's what it says. Probably an MPDT that we are doing it biweekly. Actually, we are not really putting in any milestone in the. But because it's not managed in detail because we have some implications. Because it's not managed in detail what we usually do is what we are doing at the moment. So, every two weeks. Well we put everything together. I mean which is kind of the same example as the E202. It doesn't really matter whether it's at the end of the stage or whether it's a biweekly.

BM151: [00:17:16] We're going to the next question. Yeah. Um well just how sorry I am when I'm just type up my response here. So, I've got the LOD is only to find the end of the project at the end of the stage which means it is not controlled throughout the project stage clash carried out at the end of the stage will produce more clashes and will require more rework rework in the design. You know going to have a negative impact on times cost and quality. so I am on to the next one.

Researcher: [00:18:08] OK. Thank you. Yes. So, I find it useful for achieving the purpose of my glass addiction exercise. So, the propose yes to remind you was...

Researcher: [00:18:21] Glass zap it here detects and eliminate clashes pre-construction and coordinate disciplines by assigning tasks to users after the exercise has been performed.

BM151: [00:18:41] Yeah. Yeah, it's gonna be the same again. It's same reason.

Researcher: [00:18:58] Well there is no one is talking about the objectives which are actually more specific to the clash detection exercise which is identifying the interface between certain elements for example or finding the best routes for the pipe, pipe distance to beams hangers, anything, rebar... We are just going there with an objective in mind.

BM151: [00:19:32] I'd agree with that. You know it it's gonna meet those objectives. It's whether it's meeting them at the right time which, which is, is addressed in the other two questions I suppose. You but I agree that it would meet those objectives. I'm the kind to type the response and I'll read it out to you. Okay. Sure, the class action card will achieve the objectives. However, the timing of the detection could be improved. Okay thank you.

BM151: [00:21:25] Yeah well because, because you're only doing it at the end and that's it's not really going to be that useful is it.

Researcher: [00:21:32] Well at the end or every two weeks or every few weeks.

BM151: [00:21:37] At the diagram it's at the end of the...

BM151: [00:21:41] Yeah. It was at the end. But what I mean it's that information is not managed. It's not much a useful information workflow or using the MPDT. So a

solution to that they say you do it every three weeks every month every two weeks at the end. Said I'll how you do it. When we have a achieved this, this and this and this. Yeah.

Researcher: [00:22:12] So there's a difference. I mean I know that it's confusing because I depicted it, I draw it like this.

BM151: [00:22:30] Yeah. That says at the end of each phase. Yes. Which is... Which is say and this is three you have to achieve a 300 or 350. Yes. While the other one is set project milestones. Yes. OK. Yeah. So, I think your diagrams are they're fine. Yeah, I know. You mean you could go to class action biweekly but you're right. If the fellow the 350 does not need to be achieved until the end of the state.

Researcher: [00:23:07] Yeah, yeah right, you're right. Yeah.

BM151: [00:23:13] So I disagree. I'll just type this into words for the questionnaire.

BM151: [00:24:04] So this is whether it's easy. Yeah, I strongly agree it probably gonna be easier because yeah you just do it at the end.

Researcher: [00:24:13] Oh so probably easiest to communicate to the team. Right. I mean yeah yeah I'll train them all right. I know. Yeah you know what I'm talking about right.

BM151: [00:24:27] That's that's more straightforward given your process. Yeah, it's like dealing with wicked problems. It's a bit more of a you know overlapping of tasks and more exchanges of information. That's the management is more complicated. Yeah. This this one is more just like a data dump at the end. This is this is it this is it's all LOD 350 and can you check it from me. Yeah.

BM151: [00:25:43] It's to be achieved therefore easier to understand. For the reason why not. So, find a coordinated clash detection workshops.

Researcher: [00:25:56] Yeah. This from the point of view of the manager or the BIM Coordinator. Yeah. So, what I have seen is that it has to be Federated. Then you go there. You analyse the model with the other participants right. Yeah.

BM151: [00:26:26] So I disagree too. Because the LOD which has been provided is this is a few words in a class action not, not at the end or throughout at this stage and my intent is that at the end.

Researcher: [00:26:50] The LOD will be achieved at the end we might be having less coordination meetings weekly bi weekly or whenever. Yeah.

BM151: [00:27:21] The LOD is provided throughout the stages is not defined, is only defined for the end of the stage. Therefore, we know that the clash detections are not going to be as control from a management point of view. You are running clash detections but that's not going to be... For the LOD that you want it to be.

BM151: [00:27:45] The symptoms are different stages in the design, and you know that sometimes it's just not coordinated to a level that allows you to do a clash detection. You know it might be a model to LOD 300 350 through the distance. It's not it's not coordinated as well. Say the building could move you know which is having a couple of times for there. That's it's moved and then the MEP or structures just having a timed up there. So that's what the building is completely offset so it's it's not much. Yeah. Our roofs have been raised it's been lowered. So, which is fine for the stage. Yeah. You just need to go did understand on that.

BM151: [00:29:27] (AIA E202_Intention to Continue to Use comment) Strongly disagree. It's just the management process. It's not reflective of the design process. You want to just break it up and systems like you've done for the for the pipes and slabs and you know as long as the two interfacing parties are more lenders him LOD. And then the both reach it at the same milestone then then it's gonna make it a lot more useful to run class detection action against those two disciplines.

BM151: [00:34:57] (AIA G202_Perceived Usefulness) So I can say it is gonna be I can go through this really quickly and just it's just going to be the opposite angle from what I've got on the other hand. So if it's the first one for example is the LOD is fine at set milestones which means it is controlled though project stage class action carried out. At the end of the milestone will produce less classes, I mean which means less rework in the design. This will have a positive impact on time cost and quality. This.

BM151: [00:39:10] (Perceived Ease of Use G202) It's the management method for class action exercises... Is easy? Disagree. It's a bit more complex.

Researcher: [00:39:29] So will you be able to talk about for sample... So same as us you went to the interface meetings. Would that the manager or the BIM coordinator. Will they need to go to their to the team meetings where they talk about design. When they talk about when assigning actions to the different team members. So probably the person who created what workflows will have to be more involved within the team meeting the design meetings?

BM151: [00:40:07] Yeah. Yeah. The design team meetings should be permeable, so the models are what is reflecting the design. So, so the BIM Coordinator, that it didn't let any design responsibilities so they can't really say who's responsible for fixing what...

That doesn't come from the design team. All all that the coordinator can do is point out that there is an issue there come they can´t say how you fix that issue.

BM151: [00:40:46] Yes that's up that's up the design team to come up with a design solution.

Researcher: [00:40:51] And when creating that diagram creating that information flow of different roles will be needed there. Right. Let's say that the team leaders. I mean that would be difficult actually to manage in my opinion. I mean to do such a detailed information workflow such as this one (Pointing at G202) or a Gantt diagram if you don´t do something like this or an MPDT more elaborated with more columns.

BM151: [00:41:23] Yeah. Yeah. Yes. Yes. It's gonna be something like that the MPDT with more and more columns for the milestones and then you just pull in the other day which each element has to meet at that date?

Researcher: [00:41:38] Would that be difficult?

BM151: [00:41:40] It would be easy to make the document. It's always made it 90 percent of the stuff is right communication and communicating with the team and making sure that they understand it...

Researcher: [00:41:53] As well if something unexpected happens. It has to be change. Do you think it will be? I mean how effective do you think it will be taken into account that you can´t control certain aspects of the design. Oh, probably probably yes. I don´t know...

BM151: [00:42:10] It should be informed by the designer that you know you don´t want to be dictating the design process. There's probably gonna be the design leads and the design manager which can you know come up with a design program and then and then you push your MPDT around that here and that's what what are the key dates in the design program for each discipline for each its system. You know, both should match. So that's not just about more or less documenting what should be achieved in the environment to reflect the design program.

Researcher: [00:43:59] One question, do you use dynamo or Grashopper in architecture?

BM151: [00:44:04] Mostly is grasshopper. And do you think this will help to organize information better. When created that script or that information workflow inside Grasshopper.

BM151: [00:44:31] No. I would just have to manage it. When. When you do it. know what. It's not going to impact on that. It's just in terms of time. It would help manage when when you when you do each task.

Researcher: [00:44:48] Because what they found one great is that great in the script in dynamo is that... Well I would say that at a certain node will be actually selecting the family at a certain LOD. So, what they are the one creating the script.

Researcher: [00:45:19] Anyway, so imagine that one of the orange nodes allows you to select the family. The [redacted] family. OK. So the family has certain geometry at a certain LOD and as an input... Here you have the attributes in the blue ones...As an input that geometry was modified using certain attributes. Mm hmm. So for me it helped me... I

mean I didn't really whether in Grashopper you do it differently. It helped me actually having that information workflow prepared first to know what I had to do which point and in which sequential sequence. Sorry for that. You know like one step then the other. Now I take this information from this family at this LOD of geometry information detail and then I will modify it and then I will put it into that Excel spreadsheet... I will modify the drainage. So I created it. I created a parametric design doing that. So, it actually helped me. I don't feel good about I know different people do it differently. So, you never really know whether that may help having such a structure...diagram.

BM151: [00:46:57] Yes. It's probably. I know what you mean. It was probably very similar to what we've done anyway. Yeah. It's just are just doing it at a different stage. You know you do not meet a milestone rather than just just doing it through a block of time put across the projects stage. But I think what you said at the start was to get to get it more connected with the engineers and then for example someone like that's actually doing the modelling. Yeah but that's sort of separate issue than what you what your PhD is about. But that's. To integrate the engineers more in the BIM process and your inputs and outputs rather than you know having more user inputs you just pull all information straight from their Excel sheet.

Researcher: [00:48:07] Yeah, it's.

BM151: [00:48:10] Which is it gonna be less error errors in the design because you just have to hand it in. That it's gonna be quicker to update your time cost and quality performance indicators will will improve.

Questionnaire D221

Consents form

Role: ASSOCIATE DIRECTOR

Years of experience: 46

Company size: ~ 15,000

Type of projects involved: High hazard – tunnels, MOD's

Average No. of disciplines per project: 16

Contact email address:

Participant identification: D221

Title of project: Explaining LOD constructs usage: Comparing two LOD standards as per clash detection use.

Contact details: AXG392@student.bham.ac.uk

I agree to take part in the above research. I have read through the Participant Information and I understand what my role will be in this research, and all my questions have been answered to my satisfaction. ☑

I understand that in order to withdraw from participation I must complete the slip at the bottom and return it to the researchers ☑

I have been informed that the confidentiality of the information I provide will be safeguarded. ☑

I am free to ask any questions at any time before and during the study. ☑

I have been provided with participant Information. ☑

4

I understand that I am under no obligation to complete the study once it has commenced and can stop it at any time. ☑

I would like to receive a copy of the results of the workshop ☑

Data Protection: I agree to the University of Birmingham processing personal data, which I have supplied. I agree to the processing of such data for any purposes connected with the Research Project as outlined to me.

Signed.. [redacted] .....Date..14/02/2019.....

Consents form

Name of participant ..... Date.....

I wish to withdraw my data from the study titled: Explaining LOD constructs usage: Comparing two LOD standards as per clash detection use.

Signed .....

5

Questionnaire

AIA E202 management method

Perceived usefulness

Overall, I find AIA E202 management method useful for coordinating clash detection exercises

1.Strongly disagree/2. Disagree/3. Neither agree nor disagree/4. Agree/5. Strongly agree

Why? Based on my role – I expect the models to have been 'thro' clash detection – then be 'glassed boxed' for peripheral clash detection.

I find AIA E202 management method useful for achieving the purpose of my clash detection exercises

1.Strongly disagree/2. Disagree/3. Neither agree nor disagree/4. Agree/5. Strongly agree

Why? Sort of agree – but feel compliance could be too late in process.

I find AIA E202 management method helps me in meeting my clash detection objectives

1.Strongly disagree/2. Disagree/3. Neither agree nor disagree/4. Agree/5. Strongly agree

Why? I have no pre conceived objectives – however in accepting some clashes it could prove a useful evidence based approach.

6

Perceived ease of use

I find easy to coordinate clash detection exercises in the way I intended using the AIA E202 management method

1.Strongly disagree/2. Disagree/3. Neither agree nor disagree/4. Agree/5. Strongly agree

Why? In my role it is difficult to get designers to extend the remit of clash detection.

I find learning AIA E202 management method for clash coordination exercises is easy.

1.Strongly disagree/2. Disagree/3. Neither agree nor disagree/4. Agree/5. Strongly agree

Why? no effective experience

I find coordinating clash detection workshops using the AIA E202 management method is easy

1.Strongly disagree/2. Disagree/3. Neither agree nor disagree/4. Agree/5. Strongly agree

Why? Agree on the basis - I encourage wider consideration of clash detection.

7

Intention to continue to use

If I retain access to the AIA E202 management method my intention would be to continue to use it for clash detection coordination.

1.Strongly disagree/2. Disagree/3. Neither agree nor disagree/4. Agree/5. Strongly agree

Why?

In the future, I expect I will continue to use AIA E202 management method for clash detection coordination.

1.Strongly disagree/2. Disagree/3. Neither agree nor disagree/4. Agree/5. Strongly agree

Why? Personally I think emerging techniques will come to the fore ~ perhaps instant & automated.

I prefer to continue to use AIA E202 management method for clash detection coordination over other standard management methods.

1.Strongly disagree/2. Disagree/3. Neither agree nor disagree/4. Agree/5. Strongly agree

Why? As above

8

AIA G202 management method

Overall, I find AIA G202 management method useful for coordinating clash detection exercises.

1.Strongly disagree/2. Disagree/3. Neither agree nor disagree/4. Agree/5. Strongly agree

Why? Can be better adopted based on complexity of the project / engineering.

I find AIA G202 management method useful for achieving the purpose of my clash detection exercises.

1.Strongly disagree/2. Disagree/3. Neither agree nor disagree/4. Agree/5. Strongly agree

Why? Does not 'glass box'

I find AIA G202 management method helps me in meeting my clash detection objectives.

1.Strongly disagree/2. Disagree/3. Neither agree nor disagree/4. Agree/5. Strongly agree

Why? It could improve certainty of the detail earlier.

9

Perceived ease of use

I find easy to coordinate clash detection exercises in the way I intended using the AIA G202 management method

1.Strongly disagree/2. Disagree/3. Neither agree nor disagree/4. Agree/5. Strongly agree

Why? As E202 response

I find learning AIA G202 management method for clash coordination exercises is easy.

1.Strongly disagree/2. Disagree/3. Neither agree nor disagree/4. Agree/5. Strongly agree

Why? As E202

I find coordinating clash detection workshops using the AIA G202 management method is easy.

1.Strongly disagree/2. Disagree/3. Neither agree nor disagree/4. Agree/5. Strongly agree

Why? As E202 - any workshops should add benefit.

10

Intention to continue to use

If I retain access to the AIA G202 management method my intention would be to continue to use it for clash detection coordination.

1.Strongly disagree/2. Disagree/3. Neither agree nor disagree/4. Agree/5. Strongly agree

Why?

In the future, I expect I will continue to use AIA G202 management method for clash detection coordination.

1.Strongly disagree/2. Disagree/3. Neither agree nor disagree/4. Agree/5. Strongly agree

Why? As E202 response.

I prefer to continue to use AIA G202 management method for clash detection coordination over other standard management methods.

1.Strongly disagree/2. Disagree/3. Neither agree nor disagree/4. Agree/5. Strongly agree

Why? As above.

PTO.

11

Clash detection is precise - which is right for primary / major clashes.

However, glass boxes around components, features, zones etc can establish conflicts with peripheral clashes.
ie. a glass box 1m greater around a pad foundation may clash with a utility service ~ or light standard when lowered intrudes into an ATEX zone.

Glass box for construction tolerances?
Glass box for space for fixings?
Glass box for maintenance?

100 ø drain fits snugly between two beams ~ does this take into account the soffit fixings, clamps around, space to instal, space to maintain (remedial work).

How do the above sit within both approaches ~ later stages of design is not an acceptable response?

Both seem too precise.

Questionnaire BM342

Consents form

Role: BIM Manager

Years of experience:8

Company size:15000

Type of projects involved: Building projects general

Average No. of disciplines per project: 3 to 4

Contact email address:

Participant identification: BM342

Title of project: Explaining LOD constructs usage: Comparing two LOD standards as per clash detection use.

Contact details: AXG392@student.bham.ac.uk

I agree to take part in the above research. I have read through the Participant Information and I understand what my role will be in this research, and all my questions have been answered to my satisfaction. Yes ☐

I understand that in order to withdraw from participation I must complete the slip at the bottom and return it to the researchers Yes ☐

I have been informed that the confidentiality of the information I provide will be safeguarded. Yes ☐

I am free to ask any questions at any time before and during the study. Yes ☐

I have been provided with participant Information. YEs ☐

4

I understand that I am under no obligation to complete the study once it has commenced and can stop it at any time. Yes ☐

I would like to receive a copy of the results of the workshop Yes ☐

Data Protection: I agree to the University of Birmingham processing personal data, which I have supplied. I agree to the processing of such data for any purposes connected with the Research Project as outlined to me.

Signed...  Date.....190301.....

Consents form

Name of participant ..... Date.....

I wish to withdraw my data from the study titled: Explaining LOD constructs usage: Comparing two LOD standards as per clash detection use.

Signed .....

5

Questionnaire

AIA E202 management method

Perceived usefulness

Overall, I find AIA E202 management method useful for coordinating clash detection exercises

~~*1.Strongly disagree/*~~*2. Disagree*~~*/3. Neither agree nor disagree/4. Agree/5. Strongly agree*~~

Why? It's not saying anything about coordination level of specific objects through the design phase.

I find AIA E202 management method useful for achieving the purpose of my clash detection exercises

~~*1.Strongly disagree/2. Disagree/*~~*3. Neither agree nor disagree*~~*/4. Agree/5. Strongly agree*~~

Why? It's a good way to set formal mile stones which are in line with contracts and agreements.

I find AIA E202 management method helps me in meeting my clash detection objectives

~~*1.Strongly disagree/2. Disagree/*~~*3. Neither agree nor disagree*~~*/4. Agree/5. Strongly agree*~~

Why? It's saying something about the end goal. Nothing about the process.

6

Perceived ease of use

I find easy to coordinate clash detection exercises in the way I intended using the AIA E202 management method

~~*1.Strongly disagree/2. Disagree/3. Neither agree nor disagree/4.Agree/5. Strongly agree*~~

Why? E202 Doesn't really say something about level of coordination

I find learning AIA E202 management method for clash coordination exercises is easy.

~~*1.Strongly disagree/2. Disagree/3. Neither agree nor disagree/4. Agree/5. Strongly agree*~~

Why? Agree but it's insufficient.

I find coordinating clash detection workshops using the AIA E202 management method is easy

~~*1.Strongly disagree/2. Disagree/3. Neither agree nor disagree/4.Agree/5. Strongly agree*~~

Why? I'm not fully using it.

7

Intention to continue to use

If I retain access to the AIA E202 management method my intention would be to continue to use it for clash detection coordination.

1.Strongly disagree/~~2. Disagree/3. Neither agree nor disagree/4. Agree/5. Strongly agree~~

Why? Not really usefull

In the future, I expect I will continue to use AIA E202 management method for clash detection coordination.

1.Strongly disagree/~~2. Disagree/3. Neither agree nor disagree/4. Agree/5. Strongly agree~~

Why? See above

I prefer to continue to use AIA E202 management method for clash detection coordination over other standard management methods.

~~1.Strongly disagree/2. Disagree/~~3. Neither agree nor disagree~~/4. Agree/5. Strongly agree~~

Why? Not sure what a standard management method in this context would be.

8

AIA G202 management method

Overall, I find AIA G202 management method useful for coordinating clash detection exercises.

~~*1.Strongly disagree/2. Disagree/3. Neither agree nor disagree/*~~*4. Agree/*~~*5. Strongly agree*~~

Why? It's a step forwatd in comparison to E202

I find AIA G202 management method useful for achieving the purpose of my clash detection exercises.

1.~~*Strongly disagree/2. Disagree/3. Neither agree nor disagree/*~~*4. Agree/*~~*5. Strongly agree*~~

Why? Only if milestones are devined well and thought through.

I find AIA G202 management method helps me in meeting my clash detection objectives.

~~*1.Strongly disagree/2. Disagree/*~~*3. Neither agree nor disagree*~~*/4. Agree/5. Strongly agree*~~

Why? Never used it but it might be usefull.

9

Perceived ease of use

I find easy to coordinate clash detection exercises in the way I intended using the AIA G202 management method

~~*1.Strongly disagree/2. Disagree/3. Neither agree nor disagree*~~*/4. Agree*~~*/5. Strongly agree*~~

Why? ? It's a step forwatd in comparison to E202

I find learning AIA G202 management method for clash coordination exercises is easy.

~~*1.Strongly disagree/2. Disagree/*~~*3. Neither agree nor disagree*~~*/4. Agree/5. Strongly agree*~~

Why? Hard to say milestone definition is going to be key for success.

I find coordinating clash detection workshops using the AIA G202 management method is easy.

~~*1.Strongly disagree/2. Disagree/3. Neither agree nor disagree*~~*/4. Agree*~~*/5. Strongly agree*~~

Why? It's going to be easier to focus on certain aspects and add more value.

10

Intention to continue to use

If I retain access to the AIA G202 management method my intention would be to continue to use it for clash detection coordination.

~~*1.Strongly disagree/2. Disagree/3. Neither agree nor disagree/*~~*4. Agree/*~~*5. Strongly agree*~~

Why? I would prefer it above E202

In the future, I expect I will continue to use AIA G202 management method for clash detection coordination.

~~*1.Strongly disagree/2. Disagree/3. Neither agree nor disagree/*~~*4. Agree*~~*/5. Strongly agree*~~

Why?

I prefer to continue to use AIA G202 management method for clash detection coordination over other standard management methods.

~~*1.Strongly disagree/2. Disagree/*~~*3. Neither agree nor disagree*~~*/4. Agree/5. Strongly agree*~~

Why? Not sure what a standard management method in this context would be.

11

Questionnaire BM341

Consents form

Role: BIM Manager

Years of experience: 29 total, 10 as BIM Manager

Company size: 16,000

Type of projects involved: All/Any

Average No. of disciplines per project: 10 Contact

email address:

Participant identification: BM341

Title of project: Explaining LOD constructs usage: Comparing two LOD standards as per clash detection use.

Contact details: AXG392@student.bham.ac.uk

I agree to take part in the above research. I have read through the Participant Information and I understand what my role will be in this research, and all my questions have been answered to my satisfaction. ☑

I understand that in order to withdraw from participation I must complete the slip at the bottom and return it to the researchers ☑

I have been informed that the confidentiality of the information I provide will be safeguarded. ☑

I am free to ask any questions at any time before and during the study. ☑

I have been provided with participant Information. ☑

4

I understand that I am under no obligation to complete the study once it has commenced and can stop it at any time. ☑

I would like to receive a copy of the results of the workshop ☑

Data Protection: I agree to the University of Birmingham processing personal data, which I have supplied. I agree to the processing of such data for any purposes connected with the Research Project as outlined to me.

Signed... [redacted] .....Date.....01/03/19.....

Consents form

Name of participant ..... Date.....

I wish to withdraw my data from the study titled: Explaining LOD constructs usage: Comparing two LOD standards as per clash detection use.

Signed .....

5

Questionnaire

AIA E202 management method

Assume throughout that management method means use of LOD, MPDT, MIDP

Perceived usefulness

Overall, I find AIA E202 management method useful for coordinating clash detection exercises

1.~~Strongly disagree/2. Disagree/3. Neither agree nor disagree~~/4. Agree/5. ~~Strongly agree~~

Why?

It at least gives clarity of responsibility for each category of element, and an expectation for element maturity.

I find AIA E202 management method useful for achieving the purpose of my clash detection exercises

1.~~Strongly disagree/2. Disagree/3. Neither agree nor disagree~~/4. Agree/5. ~~Strongly agree~~

Why?

As above

I find AIA E202 management method helps me in meeting my clash detection objectives

1.~~Strongly disagree/2. Disagree/3. Neither agree nor disagree~~/4. Agree/5. ~~Strongly agree~~

Why?

6

As above

Perceived ease of use

I find easy to coordinate clash detection exercises in the way I intended using the AIA E202 management method

~~*1.Strongly disagree/2. Disagree/3. Neither agree nor disagree/4. Agree/5. Strongly agree*~~

Why?

I find the LOD100>500 easier to comprehend and visualise on an MDPT than the NBS 1>6, because with the AIA system 200 is always generic, 300 always specific etc, whereas NBS just definitions are less consistent and clear.

I find learning AIA E202 management method for clash coordination exercises is easy.

~~*1.Strongly disagree/2. Disagree/3. Neither agree nor disagree/4.*~~ *Agree/*~~*5. Strongly agree*~~

Why?

I find coordinating clash detection workshops using the AIA E202 management method is easy

~~*1.Strongly disagree/2. Disagree/3. Neither agree nor disagree/4. Agree/5. Strongly agree*~~

Why?

7

Intention to continue to use

If I retain access to the AIA E202 management method my intention would be to continue to use it for clash detection coordination.

1.Strongly disagree/2. Disagree/~~3. Neither agree nor disagree~~/4. Agree/5. Strongly agree

Why?

Granularity of G202 is attractive.

Not always our option to choose the system used on a project.

In the future, I expect I will continue to use AIA E202 management method for clash detection coordination.

~~1.Strongly disagree/2. Disagree~~/3. Neither agree nor disagree/~~4. Agree/5. Strongly agree~~

Why?

I prefer to continue to use AIA E202 management method for clash detection coordination over other standard management methods.

~~1.Strongly disagree~~/2. Disagree/~~3. Neither agree nor disagree/4. Agree/5. Strongly agree~~

Why?

8

Having seen the G202 it makes more sense.

AIA G202 management method

Overall, I find AIA G202 management method useful for coordinating clash detection exercises.

~~*1.Strongly disagree/2. Disagree/3. Neither agree nor disagree/4. Agree*~~*/5. Strongly agree*

Why?

As per E202, plus granularity adds better context to decision making.

I find AIA G202 management method useful for achieving the purpose of my clash detection exercises.

~~*1.Strongly disagree/2. Disagree/3. Neither agree nor disagree/4. Agree*~~*/5. Strongly agree*

Why?

As above

I find AIA G202 management method helps me in meeting my clash detection objectives.

~~*1.Strongly disagree/2. Disagree/3. Neither agree nor disagree/4. Agree*~~*/5. Strongly agree*

Why?

As above

Perceived ease of use

I find easy to coordinate clash detection exercises in the way I intended using the AIA G202 management method

~~*1.Strongly disagree/2. Disagree/3. Neither agree nor disagree/4. Agree*~~*/5. Strongly agree*

Why?

As E202 + granularity in maturity development.

I find learning AIA G202 management method for clash coordination exercises is easy.

~~*1.Strongly disagree/2. Disagree/3. Neither agree nor disagree/4. Agree/*~~*5. Strongly agree*

Why?

I find coordinating clash detection workshops using the AIA G202 management method is easy.

~~*1.Strongly disagree/2. Disagree/3. Neither agree nor disagree/4. Agree*~~*/5. Strongly agree*

Why?

10

Intention to continue to use

If I retain access to the AIA G202 management method my intention would be to continue to use it for clash detection coordination.

~~*1.Strongly disagree/2. Disagree/3. Neither agree nor disagree/4. Agree*~~*/5. Strongly agree*

Why?

In the future, I expect I will continue to use AIA G202 management method for clash detection coordination.

~~*1.Strongly disagree/2. Disagree*~~*/3. Neither agree nor disagree/*~~*4. Agree/5. Strongly agree*~~

Why?

AS E202

I prefer to continue to use AIA G202 management method for clash detection coordination over other standard management methods.

~~*1.Strongly disagree/2. Disagree/3. Neither agree nor disagree/4. Agree*~~*/5. Strongly agree*

Why?

Questionnaire BM511

Consents form

Role: BIM LEAD

Years of experience: 5

Company size: 13,000

Type of projects involved: RAIL

Average No. of disciplines per project: 10+

Contact email address:

Participant identification: BM511

Title of project: Explaining LOD constructs usage: Comparing two LOD standards as per clash detection use.

Contact details: AXG392@student.bham.ac.uk

I agree to take part in the above research. I have read through the Participant Information and I understand what my role will be in this research, and all my questions have been answered to my satisfaction. ☑

I understand that in order to withdraw from participation I must complete the slip at the bottom and return it to the researchers ☑

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I am free to ask any questions at any time before and during the study. ☑

I have been provided with participant Information. ☑

4

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I would like to receive a copy of the results of the workshop ☑

Data Protection: I agree to the University of Birmingham processing personal data, which I have supplied. I agree to the processing of such data for any purposes connected with the Research Project as outlined to me.

Signed. [redacted] .....Date.....20/03/19.....

Consents form

Name of participant ..... Date.....

I wish to withdraw my data from the study titled: Explaining LOD constructs usage: Comparing two LOD standards as per clash detection use.

Signed .....

5

Questionnaire

AIA E202 management method

Perceived usefulness

- Overall, I find AIA E202 management method useful for coordinating clash detection exercises

2. Disagree

Why?

The LOD is only defined at the end of the stage, which means it is not controlled throughout the project stage. Clash detection carried out at the end of the project stage will produce more clashes and will require more rework in the design. Which will have a negative impact on time, cost and quality.

- I find AIA E202 management method useful for achieving the purpose of my clash detection exercises

2. Disagree

Why?

The LOD is only defined at the end of the stage, which means it is not controlled throughout the project stage. Clash detection carried out at the end of the project stage will produce more clashes and will require more rework in the design. Which will have a negative impact on time, cost and quality.

1

- I find AIA E202 management method helps me in meeting my clash detection objectives

4. Agree

Why?

The clash detection carried out will achieve the objectives. However, the timing of the detection could be improved.

Perceived ease of use

- I find easy to coordinate clash detection exercises in the way I intended using the AIA E202 management method

2. Disagree

Why?

The LOD is only defined for the end of the project stage. Therefore, clash detection throughout the project stage will not be undertaken to the desired LOD.

- I find learning AIA E202 management method for clash coordination exercises is easy.

5. Strongly agree

Why?

The process is more linear with less key dates to be achieved, therefore easier to understand.

2

- I find coordinating clash detection workshops using the AIA E202 management method is easy

2. Disagree

Why?

The LOD which is provided throughout the stage is not defined, it is more difficult to make use of clash detections throughout the stage.

Intention to continue to use

- If I retain access to the AIA E202 management method my intention would be to continue to use it for clash detection coordination.

1.Strongly disagree

Why?

The management process in relation to uncontrolled LOD are not reflective of the iterative design process.

- In the future, I expect I will continue to use AIA E202 management method for clash detection coordination.

1.Strongly disagree

Why?

The clash detection process in relation to uncontrolled LOD are not reflective of the iterative design process.

3

- I prefer to continue to use AIA E202 management method for clash detection coordination over other standard management methods.

1.Strongly disagree

Why?

The clash detection process in relation to uncontrolled LOD are not reflective of the iterative design process.

4

AIA G202 management method

Perceived usefulness

- Overall, I find AIA G202 management method useful for coordinating clash detection exercises.

4. Agree

Why?

The LOD is defined at set milestones, which means it is controlled throughout the project stage. Clash detection carried out at the end of the milestone will produce less clashes which means less rework in the design. This will have a positive impact on time, cost and quality.

- I find AIA G202 management method useful for achieving the purpose of my clash detection exercises.

4. Agree

Why?

The LOD is defined at set milestones, which means it is controlled throughout the project stage. Clash detection carried out at the end of the milestone will produce less clashes which means less rework in the design. This will have a positive impact on time, cost and quality.

- I find AIA G202 management method helps me in meeting my clash detection objectives.

4. Agree

5

Why?

The clash detection carried out will achieve the objectives.

Perceived ease of use

- I find easy to coordinate clash detection exercises in the way I intended using the AIA G202 management method

4. Agree

Why?

The LOD is defined for the end of the project milestones. Therefore, clash detection throughout the project stage will be undertaken to the desired LOD.

- I find learning AIA G202 management method for clash coordination exercises is easy.

2. Disagree

Why?

The process is more complex which requires with more key dates to be achieved, therefore harder to understand and communicate.

- I find coordinating clash detection workshops using the AIA G202 management method is easy.

5. Strongly agree

Why?

The LOD which is provided throughout the stage is defined at specific milestones, it is therefore more easy to make use of clash detections throughout the stage.

6

Intention to continue to use

- If I retain access to the AIA G202 management method my intention would be to continue to use it for clash detection coordination.

4. Agree

Why?

The management process in relation to controlled LOD are reflective of the iterative design process.

- In the future, I expect I will continue to use AIA G202 management method for clash detection coordination.

4. Agree

Why?

The clash detection process in relation to controlled LOD are reflective of the iterative design process.

- I prefer to continue to use AIA G202 management method for clash detection coordination over other standard management methods.

4. Agree

Why?

The clash detection process in relation to controlled LOD are reflective of the iterative design process.A

7

Questionnaire BM151

Consents form

Role: BIM Manager

Years of experience: 8

Company size: 15,000

Type of projects involved: I Infrastructure / Bridges

Average No. of disciplines per project: ~10+

Contact email address:

Participant identification: BM151

Title of project: Explaining LOD constructs usage: Comparing two LOD standards as per clash detection use.

Contact details: AXG392@student.bham.ac.uk

I agree to take part in the above research. I have read through the Participant Information and I understand what my role will be in this research, and all my questions have been answered to my satisfaction. ☑

I understand that in order to withdraw from participation I must complete the slip at the bottom and return it to the researchers ☑

I have been informed that the confidentiality of the information I provide will be safeguarded. ☑

I am free to ask any questions at any time before and during the study. ☑

I have been provided with participant Information. ☑

3

I understand that I am under no obligation to complete the study once it has commenced and can stop it at any time. ☑

I would like to receive a copy of the results of the workshop ☑

Data Protection: I agree to the University of Birmingham processing personal data, which I have supplied. I agree to the processing of such data for any purposes connected with the Research Project as outlined to me.

Signed.. [redacted] .....Date...12/02/19.....

Consents form

Name of participant ..... Date.....

I wish to withdraw my data from the study titled: Explaining LOD constructs usage: Comparing two LOD standards as per clash detection use.

Signed .....

4

Questionnaire

AIA E202 management method

Perceived usefulness

Overall, I find AIA E202 management method useful for coordinating clash detection exercises

1.Strongly disagree/2. Disagree/3. Neither agree nor disagree/4. Agree/5. Strongly agree

Why? Captures all clashes at same time

I find AIA E202 management method useful for achieving the purpose of my clash detection exercises

1.Strongly disagree/2. Disagree/3. Neither agree nor disagree/4. Agree/5. Strongly agree

Why? Same as above.

I find AIA E202 management method helps me in meeting my clash detection objectives

1.Strongly disagree/2. Disagree/3. Neither agree nor disagree/4. Agree/5. Strongly agree

Why? helps to capture all clashes without risk of change

5

Perceived ease of use

I find easy to coordinate clash detection exercises in the way I intended using the AIA E202 management method

1.Strongly disagree/2. Disagree/3. Neither agree nor disagree/4. Agree/5. Strongly agree

Why? All done at same times

I find learning AIA E202 management method for clash coordination exercises is easy.

1.Strongly disagree/2. Disagree/3. Neither agree nor disagree/4. Agree/5. Strongly agree

Why?

I find coordinating clash detection workshops using the AIA E202 management method is easy

1.Strongly disagree/2. Disagree/3. Neither agree nor disagree/4. Agree/5. Strongly agree

Why? Only a few workshops at end of project.

6

Intention to continue to use

If I retain access to the AIA E202 management method my intention would be to continue to use it for clash detection coordination.

1.Strongly disagree/2. Disagree/3. Neither agree nor disagree/4. Agree/5. Strongly agree

Why?

In the future, I expect I will continue to use AIA E202 management method for clash detection coordination.

1.Strongly disagree/2. Disagree/3. Neither agree nor disagree/4. Agree/5. Strongly agree

Why? As far clash regarnenerf.

I prefer to continue to use AIA E202 management method for clash detection coordination over other standard management methods.

1.Strongly disagree/2. Disagree/3. Neither agree nor disagree/4. Agree/5. Strongly agree

Why? Detecting all clash at end of project can cause unnecessary work, rather is doing it during step of M.H.Ham design to the inside design design.

7

AIA G202 management method

Overall, I find AIA G202 management method useful for coordinating clash detection exercises.

1.Strongly disagree/2. Disagree/3. Neither agree nor disagree/4. Agree/5. Strongly agree

Why? Allows clashes to be detected during design.

I find AIA G202 management method useful for achieving the purpose of my clash detection exercises.

1.Strongly disagree/2. Disagree/3. Neither agree nor disagree/4. Agree/5. Strongly agree

Why?

I find AIA G202 management method helps me in meeting my clash detection objectives.

1.Strongly disagree/2. Disagree/3. Neither agree nor disagree/4. Agree/5. Strongly agree

Why?

8

Perceived ease of use

I find easy to coordinate clash detection exercises in the way I intended using the AIA G202 management method

1.Strongly disagree/2. Disagree/3. Neither agree nor disagree/4. Agree/5. Strongly agree

Why? Requires more coordinating, however this is not that difficult

I find learning AIA G202 management method for clash coordination exercises is easy.

1.Strongly disagree/2. Disagree/3. Neither agree nor disagree/4. Agree/5. Strongly agree

Why?

I find coordinating clash detection workshops using the AIA G202 management method is easy.

1.Strongly disagree/2. Disagree/3. Neither agree nor disagree/4. Agree/5. Strongly agree

Why? Same as above.

9

Intention to continue to use

If I retain access to the AIA G202 management method my intention would be to continue to use it for clash detection coordination.

1.Strongly disagree/2. Disagree/3. Neither agree nor disagree/4. Agree/5. Strongly agree

Why?

In the future, I expect I will continue to use AIA G202 management method for clash detection coordination.

1.Strongly disagree/2. Disagree/3. Neither agree nor disagree/4. Agree/5. Strongly agree

Why? As per Client and project req.

I prefer to continue to use AIA G202 management method for clash detection coordination over other standard management methods.

1.Strongly disagree/2. Disagree/3. Neither agree nor disagree/4. Agree/5. Strongly agree

Why? It allows clashes to be det. during the design. Storing unnecessary work.

10

Questionnaire BC511

Consents form

Role: BIM Coordinator

Years of experience: 4-5

Company size: 15000

Type of projects involved: ~~Infrastructure~~ Infrastructure

Average No. of disciplines per project: 5

Contact email address:

Participant identification: BC511

Title of project: Explaining LOD constructs usage: Comparing two LOD standards as per clash detection use.

Contact details: AXG392@student.bham.ac.uk

I agree to take part in the above research. I have read through the Participant Information and I understand what my role will be in this research, and all my questions have been answered to my satisfaction. ☑

I understand that in order to withdraw from participation I must complete the slip at the bottom and return it to the researchers ☑

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I am free to ask any questions at any time before and during the study. ☑

I have been provided with participant Information. ☑

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Signed.. [redacted] .....Date...12/02/2019.....

Consents form

Name of participant ..... Date.....

I wish to withdraw my data from the study titled: Explaining LOD constructs usage: Comparing two LOD standards as per clash detection use.

Signed .....

4

Questionnaire

AIA E202 management method

Perceived usefulness

Overall, I find AIA E202 management method useful for coordinating clash detection exercises

1.Strongly disagree/2. Disagree/3. Neither agree nor disagree/4. Agree/5. Strongly agree

Why? Simple to use well understood.

I find AIA E202 management method useful for achieving the purpose of my clash detection exercises

1.Strongly disagree/2. Disagree/3. Neither agree nor disagree/4. Agree/5. Strongly agree

Why? Very last minute checks as some disciplines still model last minute

I find AIA E202 management method helps me in meeting my clash detection objectives

1.Strongly disagree/2. Disagree/3. Neither agree nor disagree/4. Agree/5. Strongly agree

Why? Assigning people to check and resolve clashes outside of the coordination meeting will make it alot quicker.

5

Perceived ease of use

I find easy to coordinate clash detection exercises in the way I intended using the AIA E202 management method

1.Strongly disagree/2. Disagree/3. Neither agree nor disagree/4. Agree/5. Strongly agree

Why? Simple to use but will be very last minute

I find learning AIA E202 management method for clash coordination exercises is easy.

1.Strongly disagree/2. Disagree/3. Neither agree nor disagree/4. Agree/5. Strongly agree

Why? Know by that what point everything needs to be at and everything seems to move in sequence.

I find coordinating clash detection workshops using the AIA E202 management method is easy

1.Strongly disagree/2. Disagree/3. Neither agree nor disagree/4. Agree/5. Strongly agree

Why? Set dates and times

6

Intention to continue to use

If I retain access to the AIA E202 management method my intention would be to continue to use it for clash detection coordination.

1.Strongly disagree/2. Disagree/3. Neither agree nor disagree/4. Agree/5. Strongly agree

Why?

In the future, I expect I will continue to use AIA E202 management method for clash detection coordination.

1.Strongly disagree/2. Disagree/3. Neither agree nor disagree/4. Agree/5. Strongly agree

Why? Client requirement / knowledg / they only care about the end product

I prefer to continue to use AIA E202 management method for clash detection coordination over other standard management methods.

1.Strongly disagree/2. Disagree/3. Neither agree nor disagree/4. Agree/5. Strongly agree

Why? There are aspects I like of multiple management systems.

7

AIA G202 management method

Overall, I find AIA G202 management method useful for coordinating clash detection exercises.

1.Strongly disagree/2. Disagree/3. Neither agree nor disagree/4. Agree/5. Strongly agree

Why? brings more detail earlier So have more time to resolve

I find AIA G202 management method useful for achieving the purpose of my clash detection exercises.

1.Strongly disagree/2. Disagree/3. Neither agree nor disagree/4. Agree/5. Strongly agree

Why?

I find AIA G202 management method helps me in meeting my clash detection objectives.

1.Strongly disagree/2. Disagree/3. Neither agree nor disagree/4. Agree/5. Strongly agree

Why? brings checks more detailed ~~earlier~~ earlier

8

Perceived ease of use

I find easy to coordinate clash detection exercises in the way I intended using the AIA G202 management method

1.Strongly disagree/2. Disagree/3. Neither agree nor disagree/4. Agree/5. Strongly agree

Why? Communication not just MPDT needs to be programed

I find learning AIA G202 management method for clash coordination exercises is easy.

1.Strongly disagree/2. Disagree/3. Neither agree nor disagree/4. Agree/5. Strongly agree

Why? Needs to be managed and programed well and needs the whole team to be aware.

I find coordinating clash detection workshops using the AIA G202 management method is easy.

1.Strongly disagree/2. Disagree/3. Neither agree nor disagree/4. Agree/5. Strongly agree

Why? It will be better early on due to it being more targeted but will be harder later as more changes happen.

9

Intention to continue to use

If I retain access to the AIA G202 management method my intention would be to continue to use it for clash detection coordination.

1.Strongly disagree/2. Disagree/3. Neither agree nor disagree/4. Agree/5. Strongly agree

Why?

In the future, I expect I will continue to use AIA G202 management method for clash detection coordination.

1.Strongly disagree/2. Disagree/3. Neither agree nor disagree/4. Agree/5. Strongly agree

Why? Clients won't see the benefits for themselves

I prefer to continue to use AIA G202 management method for clash detection coordination over other standard management methods.

1.Strongly disagree/2. Disagree/3. Neither agree nor disagree/4. Agree/5. Strongly agree

Why? I would like to test as I see personal benefit

10

Questionnaire BC341

Consents form

Role: Structural Technician

Years of experience: 4

Company size: ~~4~~ 12000 +

Type of projects involved: Sports + Social / Further education all Structural Some Civil

Average No. of disciplines per project: ~~5~~ 4/5

Contact email address:

Participant identification: BC341

Title of project: Explaining LOD constructs usage: Comparing two LOD standards as per clash detection use.

Contact details: AXG392@student.bham.ac.uk

I agree to take part in the above research. I have read through the Participant Information and I understand what my role will be in this research, and all my questions have been answered to my satisfaction. ☑

I understand that in order to withdraw from participation I must complete the slip at the bottom and return it to the researchers ☑

I have been informed that the confidentiality of the information I provide will be safeguarded. ☑

I am free to ask any questions at any time before and during the study. ☑

I have been provided with participant Information. ☑

4

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I would like to receive a copy of the results of the workshop ☑

Data Protection: I agree to the University of Birmingham processing personal data, which I have supplied. I agree to the processing of such data for any purposes connected with the Research Project as outlined to me.

Signed..[redacted].....Date..01/03/2019.....

Consents form

Name of participant ..... Date.....

I wish to withdraw my data from the study titled: Explaining LOD constructs usage: Comparing two LOD standards as per clash detection use.

Signed .....

5

Questionnaire

AIA E202 management method

Perceived usefulness

Overall, I find AIA E202 management method useful for coordinating clash detection exercises

1.Strongly disagree/2. Disagree/3. Neither agree nor disagree/4. Agree/5. Strongly agree

Why? Clash detection done after alot of design at key phases → a reduction in false clashes potentially.

I find AIA E202 management method useful for achieving the purpose of my clash detection exercises

1.Strongly disagree/2. Disagree/3. Neither agree nor disagree/4. Agree/5. Strongly agree

Why? typical method

I find AIA E202 management method helps me in meeting my clash detection objectives

1.Strongly disagree/2. Disagree/3. Neither agree nor disagree/4. Agree/5. Strongly agree

Why? clash detection often done in the meeting rather than resolve clashes.

6

Perceived ease of use

I find easy to coordinate clash detection exercises in the way I intended using the AIA E202 management method

1.Strongly disagree/2. Disagree/3. Neither agree nor disagree/4. Agree/5. Strongly agree

Why?

I find learning AIA E202 management method for clash coordination exercises is easy.

1.Strongly disagree/2. Disagree/3. Neither agree nor disagree/4. Agree/5. Strongly agree

Why? easy to follow, Simple workflow

I find coordinating clash detection workshops using the AIA E202 management method is easy

1.Strongly disagree/2. Disagree/3. Neither agree nor disagree/4. Agree/5. Strongly agree

Why? most developed model at a place

7

Intention to continue to use

If I retain access to the AIA E202 management method my intention would be to continue to use it for clash detection coordination.

1.Strongly disagree/2. Disagree/3. Neither agree nor disagree/4. Agree/5. Strongly agree

Why? not frequent enough

In the future, I expect I will continue to use AIA E202 management method for clash detection coordination.

1.Strongly disagree/2. Disagree/3. Neither agree nor disagree/4. Agree/5. Strongly agree

Why? often the quickest method and done before large model issues.

I prefer to continue to use AIA E202 management method for clash detection coordination over other standard management methods.

1.Strongly disagree/2. Disagree/3. Neither agree nor disagree/4. Agree/5. Strongly agree

Why? Clash detection should be done continuesly

AIA G202 management method

Overall, I find AIA G202 management method useful for coordinating clash detection exercises.

1.Strongly disagree/2. Disagree/3. Neither agree nor disagree/4. Agree/5. Strongly agree

Why? regular clash detection is important, may reduce the number of false clashes?

I find AIA G202 management method useful for achieving the purpose of my clash detection exercises.

1.Strongly disagree/2. Disagree/3. Neither agree nor disagree/4. Agree/5. Strongly agree

Why? easy to get into a habit of clash detection at milestones as long as they are set.

I find AIA G202 management method helps me in meeting my clash detection objectives.

1.Strongly disagree/2. Disagree/3. Neither agree nor disagree/4. Agree/5. Strongly agree

Why? gives clear regular clashes as required

Perceived ease of use

I find easy to coordinate clash detection exercises in the way I intended using the AIA G202 management method

1.Strongly disagree/2. Disagree/3. Neither agree nor disagree/4. Agree/5. Strongly agree

Why?

I find learning AIA G202 management method for clash coordination exercises is easy.

1.Strongly disagree/2. Disagree/3. Neither agree nor disagree/4. Agree/5. Strongly agree

Why? repetative process although more complicated than E202

I find coordinating clash detection workshops using the AIA G202 management method is easy.

1.Strongly disagree/2. Disagree/3. Neither agree nor disagree/4. Agree/5. Strongly agree

Why? Clashes identified before the end of each phase and often before meetings.

10

Intention to continue to use

If I retain access to the AIA G202 management method my intention would be to continue to use it for clash detection coordination.

1.Strongly disagree/2. Disagree/3. Neither agree nor disagree/4. Agree/5. Strongly agree

Why? is something we already do typically.

In the future, I expect I will continue to use AIA G202 management method for clash detection coordination.

1.Strongly disagree/2. Disagree/3. Neither agree nor disagree/4. Agree/5. Strongly agree

Why? as above.

I prefer to continue to use AIA G202 management method for clash detection coordination over other standard management methods.

1.Strongly disagree/2. Disagree/3. Neither agree nor disagree/4. Agree/5. Strongly agree

Why? regular clash detection saves time remodelling and repeat clashes in meetings.

11

Questionnaire SD221

Consents form

Role: GRADUATE ENGINEER

Years of experience: 1.5 YEARS

Company size: 15 000

Type of projects involved: CIVIL ENGINEERING

Average No. of disciplines per project:

Contact email address:

Participant identification: SD221

Title of project: Explaining LOD constructs usage: Comparing two LOD standards as per clash detection use.

Contact details: AXG392@student.bham.ac.uk

I agree to take part in the above research. I have read through the Participant Information and I understand what my role will be in this research, and all my questions have been answered to my satisfaction. ☒

I understand that in order to withdraw from participation I must complete the slip at the bottom and return it to the researchers ☒

I have been informed that the confidentiality of the information I provide will be safeguarded. ☒

I am free to ask any questions at any time before and during the study. ☒

I have been provided with participant Information. ☒

4

I understand that I am under no obligation to complete the study once it has commenced and can stop it at any time. [X]

I would like to receive a copy of the results of the workshop [X]

Data Protection: I agree to the University of Birmingham processing personal data, which I have supplied. I agree to the processing of such data for any purposes connected with the Research Project as outlined to me.

Signed..... .....Date.....14/02/2019.....

Consents form

Name of participant .....Date.....

I wish to withdraw my data from the study titled: Explaining LOD constructs usage: Comparing two LOD standards as per clash detection use.

Signed .....

5

Questionnaire

AIA E202 management method

Perceived usefulness

Overall, I find AIA E202 management method useful for coordinating clash detection exercises

1.Strongly disagree/2. Disagree/3. Neither agree nor disagree/4. Agree/5. Strongly agree

Why? Time efficiency and quality.

I find AIA E202 management method useful for achieving the purpose of my clash detection exercises

1.Strongly disagree/2. Disagree/3. Neither agree nor disagree/4. Agree/5. Strongly agree

Why?

I find AIA E202 management method helps me in meeting my clash detection objectives

1.Strongly disagree/2. Disagree/3. Neither agree nor disagree/4. Agree/5. Strongly agree

Why?

6

Perceived ease of use

I find easy to coordinate clash detection exercises in the way I intended using the AIA G202 management method

1.Strongly disagree/2. Disagree/3. Neither agree nor disagree/4. Agree/5. Strongly agree

Why?

I find learning AIA G202 management method for clash coordination exercises is easy.

1.Strongly disagree/2. Disagree/3. Neither agree nor disagree/4. Agree/5. Strongly agree

Why? Learning and understanding how it works seem to be easier to implement. To make it work all the teams should become aware of its importance

I find coordinating clash detection workshops using the AIA G202 management method is easy

1.Strongly disagree/2. Disagree/3 Neither agree nor disagree/4. Agree/5. Strongly agree

Why? As said before, it seems easier to understood the process rather than implement it

7

Intention to continue to use

If I retain access to the AIA E202 management method my intention would be to continue to use it for clash detection coordination.

1.Strongly disagree/2. Disagree/3. Neither agree nor disagree/4. Agree/5. Strongly agree

Why? But I would need further training

In the future, I expect I will continue to use AIA E202 management method for clash detection coordination.

1.Strongly disagree/2. Disagree/3. Neither agree nor disagree/4. Agree/5. Strongly agree

Why?

I prefer to continue to use AIA E202 management method for clash detection coordination over other standard management methods.

1.Strongly disagree/2. Disagree/3. Neither agree nor disagree/4. Agree/5. Strongly agree

Why?

8

AIA G202 management method

Overall, I find AIA G202 management method useful for coordinating clash detection exercises.

1.Strongly disagree/2. Disagree/3. Neither agree nor disagree/4. Agree/5. Strongly agree

Why? It is useful, but clashes may be detected in further stages leading to repetition of an important amount of the job done.

I find AIA G202 management method useful for achieving the purpose of my clash detection exercises.

1.Strongly disagree/2. Disagree/3. Neither agree nor disagree/4. Agree/5. Strongly agree

Why?

I find AIA G202 management method helps me in meeting my clash detection objectives.

1.Strongly disagree/2. Disagree/3. Neither agree nor disagree/4. Agree/5. Strongly agree

Why?

9

Perceived ease of use

I find easy to coordinate clash detection exercises in the way I intended using the AIA G202 management method

1.Strongly disagree/2. Disagree/3. Neither agree nor disagree/4. Agree/5. Strongly agree

Why? As said before, easy to detect but not as soon as desired

I find learning AIA G202 management method for clash coordination exercises is easy.

1.Strongly disagree/2. Disagree/3. Neither agree nor disagree/4. Agree/5. Strongly agree

Why?

I find coordinating clash detection workshops using the AIA G202 management method is easy.

1.Strongly disagree/2. Disagree/3. Neither agree nor disagree/4. Agree/5. Strongly agree

Why?

10

Intention to continue to use

If I retain access to the AIA G202 management method my intention would be to continue to use it for clash detection coordination.

1.Strongly disagree/2. Disagree/3. Neither agree nor disagree/4. Agree/5. Strongly agree

Why?

In the future, I expect I will continue to use AIA G202 management method for clash detection coordination.

1.Strongly disagree/2. Disagree/3. Neither agree nor disagree/4. Agree/5. Strongly agree

Why?

I prefer to continue to use AIA G202 management method for clash detection coordination over other standard management methods.

1.Strongly disagree/2. Disagree/3. Neither agree nor disagree/4. Agree/5. Strongly agree

Why?

11

Questionnaire SD131

Consents Form

Role: Bridge assistant Engineer
Years of experience: 5
Company size: 10.000 employees (UK only)
Type of projects involved: bridg designs, assesments and refurbishment
Average No. of disciplines per project: 4
Contact email address: N/A
Participant identification: SD131
Title of project: Explaining LOD constructs usage: Comparing two LOD standards as per clash detection use.
Contact details: AXG392@student.bham.ac.uk

1. I agree to take part in the above research. I have read through the Participant Information and I understand what my role will be in this research, and all my questions have been answered to my satisfaction. ☑
2. I understand that in order to withdraw from participation I must complete the slip at the bottom and return it to the researcher. ☑
3. I have been informed that the confidentiality of the information I provide will be safeguarded. ☑
4. I am free to ask any question at any time before and during the study. ☑
5. I have been provided with participant information. ☑
6. I understand that I am under no obligation to complete the study once it has commenced and can stop it at any time. ☑
7. I would like to receive a copy of the results of the workshop. ☑

Data Protection

I agree to the University processing personal data, which have supplied. I agree to the processing of such data for any purposes connected with the Research Project as outlined to me.

Signed.....

Date.....27th March 2019.....

Withdrawal Form

Name of participant:
I wish to withdraw my data from the study titled: Explaining LOD constructs usage: Comparing two LOD standards as per clash detection use. That is being carried out by Angel Gigante Barrera

Signed..... Date.....

Translation verification Form

Participant ID: SD131

I confirm that the interview from the study titled: Explaining LOD constructs usage: Comparing two LOD standards as per clash detection use that is being carried out by Angel Gigante Barrera has been translated from Spanish to English and that its content is reliable and accurate.

Signed...  Date... 7th March 2019

Participant: SD131

AIA E202 management method

Perceived usefulness

- Overall, I find AIA E202 management method useful for coordinating clash detection exercises

1.Strongly disagree/2. Disagree/3. Neither agree nor disagree/4. Agree/5. Strongly agree

Why? Because it allows disciplines working independently and more effectively. As far as there is not any interdisciplinary problem.

- I find AIA E202 management method useful for achieving the purpose of my clash detection exercises

1.Strongly disagree/2. Disagree/3. Neither agree nor disagree/4. Agree/5. Strongly agree

Why? Because the interferences instances are clearer.

- I find AIA E202 management method helps me in meeting my clash detection objectives

1.Strongly disagree/2. Disagree/3. Neither agree nor disagree/4. Agree/5. Strongly agree

Why? The clashes are detected easily and in a clear way, but once the clashes are detected it might be too late to address the issue.

Perceived ease of use

- I find easy to coordinate clash detection exercises in the way I intended using the AIA E202 management method

1.Strongly disagree/2. Disagree/3. Neither agree nor disagree/4. Agree/5. Strongly agree

Why? Because there is not any degree of coordination.

- I find learning AIA E202 management method for clash coordination exercises is easy.

1.Strongly disagree/2. Disagree/3. Neither agree nor disagree/4. Agree/5. Strongly agree

Why? Because only one LOD is assigned at the end of the stage, but there is a risk associated to leave the LOD coordination process unmanaged.

- I find coordinating clash detection workshops using the AIA E202 management method is easy.

1.Strongly disagree/2. Disagree/3. Neither agree nor disagree/4. Agree/5. Strongly agree

Why? Because the clash is very easy to see.

Intention to continue to use

- If I retain access to the AIA E202 management method my intention would be to continue to use it for clash detection coordination.

1.Strongly disagree/2. Disagree/3. Neither agree nor disagree/4. Agree/5. Strongly agree

Why? It depends on whether the associated problems are easy to solve or implies redesign, if this is the case no. But if they are easy or is improbably that it makes an impact on redesign, yes.

- In the future, I expect I will continue to use AIA E202 management method for clash detection coordination.

1.Strongly disagree/2. Disagree/3. Neither agree nor disagree/4. Agree/5. Strongly agree

Why? As above

- I prefer to continue to use AIA E202 management method for clash detection coordination over other standard management methods.

1.Strongly disagree/2. Disagree/3. Neither agree nor disagree/4. Agree/5. Strongly agree

Why? If there is an elevated risk associated to redesign, no.

AIA G202 management method

- Overall, I find AIA G202 management method useful for coordinating clash detection exercises.

1.Strongly disagree/2. Disagree/3. Neither agree nor disagree/4. Agree/5. Strongly agree

Why? Because it facilitates taking the needed decisions to develop the project and for example avoiding clashes problems.

- I find AIA G202 management method useful for achieving the purpose of my clash detection exercises.

1.Strongly disagree/2. Disagree/3. Neither agree nor disagree/4. Agree/5. Strongly agree

Why? Because it avoids clashes before they are produced. If the exercise of bringing all the team together is more expensive than redesigning, then it isn´t useful. Everything depends on the risk implications of having or not having clashes in terms of cost and time.

- I find AIA G202 management method helps me in meeting my clash detection objectives.

1.Strongly disagree/2. Disagree/3. Neither agree nor disagree/4. Agree/5. Strongly agree

Why? Because it allows to achieve the best solution. Is the only way to take that kind of decisions.

Perceived ease of use

- I find easy to coordinate clash detection exercises in the way I intended using the AIA G202 management method

1.Strongly disagree/2. Disagree/3. Neither agree nor disagree/4. Agree/5. Strongly agree

Why? Is difficult to know to what level of information each discipline needs to develop the model at each milestone.

- I find learning AIA G202 management method for clash coordination exercises is easy.

1.Strongly disagree/2. Disagree/3. Neither agree nor disagree/4. Agree/5. Strongly agree

Why? As above

- I find coordinating clash detection workshops using the AIA G202 management method is easy.

1.Strongly disagree/2. Disagree/3. Neither agree nor disagree/4. Agree/5. Strongly agree

Why? Is the only way of coordinating disciplines. One of them can be regarded as a tool to coordinate disciplines whereas the other is not a tool.

Intention to continue to use

- If I retain access to the AIA G202 management method my intention would be to continue to use it for clash detection coordination.

1.Strongly disagree/2. Disagree/3. Neither agree nor disagree/4. Agree/5. Strongly agree

Why? Because it forces disciplines to work more between them. I will would use it if there is a high risk in case of clashing.

- In the future, I expect I will continue to use AIA G202 management method for clash detection coordination.

1.Strongly disagree/2. Disagree/3. Neither agree nor disagree/4. Agree/5. Strongly agree

Why? Because people are used to work independently, and my company works in big size projects where is difficult to coordinate disciplines.

- I prefer to continue to use AIA G202 management method for clash detection coordination over other standard management methods.

1.Strongly disagree/2. Disagree/3. Neither agree nor disagree/4. Agree/5. Strongly agree

Why? Depends on the project and the risks associated.

Questionnaire Quantitative results

Table C- 0-1: Questionnaire Quantitative results

	D221	BM151	BM341	BM342	BM511	BC511	BC341	SD221	SD131
PU-E202-1	2	2	4	2	4	4	4	4	3
PU-E202-2	4	2	4	3	4	1	4	5	4
PU-E202-3	3	4	4	3	4	5	2	4	3
PEU-E202-1	2	2	4	2	4	3	4	5	1
PEU-E202-2	3	5	4	4	4	5	4	5	4
PEU-E202-3	4	2	4	3	4	5	4	3	5
ICU-E202-1	3	1	3	1	4	5	2	3	3
ICU-E202-2	2	1	3	1	4	5	4	3	4
ICU-E202-3	2	1	2	3	2	3	2	5	3
PU-G202-1	4	4	5	4	5	5	4	5	4
PU-G202-2	2	4	5	4	4	4	5	5	5
PU-G202-3	3	4	5	3	4	5	5	5	4
PEU-G202-1	2	4	5	4	3	2	4	4	2
PEU-G202-2	3	2	5	3	4	2	4	4	2
PEU-G202-3	4	5	5	4	3	3	5	3	4
ICU-G202-1	3	4	5	4	4	4	5	4	4
ICU-G202-2	2	4	3	4	4	2	5	4	2
ICU-G202-3	2	4	5	3	4	4	5	4	3

Table C-0-2: PU_E202 Percentage Table

		Frequency	Percent	Valid Percent	Cumulative Percent
PU_E202_1					
Valid	Disagree	3	33.3	33.3	33.3
	Neither agree nor disagree	1	11.1	11.1	44.4
	Agree	5	55.6	55.6	100.0
	Total	9	100.0	100.0	
PU_E202_2					
Valid	Strongly disagree	1	11.1	11.1	11.1
	Disagree	1	11.1	11.1	22.2
	Neither agree nor disagree	1	11.1	11.1	33.3
	Agree	5	55.6	55.6	88.9
	Strongly agree	1	11.1	11.1	100.0
	Total	9	100.0	100.0	
PU_E202_3					
Valid	Disagree	1	11.1	11.1	11.1
	Neither agree nor disagree	3	33.3	33.3	44.4
	Agree	4	44.4	44.4	88.9
	Strongly agree	1	11.1	11.1	100.0
	Total	9	100.0	100.0	

Table C-0-3: PEU_E202 Percentage Table

		Frequency	Percent	Valid Percent	Cumulative Percent
PEU_E202_1					
Valid	Strongly disagree	1	11.1	11.1	11.1
	Disagree	3	33.3	33.3	44.4
	Neither agree nor disagree	1	11.1	11.1	55.6
	Agree	3	33.3	33.3	88.9
	Strongly agree	1	11.1	11.1	100.0
	Total	9	100.0	100.0	
PEU_E202_2					
Valid	Neither agree nor disagree	1	11.1	11.1	11.1
	Agree	5	55.6	55.6	66.7
	Strongly agree	3	33.3	33.3	100.0
	Total	9	100.0	100.0	
PEU_E202_3					
Valid	Disagree	1	11.1	11.1	11.1
	Neither agree nor disagree	2	22.2	22.2	33.3
	Agree	4	44.4	44.4	77.8
	Strongly agree	2	22.2	22.2	100.0
	Total	9	100.0	100.0	

Table C-0-4: ICU_E202 Percentage Table

		Frequency	Percent	Valid Percent	Cumulative Percent
ICU_E202_1					
Valid	Strongly disagree	2	22.2	22.2	22.2
	Disagree	1	11.1	11.1	33.3
	Neither agree nor disagree	4	44.4	44.4	77.8
	Agree	1	11.1	11.1	88.9
	Strongly agree	1	11.1	11.1	100.0
	Total	9	100.0	100.0	
ICU_E202_2					
Valid	Strongly disagree	2	22.2	22.2	22.2
	Disagree	1	11.1	11.1	33.3
	Neither agree nor disagree	2	22.2	22.2	55.6
	Agree	3	33.3	33.3	88.9
	Strongly agree	1	11.1	11.1	100.0
	Total	9	100.0	100.0	
ICU_E202_3					
Valid	Strongly disagree	1	11.1	11.1	11.1
	Disagree	4	44.4	44.4	55.6
	Neither agree nor disagree	3	33.3	33.3	88.9
	Strongly agree	1	11.1	11.1	100.0
	Total	9	100.0	100.0	

Table C-0-5: PU_G202 Percentage Table

		Frequency	Percent	Valid Percent	Cumulative Percent
PU_G202_1					
Valid	Agree	5	55.6	55.6	55.6
	Strongly agree	4	44.4	44.4	100.0
	Total	9	100.0	100.0	
PU_G202_2					
Valid	Disagree	1	11.1	11.1	11.1
	Agree	4	44.4	44.4	55.6
	Strongly agree	4	44.4	44.4	100.0
	Total	9	100.0	100.0	
PU_G202_3					
Valid	Neither agree nor disagree	2	22.2	22.2	22.2
	Agree	3	33.3	33.3	55.6
	Strongly agree	4	44.4	44.4	100.0
	Total	9	100.0	100.0	

Table 0-6: PEU_G202 Percentage Table

		Frequency	Percent	Valid Percent	Cumulative Percent
PEU_G202_1					
Valid	Disagree	3	33.3	33.3	33.3
	Neither agree nor disagree	1	11.1	11.1	44.4
	Agree	4	44.4	44.4	88.9
	Strongly agree	1	11.1	11.1	100.0
	Total	9	100.0	100.0	
PEU_G202_2					
Valid	Disagree	3	33.3	33.3	33.3
	Neither agree nor disagree	2	22.2	22.2	55.6
	Agree	3	33.3	33.3	88.9
	Strongly agree	1	11.1	11.1	100.0
	Total	9	100.0	100.0	
PEU_G202_3					
Valid	Neither agree nor disagree	3	33.3	33.3	33.3
	Agree	3	33.3	33.3	66.7
	Strongly agree	3	33.3	33.3	100.0
	Total	9	100.0	100.0	

Table C-0-7: ICU_G202 Percentage Table

		Frequency	Percent	Valid Percent	Cumulative Percent
ICU_G202_1					
Valid	Neither agree nor disagree	1	11.1	11.1	11.1
	Agree	6	66.7	66.7	77.8
	Strongly agree	2	22.2	22.2	100.0
	Total	9	100.0	100.0	
ICU_G202_2					
Valid	Disagree	3	33.3	33.3	33.3
	Neither agree nor disagree	1	11.1	11.1	44.4
	Agree	4	44.4	44.4	88.9
	Strongly agree	1	11.1	11.1	100.0
	Total	9	100.0	100.0	
ICU_G202_3					
Valid	Disagree	1	11.1	11.1	11.1
	Neither agree nor disagree	2	22.2	22.2	33.3
	Agree	4	44.4	44.4	77.8
	Strongly agree	2	22.2	22.2	100.0
	Total	9	100.0	100.0	

Questionnaire Qualitative Results

Table C-0-8: Questionnaire Qualitative Results – PU.

	Theme 1 (E202): Perceived Usefulness **Sub-theme: Waste time, cost, human resources.**	**Theme 1 (G202): Perceived Usefulness** **Sub-theme: Waste time, cost, human resources.**
BM	-"Captures all clashes at the same time" **BM151Q14** -"Captures all clashes at the same time" **BM151Q24** -"Helps to capture all clashes without risk of change" **BM151Q34** -"It at least gives clarity of responsibility for each category of element, and an expectation for element maturity" **BM3411Q14** -"It at least gives clarity of responsibility for each category of element, and an expectation for element maturity" **BM341Q24** -"It´s not saying anything about coordination level of specific objects through the design phase".**BM342Q12** -"It´s a good way to set formal milestones which are in line with contracts and agreements". **BM342Q23** -"It´s saying something about the end goal. Nothing about the process". **BM342Q33** -"The LOD is only defined at the end of the stage, which means it is not controlled throughout the project stage. Clash detection carried out at	-"it would help if clients had a bit more knowledge in it because you know… we kind of push…like if there were to say to a project manager ok we need to add all this information into a model and they say well what does the client want then you're like this…then they're like well why are we doing the rest let's not bother…so it kind of always comes down to client requirements so unless you can prove that there is some value in having that information there… say for analysis or something like that it won't get put in a lot of the time…it depends on how willing the people doing the modelling or the structural designers are…"**(Informational) BM151I** -"whereas if you do the stage gates in between its more for internally and (company name) …alright so this stage gate if we had this information it would then help the costing team because they'd know what material it is as such so I feel like this one is more client based…so literally alright here's the stuff as you want it whereas the

the end of the project stage will produce more clashes and will require more rework in the design. Which will have a negative impact on time, cost and quality". **BM511Q12** -"The LOD is only defined at the end of the stage, which means is not controlled throughout the project stage. Clash detection carried out at the end of the project stage will produce more clashes and will require more rework in the design. Which will have a negative impact on time, cost and quality". **BM511Q22** -"The clash detection carried out will achieve the objectives. However, the timing of the detection could be improved". **BM511Q34**	other one is better for (company name) and their digital vision erm…because internally we have models…maturing slowly but in a managed way so that everyone is aware of what they an almost use them for…so that is usually the biggest problem...people don't want to use our models because they don't know how accurate it is...so you know…"**(Informational) BM511I** -"But yeah…but if you sort of thinking about machine learning artificial intelligence …it shouldn't really matter what way you pull out. It's just the data in the end, isn't it?" **(Informational) BM511I** "because I think that's the benefit of the G202 is it have that you'd have that information earlier so could at least benefit" **(Behavioural) BM511I** -"the LOD is fine at set milestones which means it is controlled though project stage class action carried out. At the end of the milestone will produce less classes, I mean which means less rework in the design. This will have a positive impact on time cost and quality".**BM151I** -"Allows clashes to be detected during design" **BM151Q15** -"As per E202, plus granularity adds better context to decision making" **BM341Q15** -"As per E202, plus granularity adds better context to decision making" **BM341Q25**

		-"It´s a step forward in comparison to E202". **BM342Q11** -"Only if milestones are divined well and thought through". **BM342Q24** -"Never used it but it might be useful". **BM342Q33** -"The LOD is defined at set milestones, which means it is controlled throughout the project stage. Clash detection carried out at the end of the milestone will produce less clashes which means less rework in the design. This will have a positive impact on time cost and quality". **BM511Q14** -"The LOD is defined at set milestones, which means it is controlled throughout the project stage. Clash detection carried out at the end of the milestone will produce less clashes which means less rework in the design. This will have a positive impact on time cost and quality". **BM511Q24** -"The clash detection carried out will achieve the objectives ". **BM511Q34**
BC	-"Simple to use, well understood" **BC151Q14** -"Very last minute checks as some disciplines will model last minute" **BC151Q11** -"Assigning people to check and resolve clashes out of the coordination meeting will make it a lot quicker " **BC151Q15**	-"you can input the same parameters and use…so use the parameters from drainage planted from Bridges and you can input them into a model and then you can have the model regenerate itself over and over again, with slightly different parameters until it finds a solution where nothing clashes". **(Informational) BC151I**

	-"Clash detection done after a lot of design at key phases. A reduction in false clashes potentially" **BC341Q14** -"Typical method" **BC341Q24** -"Clash detection often done in the meeting rather than resolve clashes" **BC341Q32**	-"I don't think it matters when you get that information out as long as you get the information out". **(Informational) BC151I** -"Brings more detail earlier so have more time to resolve" **BC151Q15** -"Brings checks more detailed earlier" **BC151Q35** -"Regular clash detection is important, may reduce the number of false clashes" **BC341Q14** -"Easy to get into a habit of clash detection at milestones as long as they are set" **BC341Q25** -"Gives clear regular clashes as required" **BC341Q35**
SD	-"It is useful, but clashes may be detected in further stages leading to repetition of an important amount of the job done"**SD221Q14** -"Because it allows disciplines working independently and more effectively. As far as there is not any interdisciplinary problem."**SD131Q13** -"As far as there are not changes on those critical parameters of the bridge you are going to continue doing independent models. So that if there are not changes in the transversal beams or number of general beams, you think that you may adapt your final model with not very big change so your result will be close to the one... So, while there are not big changes, you can still be doing a two weeks meeting"-. **SD221I**	-"Time efficiency and quality"**SD221Q15** -"Because it facilitates taking the needed decisions to develop the project and for example avoiding clashes problems."**SD131Q14** -"Because it avoids clashes before they are produced. If the exercise of bringing all the team together is more expensive than redesigning, then isn´t useful. Everything depends on the risk implications of having or not having clashes in terms of cost and time"**SD131Q25** -"Because it allows to achieve the best solution. Is the only way to take that kind of decisions" **SD131Q34**

-"So, you can have a matrix, where whenever there is a change you fill it and you will see which discipline you have to give a shout to in order to let them know that this change is important for them. Maybe a change on the, for example a decision like ballast or slab viaduct, this is a change that is not affecting drainage. So, if you do a change you don´t even need to call them." **SD221I**

-"Because the interferences instances are clearer.."**SD131Q24**

-"The clashes are detected easily and in a clear way, but once the clashes are detected it might be too late to address the issue."**SD131Q33**

-"but if instead of 5 is 6 beams, there is an important change that hasn´t been defined as critical since the beginning and then we have to inform because the tolerance is not absorbing those changes." **SD221I**

-"We worked independently, each discipline worked independently. Then never ... We did not have information, if another discipline affected our design or not. So, I think it would be interesting to have more information of the other disciplines but at a very low level of project development so that it does not change what we have to do our input does not suppose ..." **SD131I**

-"Well I think the cost is difficult to know if it has a cost or not. What I would avoid is problems." **SD131I**

	-"What would be interesting is that in each discipline would have to be established a minimum information needed by the other so that your design is not affected". **SD131I** "So I think that for example the LOD had to be determined by the need of each discipline guided by the others at the early stages of the project" **SD131I**.	
D	-"Based on my role, I expect the models to have been through clash detection-then be glassed boxed for peripherical clash detection" **D221Q12** -"Sort of agree – but feel compliance could be too late in process" **D221Q24** -"I have no preconceived objectives, however in accepting some clashes it could prove a useful evidence based approach" **D221Q33** -"So, you could. It also the bridge moves, it flexes, drainages move, thermal, seasonal. You could put at this stage you could exaggerate certain things to give you tolerance". **D221I** -"When you get integrated detail, it might be prudent that in early clash detections you have a little glass box around that part that is slightly greater diameter so instead of a 100 mil, you are putting 120." . **D221I**	-"Can be better adopted based on complexity of the project/engineering" **D221Q14** -"Does not "glass box"" **D221Q22** -"It could improve certainty of the detail earlier" **D221Q33** "I move for periodic clash detection. For me is taking away uncertainties and removing risk and is adding assurance. But I think that they should be on an informed frequency." **D221I** -"What about maintainability. You put a gully next to there is between two and a half meters across. Who is going to check it, how are we going to get to it? Spaghetti junction designed where you cannot change the bearings. It´s probably beyond your scope, but my view is it supports periodic clash detection. With better parameters around, what are doing those, is an informed criterion." **D221I (Informational)**

Table C-0-9: Questionnaire Qualitative Results - PEU

	Theme 2 E202: Perceived Ease of Use **Sub-theme: Waste time, cost, human resources.**	**Theme 2 G202: Perceived Ease of Use** **Sub-theme: Waste time, cost, human resources.**
BM	-"All done at the same time" **BM151Q24** -"Only a few workshops at the end of the project" **BM151Q34** -"I've got the LOD is only to find the end of the project at the end of the stage which means it is not controlled throughout the project stage clash carried out at the end of the stage will produce more clashes and will require more rework rework in the design. You know going to have a negative impact on times cost and quality." **BM151I** -"The LOD is provided throughout the stages is not defined, is only defined for the end of the stage. Therefore, we know that the clash detections are not going to be as control from a management point of view." **BM151I** -"I find the LOD100-500 easier to comprehend and visualize on MPDT than the NBS1-6, because with the AIA system 200 is always generic, 300 always specific etc. whereas NBS definitions are less consistent and clear" **BM341Q14**	-"so actually having the level of detail and level of information mature between the stage -"As per client requirements" **BM151Q24** "Yeah, it's like dealing with wicked problems. It's a bit more of a you know overlapping of tasks and more exchanges of information. That's the management is more complicated. Yeah. This this one is more just like a data dump at the end." **BM151I** "It would be easy to make the document. It's always made it 90 percent of the stuff is right communication and communicating with the team and making sure that they understand it". **BM151I** There's probably gonna be the design leads and the design manager "which can you know come up with a design program and then and then you push your MPDT around that here and that's what what are the key dates in the design program for each discipline for each its system." **BM151I**

-“E202 doesn´t really say something about level of coordination”. **BM342Q12**

-“Agree but is insufficient”. **BM342Q2**

-“I am not fully using it”. **BM342Q33**

-“The LOD is only defined for the end of the project stage. Therefore, clash detection throughout the project stage will not be undertaken to the desired LOD”. **BM511Q12**

-“The process is more linear with less key dates to e achieved, therefore easier to understand”. **BM511Q25**

-“The LOD which is provided throughout the stage is not defined, it is more difficult to make use of clash detections throughout the stage”. **BM511Q32**

-“Detecting all clashes at the end of projects can cause unnecessary work, while doing it during the project allows changes to the model during design” **BM151Q32**

-“E202 + granularity in maturity development” **BM341Q15**

-“It´s a step forward in comparison to E202”. **BM342Q14**

-“Hard to say milestone definition is going to be key for success”. **BM342Q23**

-“It´s going to be easier to focus on certain aspects and add more value”. **BM342Q34**

-“The LOD is defined for the end of the project milestones. Therefore, clash detection throughout the project stage will be undertaken to the desired LOD”. **BM511Q14**

-“Thee process is more complex which requires with more key dates to be achieved. Therefore, harder to understand and communicate”. **BM511Q22**

-“The LOD which is provided throughout the stage is defined at specific milestones, it is therefore more easy to make use of clash detections throughout the stage”. **BM511Q35**

“The challenge will be to set the rule right most milestones that are actually really valuable to the project. Yeah. And then not going to be

		really pretty."**BM342I**
BC	-"Simple to use but will be very last minute " **BC151Q13** -"Know by what point everything needs to be and everything seems more in sequence " **BC151Q25** -"Set dates and times" **BC151Q35** -"Easy to follow, simple workflow" **BC341Q24** -"Most developed model at a place" **BC341Q34**	-"Client requirements, they only care about the end point" **BC151Q25** -"There are aspects I like of multiple management systems" **BC151Q33** -"Repetitive process although more complicated than E202" **BC341Q24** -"Clashes identified before the end of each phase and before meeting" **BC341Q35**
SD	-"As said before, easy to detect but not as soon as desired"**SD221Q15** -"Because there is not any degree of coordination ."**SD131Q11** -"Because only one LOD is assigned at the end of the stage, but there is a risk associated to leave the LOD coordination process unmanaged ."**SD131Q24** -"Because the clash is very easy to see" **SD131Q35** -"... Or that there is not going to be drainage here, it goes the other way or not. It is necessary or not that ... Then it has conditioned all the design of the discipline but in the end, they do not have or do not have any value but has conditioned the whole design. Maybe it has had a greater cost because to accommodate your discipline you had to adopt a better solution, maybe a little more expensive or more complicated but in the end, it was not necessary and it can be a drawback. Because maybe there is a problem if you do not do any interdisciplinary meeting	-"Learning and understanding how it works seem to be easier to implement. To make it work all the teams should become aware of its importance" **SD221Q24** -"As said before, it seems easier to understand the process rather to implement it"**SD221Q33** -"Is difficult to know to what level of information each discipline needs to develop the model at each time" **SD131Q12** -"Is difficult to know to what level of information each discipline needs to develop the model at each time" **SD131Q22** -"Is the only way of coordinating disciplines. One of them can be regarded as a tool to coordinate disciplines whereas the other is not a tool" **SD131Q34**

	throughout the project only at the end you find a problem, but it can give an easier solution than the one it would have been given adapting everything." **SD131I**	
D	-"In my role it is difficult to get designers to extend the … of clash detection " **D221Q12** -"No effective experience" **D221Q23** -"Agree on the basis – I encourage wider consideration of clash detection" **D221Q34** -"It doesn´t need to be a unique role that is necessarily digital. We are having that discussion at the moment. It´s people who can look at a drawing or a model and look at it through a different t set of eyes. A set of risk and uncertainty eyes." **D221I**	-"In my role it is difficult to get designers to extend the … of clash detection " **D221Q12** -"No effective experience" **D221Q23** -"Agree on the basis – I encourage wider consideration of clash detection" "Any workshops should add benefit" **D221Q34**

Table C-0-10: Questionnaire Qualitative Results - ICU

	Theme 3 E202: Intention to Continue to Use **Sub-theme: Waste time, cost, human resources.**	**Theme 3 G202: Intention to Continue to Use** **Sub-theme: Waste time, cost, human resources.**
BM	"Granularity of G202 is attractive. Not always our option to choose the system used on a project" **BM341Q13** -"Not really useful". **BM342Q11** -"See above". **BM342Q21** -"Not sure what a standard management method in this context would be". **BM342Q33** -"The management process in relation to uncontrolled LOD are not reflective of the iterative design process". **BM511Q11** -"The management process in relation to uncontrolled LOD are not reflective of the iterative design process". **BM511Q21** -"The management process in relation to uncontrolled LOD are not reflective of the iterative design process". **BM511Q31**	-" if it became more widely used... and more people understood it, then I'm sure it'd be a lot easier to use but I think to manage it would be quite a challenge". **(Communication)** -"As per client and project requirement" **BM151Q24** -"It allows clashes to be detected during design avoiding unnecessary work" **BM151Q34** -"I would prefer it above E202". **BM342Q14** -"Not sure what a standard management method in this context would be". **BM342Q33** -"The management process in relation to controlled LOD are reflective of the iterative design process". **BM511Q14** -"The management process in relation to controlled LOD are reflective of the iterative design process". **BM511Q24**

		-"The management process in relation to controlled LOD are reflective of the iterative design process". **BM511Q34**
BC	-"Not frequent enough" **BC34112** -"Often, the quickest method and done before large model issues" **BC341Q24** -"Clash detection should be done continuously" **BC341Q32**	-"Clients won´t see the benefits for themselves" **BC151Q22** -"I would like to test as I see personal benefit" **BC151Q34** -"Is something we already do typically" **BC341Q15** -"Is something we already do typically" **BC341Q25** -"Regular clash detection save time remodeling and repeat clashes in meeting" **BC341Q35**
SD	-"It could be standardized to be flexible". "Flexibility in the requirement of geometry information of each element ... you cannot define it because each project is different". **SD131I (Informational)**	-"But I would need further training"**SD221Q14** -" Because it forces disciplines to work more between them. I will would use it if there is a high risk in case of clashing." **SD131Q14** -" Because people are used to work independently, and my company works in big size projects where is difficult to coordinate disciplines **SD131Q22** -" Depends on the project and the risks associated" **SD131Q33** "A drawback may be that all decisions are taken, and all disciplines are changing their designs depending on the other and at the end of the project can happen that a discipline maybe due to an external element or contract or by an external element of the client or any other issue... Maybe this discipline is removed in the project, is no longer necessary or has been decided not ..." **SD131I**

D	-"Personally I think emerging techniques will come to the force – perhaps instant automated" **D221Q22** -"Personally I think emerging techniques will come to the force – perhaps instant automated" **D221Q32** -"It depends on whether the associated problems are easy to solve or it implies redesign, if this is the case, I wouldn´t use it. But if they are easy to solve or is improbably that it makes an impact on redesign, I would use it, **SD131Q13** -"If there is an elevated risk associated to redesign, I wouldn´t use it." **SD131Q33** However, another type of contract that is not a design and built. If the design is independent of the contractor, it would not be necessary to establish a design milestone because we already design in the most efficient way or in the way that the client wants and then the contractor must see if it costs the contractor more or less. **SD131I**	-"Personally I think emerging techniques will come to the force – perhaps instant automated" **D221Q22** -"Personally I think emerging techniques will come to the force – perhaps instant automated" **D221Q32** -"For example, in the methodology that establishes milestones? Maybe if you are doing a design and built in which your design is linked with the contractor because you are together in the project. Maybe there is a stage or milestone that should be the price, because to present the BIM and put it in that project you need the cost of what you are going to build. So maybe a milestone should be, we are designing but there had to be a milestone in a moment where with this minimum information we need to be able to get a price because it is needed by the contractor and we work together shoulder to shoulder" **SD131I**

Appendix D

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LOD OBJECT CONTENT SPECIFICATION FOR MANUFACTURERS WITHIN THE UK USING THE IDM STANDARD

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SUMMARY: *UK manufacturers are gradually embracing the adoption of Level 2 Building Information Modelling (BIM) standards (3D models and embedded data) within their product model elements. However, these are not always well defined due to inaccuracies related to the scope and the content of the model attributes. Product Data Templates (PDTs) are currently being created as a solution to provide structured model element data to manufacturer's clients. However, defining PDTs data has been particularly challenging for manufacturers, as there is a scarcity of content knowledge which includes BIM uses (i.e. electrical design) and processes (i.e. cable tray sizing) that support client's lifecycle processes. Similarly, few studies have investigated the Level of Development (LOD) that manufacturers should use to create their model element product data. In this paper, we therefore propose a generic industry approach to create and maintain model element product data at different LODs using the Information Delivery Manual (IDM) and we evaluate it for future improvement. The IDM can capture processes at the informational (i.e. attributes), behavioural (i.e. project stage), organisational (i.e. actor), and functional (i.e. business rules) level. A case study on Made to Stock Products for the Design use has been created to drawn recommendations for the behavioural and informational IDM perspective. In order implement the LOD on an industry basis and for its ease of use, we recommend matching the IDM Exchange models to a LOD graphical standard and keeping the BPMN free of stage bindings. This issue should be further studied for standardisation purposes. The benefit of this approach is that manufacturers could use the IDM to create product model element data in relation to their client's processes at different LODs for its inclusion within BIM Information Systems (IS).*

KEYWORDS: *Building Information Modelling, Level of Development, Exchange Model, Model Element, Industry Foundation Class, Model View Definition, Information Delivery Manual, Product Data Templates.*

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1. INTRODUCTION

BIM, as defined by the "BIM Task Group", is based on value creating collaboration which involves different stakeholders in the management of the assets and the exchange of 3D models and structured data through the entire life-cycle of the project (BIM Task Group, 2014). BIM can be considered as an Information System (IS); a database of the project where product data can be stored and retrieved to support Architectural, Engineering and Construction (AEC) processes (Berard and Karlshoej, 2012). This implicitly requires Knowledge Management (KM) techniques for the information and knowledge to be organised, created, shared and distributed by the upstream agents of the supply chain, the product manufacturers. Within the BIM manufacturing context, KM acquires the form of product library management, enabling tacit and explicit knowledge to be reused within the AEC organisations' IS. Tacit knowledge could be regarded as experience driven knowledge which is not easy to formalise and communicate within IS and explicit knowledge which is considered codified knowledge easily transferred within IS (Woo et al., 2004). The transition from tacit knowledge to explicit knowledge is the focus of the present research.

Until recently, the relationship between the IS function and BIM product model elements was not of much interest to UK manufacturing companies. In the past few years, however, several things have changed in the UK to make the relationship between the BIM product model element development set and the IS set more important. These are government documents based on the Bew and Richards BIM maturity levels. The Bew & Richards maturity model (BSI, 2013) is a useful tool for exploring the level of BIM deployment within the UK. Given that the focus of this research is on BIM maturity implementation for manufacturers, the examples given are within the following context: Level 0; paper product specifications and paper drawings, Level 1; paper product specifications, 2D and 3D "Computer Aided Design" (CAD) objects, Level 2; electronic product specification data embedded within 3D BIM objects (library management and file based collaboration) and Level 3; enhanced interoperable data exchange of 3D BIM objects (Integrated web services, BIM hub). To clarify, a desired state of interoperability can be defined as the exchange of information between multiple parties that use different software vendors without the loss of information, thus enabling collaboration (Steel et al., 2012).

The first of these drivers is the "Government Construction Strategy" level 2 BIM pull approach that mandates electronic product specification data embedded within 3D BIM objects (library management and file based collaboration) on its projects by 2016 (Cabinet Office, 2011). Second, the "Digital Built Britain Level 3 Building Information Modelling Strategic Plan" which recommends the enhanced interoperable data exchange of 3D BIM objects (Integrated web services, BIM hub) (HM Government, 2015). Third, the UK "PAS 1192-2-2013 Capex" Level of Definition that provides a definition of BIM model progression along the different stages of a project to be referenced by model specifiers (BSI, 2013). Because of these changes, there is increasing concern on the part of manufacturing BIM management that BIM product development integration within IS could succeed.

Despite this perceived need for product model element data integration within IS, few manufacturers provide product model elements data to be used effectively within IS. For example, according to the "BIM Adoption by Product Manufacturers" survey conducted by the UK "BIM 4 Manufacturers and Manufacturing" (BIM4M2) workgroup in 2014 (BIM4M2, 2014), 52.6% of the manufacturers reported that they were uncertain about what BIM object content requirements (see TABLE 8) and its associated uses (see FIG 5) were providing to the rest of the supply chain. In other words, which LOD they were using to create their BIM objects. This problem not only affects the UK, but also other countries. For example, the "Australian and New Zealand Revit Standards" (ANZRS) suggest that the lack of knowledge in BIM object content is a result of the manufacturer not being informed of the typical design workflow and the consequential model requirements (Van Kolck et al., 2012).

If several guides which specify BIM model element LOD data by model users are available (see TABLE 1), then the obvious question is why are so many manufacturing firms uncertain about the content of BIM object requirements? Could it be that in those firms which are trying to plan their BIM content unsuccessfully, information was not perceived to be accurate, beneficial or easy to integrate? To better understand the context of KM implementation for the creation of BIM product libraries, section 1.1 and 1.2 explains the method currently used to organise, create, share and distribute the manufacturer data for Level 2 BIM and Level 3 BIM purposes within the UK.

TABLE 1. Non-exhaustive list of LOD attribute guidelines.

Year	Organisation and standard name	Model Element Definition	Inherited from
2010	[VA]The VA BIM Object Element Matrix Manual Release v1.0 (attributes) (VA CFM, 2010)	Level of Development	[AIA] 2008
2012	[NYC DDC] BIM Guidelines (NYCDDC, 2012)	Level of Development	[AIA] 2008
2014	[USACE] Minimum Model Element Matrix M3 v1.3 (attributes) (USACE, 2014)	Level of Development (accuracy) and grade	Not Found
2015	[AGC, AIA, BIM Forum] LOD Specification v2015 (attributes) (BIM Forum, 2015)	Level of Development	2013 [AIA], [AGC, AIA, BIM Forum] 2014

1.1 Product Data template

Product Data Templates (PDTs) are created by the Chartered Institute of Building Services (CIBSE) as a solution to avoid manufacturers completing bespoke data sheets for contractors and designers. These templates are a standardised data repository for every product type (see TABLE 8 for an example). The idea behind the PDT is to have a standard form, which can be populated with data from the manufacturer and become a non-graphical description of the product (CIBSE, 2015). Currently, successful BIM product library management implies the integration of manufacturer's PDTs within the downstream supply chain agent's IS. The following non- linear steps are needed to integrate the PDT within the AEC IS (see TABLE 2 and FIG 1):

- Collect knowledge: Manufacturer product specification data (explicit Knowledge) is selected to be included within the PDT. The data is organised into sections, horizontal rows in TABLE 8, which corresponds to predefined BIM uses. The CIBSE oversees the creation of the PDT, which should be elaborated in collaboration with manufacturer's experts for a specific product (CIBSE, 2015).
- Record Knowledge: The PDT vertical value column (TABLE 8) is filled with manufacturing data. While, the previous step consisted on gathering attributes from paper specifications, this stage defines the attributes with parameters (text or numbers). When this process is finished, the PDT becomes a Product Data Sheet (PDS) (CIBSE, 2015).
- Store knowledge: The PDT is stored within the CIBSE website. Manufacturer's PDTs for different construction products are published within the CIBSE website: http://www.cibse.org/knowledge/bim-building-information-modelling/published-pdts. Manufacturers should then download the PDTs from the CIBSE website and complete the value column as shown in TABLE 8. Manufacturers then become responsible for the accuracy and completion of the data, which can be shared with clients from their company websites (CIBSE, 2015).
- Share knowledge: The next phase needed to complete the BIM IS data is to create a Product Data Set (PDS). Designers can download the PDS from the manufacturer website. Once the PDS is in possession of the designer, the data is sourced and downloaded into the project. This PDS is contained as an Extensible Markup Language (XML) spreadsheet which makes the information interoperable and manageable electronically (CIBSE, 2015).

TABLE 2. PDT Information System implementation description.

	Collect knowledge	Record knowledge	Store knowledge	Share knowledge
PDT knowledge collection process scenario	Data collection: Manufacturer BIM manager and CIBSE experts	XML Excel spreadsheet	Manufacturer Website	Revit model + XML data

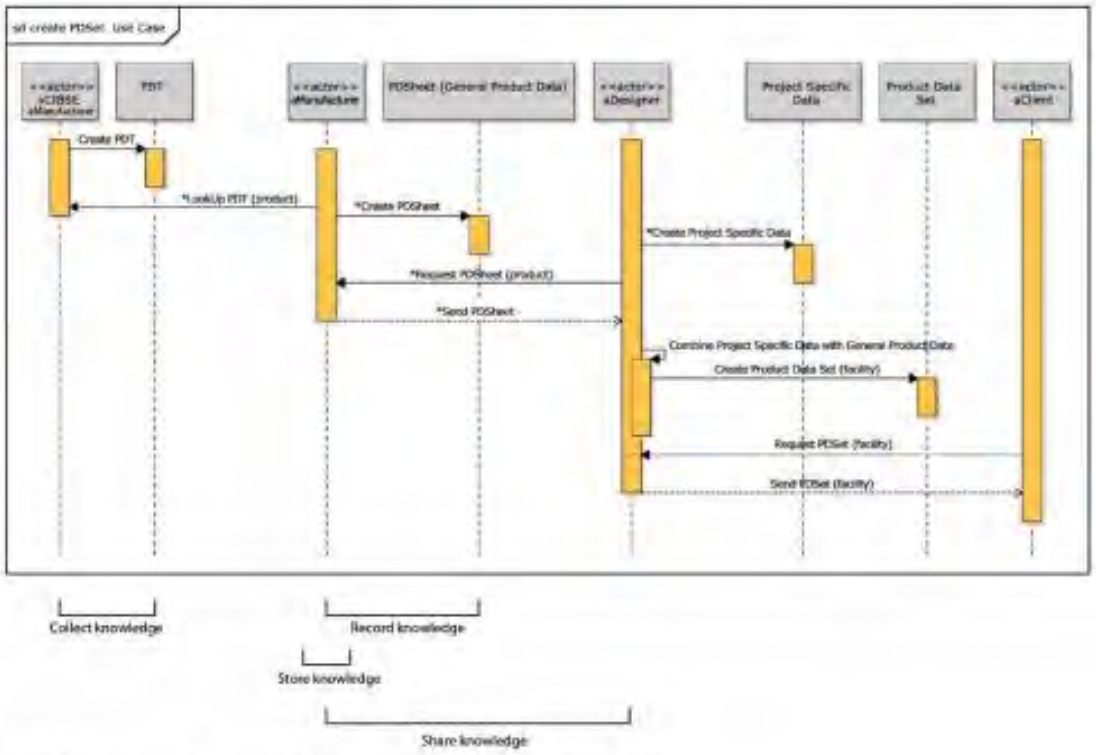


FIG 1. Sequence diagram of the PDT integration within the AEC IS.

1.2 Information Delivery Manual

While the PDT is a solution based on collecting data from paper product specifications and transcribing them into an electronic XML format, the IDM provides a framework for the creation and maintenance of BIM object data to be included within IS. According to Berard and Karlshoej (2012), IDM is a business process modelling language based on the Business Process Modelling Notattion (BPMN) which consists of the following perspectives (see FIG 2): *"process map (behavioural), narratives (organisational), exchange requirements (informational), and narrative business rules (functional)"*. Curtis et al (1992), further explains these dimensions:

- The behavioural perspective represents when the processes are performed (i.e. project stage) or how they are performed (i.e. feedback loops).
- The organisational perspective represents which agents perform the process elements (i.e. engineer, architect, and so forth).
- The information perspective represents the information entities produced by a process (i.e. attributes such as weight or object type).
- Finally, the functional perspective represents what information entities are important for that process (i.e. window width).

A review on the BPMN 1.1 conducted by Recker (2010), provided insights about the way BPMN was implemented for process modeling. Three of the perspectives (functional, behavioural and organisational) had scope to improve, while the information perspective was not studied. Similarly, a review carried out by List and Korherr (2006)

raised concerns about the implementation of the organisational and informational perspective. Berard and Karlshoej (2012) sustain that the IDM language was proposed to overcome the BPMN 1.1 shortcomings.

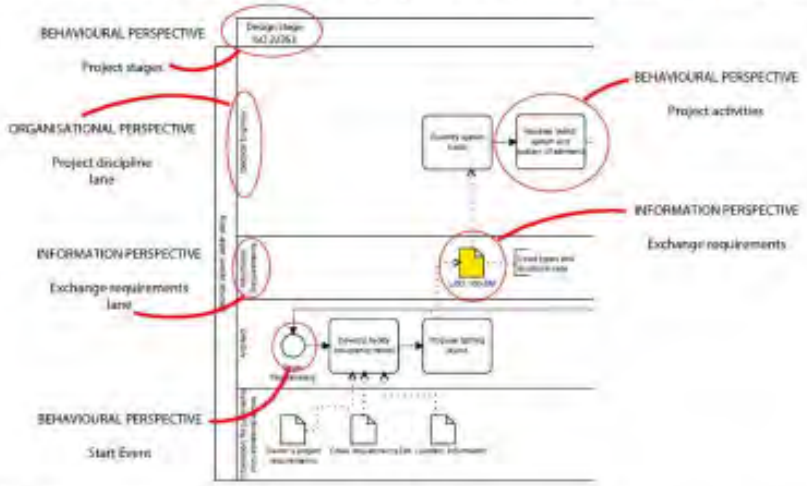


FIG 2. IDM BPMN perspectives adapted from Aram et al. (2010).

The IDM is a business process modelling language needed to certify Industry Foundation Class (IFC) Software (Wix and Karlshøj, 2010). Since the publication of the IDM (ISO, 2010), several business processes have been captured using the IDM specification. For instance, the IDM has been used in a research study to capture precise data and processes for architectural precast concrete (Eastman et al., 2010). Model View Definitions (MVD), which are subsets of the IFC format are documents used by software developers for IFC implementation within interoperable software (Wix and Karlshøj, 2010). It has been demonstrated that the MVD requires a clear definition of the IDM Exchange Models (EM), which are information exchanges (see FIG 2) between tasks and processes (Nawari, 2012). In relation to this fact, authors such as Eastman et al. (2010) and Eastman and Sacks (2010) argue that data sets could be used without the required binding of data to a data structure required for the creation of MVDs, thus easing the IDM development process. Therefore, within the present research, the IDM provides a simple framework (see TABLE 3) needed to capture data from processes to be incorporated within BIM models for Level 2 purposes. For example, 3D models and XML data. The IDM also sets a starting point from which to develop Level 3 BIM interoperable data.

Wix and Karlshøj (2010) defines the steps needed for the creation of data sets and its inclusion within information systems: (Wix and Karlshøj, 2010). These steps are summarised in the following point:

- Create knowledge: The process map creation process requires a collaborative team of industry professionals. The process map will represent a business process (from a behavioural and organisational perspective), where the data sets or exchange requirements are identified by industry professionals (information perspective). Finally, if required, business rules (functional perspective) are defined to determine properties or attributes to be asserted or to control its values.

TABLE 3. IDM Information System implementation description.

	Create knowledge	**Record knowledge**	**Store knowledge**	**Share knowledge**
IDM knowledge creation process scenario	Data mining using the BPMN: Manufacturer BIM manager, Industry specialist and CIBSE experts	XML Excel spreadsheet	Manufacturer Website	Revit model + XML data

2. RESEARCH PROBLEM

The PDT elaboration process claims to be a methodology to provide accurate product data for its inclusion within IS. As mentioned within the introduction, there are several drivers within the UK that urge manufacturers to classify product specification data according to an LOD classification (Cabinet Office, 2011, HM Government, 2015, BSI, 2013). However, PDTs are not created with the aim to specify LOD data. The present research aims to explain the LOD integration process within manufacturers' IS. TABLE 2 and TABLE 3 show two LOD implementation frameworks which differ on its approach to data implementation (collection and creation of data respectively). FIG 3 shows the PDT knowledge collection process scenario which requires collection of data from manufacturer paper product specifications and LOD attributes guidelines such as the LOD Specification v2015 attributes table or the VA BIM Object Element Matrix Manual Release v1.0 among others (see TABLE 1).

However, the attributes found within these guidelines (see TABLE 4 for an example) are not sufficient to accurately define a BIM object LOD. For example, the VA BIM Object Element Matrix Manual release v1.0 provides LOD attributes for general products such as electrical equipment. However, specific products such as cable trays (found within manufacturer's product specifications) would require specific attributes (gauge, finish or maximum load), which might differ from the attributes given within these guidelines. Furthermore, these guidelines do not provide the data context (processes). Therefore, complicating the manufacturer's task of LOD specification.

TABLE 4. The VA BIM Object Element Matrix Manual release v1.0 compared against Legrand's Electric Ltd. cable tray product specification.

Physical Properties of BIM Objects & Elements	
Electrical Equipment attributes (VA CFM, 2010).	
100	Overall Length, Overall Width, Overall Height, Overall Area, Overall Volume
200	Length, Width, Height, Area, Volume, Maximum Size
300	Nominal Size, Connections, Capacity, Perimeter, Angle, Plane, Cross Section
Cable Tray lengths attributes (Legrand Electric Ltd., 2016)	
	Gauge, Width, Weight, Finish, Maximum load

When there is no data available within any of the TABLE 1 guidelines, it could be concluded that there is no solution to LOD specification (see FIG 3). If the LOD attribute guidelines were reliable enough to clarify BIM object attributes in terms of BIM uses, manufacturers would be in a position where they could specify their own BIM object content. Therefore, within this study we aimed to test whether the IDM BPMN could create the right scenario to specify LOD product data to be implemented within manufacturers' IS.



FIG 3. Process for PDT LOD data collection.

2.1 Previous studies

While LOD BIM uses has been studied within the literature, for example "Cost" (Wood et al., 2014), "4D BIM" (Han et al., 2015) or "Sustainability" (Maria-Angeliki et al., 2014, Wu and Issa, 2015), the cited research does not establish a study of the attributes that the manufacturers BIM objects should contain to serve BIM life-cycle uses. Some LOD attributes are found within the "LOD 2015 Element attributes table" (BIM Forum, 2016) and similar

guidelines (see TABLE 1). However, the methodology used to deduct these attributes (see TABLE 4) has not been defined within these guidelines.

Berard and Karlshoej (2012) state that the IDM BPMN has been created with the aim to overcome problems associated with the functional, behavioural, informational, and organisational BPMN perspective. From an informational perspective, research has shown that the IDM BPMN could be used to specify detailed data resulting in more effective interoperable data exchanges (Eastman et al., 2010). Berard and Karlshoej (2012) reviewed the bidding process for a design-built project from the functional perspective and found the IDM suitable for companies to develop business rules and attributes to be implemented within BIM objects. Furthermore, Recker (2010) found flaws within the behavioural and organisational perspective. However, these are claimed to be solved within the IDM by the BuildingSMART guide for IDM development (Wix and Karlshøj, 2010). Despite these improvements, Lee et al.'s, (2016) study suggests that the IDM still lacks some specific criteria for defining Exchange Requirements (informational perspective under the present study). The authors of the present paper had previously proposed that manufacturers could link Exchange Requirements to a LOD specification to create product data (Gigante-Barrera and Ruikar, 2016). Therefore, a criterion based on the LOD standard could help to overcome the inconsistencies in the development of the IDM Exchange Requirements (Lee et al., 2016, Gigante-Barrera and Ruikar, 2016). Current research on LOD has approached it from an applied research perspective; documenting functionality extensions to the core principles of the specification. For example, Wood et al. (2014) recommended using the LOD as a benchmark based on cost curves. Other researchers have also examined the benefits of low and high detailed LODs in design and construction (Luth et al., 2014, Fai and Rafeiro, 2014). In a similar line to the present study, Maria-Angeliki et al.'s study (2014) proposed using the Integration Definition (IDEF) process modelling language to identify critical decision actions and LOD exchanges for building performance analysis processes. Despite previous efforts, LOD integration within the IDM BPMN has not yet been studied. The present study therefore attempts to address it from the informational and related perspectives.

Manufacturers currently face the problem of providing accurate LOD data in terms of scope and content to the rest of the supply chain. The present study therefore aims to: (1) to propose a LOD implementation (IDM process method) within a manufacturing company IS; and (2) to evaluate the technical and business usage context of the implementation.

3. RESEARCH METHODOLOGY

This study requires the researcher to be actively involved in the implementation practices that an electrical manufacturer is carrying out to obtain BIM organisational efficiency within their BIM objects. It also involves evaluating and critically reflecting on the evidence gathered from interviews, workshops and case studies carried out within the case study organisation. This type of research is referred to as Action Research (AR) and is a method that aims to improve peoples' practical concerns (Gilmore et al., 1986). AR within this research context is regarded as the "what" for Organisational Development (OD) which acts as a catalyst for aligning people, processes and practices (Jones and Brazzel, 2014). Within this research, OD is used in order to change a company from an actual State A: "PDT knowledge collection process scenario" to a desired future State B: "IDM knowledge creation process scenario".

AR is implemented in a spiral of steps, each composed of a circular process of "planning, action and fact finding about the result of the action" (Jones and Brazzel, 2014). AR involves data gathering methods and interpretive methods such as interviews, focus groups, observation, simulations, and surveys among others (Jones and Brazzel, 2014). OD is based on a sequence of stages that can be conceptualised into four steps: Start-up, Diagnosis, Intervention and Transition, as shown in FIG 4 (Jones and Brazzel, 2014).

- The "Start-up" stage (section 4.1) within this research consists of a SMART analysis, which stands for "Specific, Measurable, Attainable, Realistic and Time sensitive objectives" (Shahin and Mahbod, 2007). This stage is set up to increase awareness of the company's processes BIM maturity Level and to identify the desired outcome.
- The second stage is "Diagnosis" (section 4.2) and involves establishing whether a change is desirable. Therefore, in the present study, the current approach to LOD creation and its use were investigated. The focus was on the LOD constructs to be implemented within the IDM BPMN.

- The "Intervention" stage (section 4.3), helps the company to adapt to the new paradigm "IDM knowledge creation process scenario". Thus, a case study based on the IDM methodology and LOD was carried out to deduct attributes for the creation of PDTs. The output from this stage is a process used to generically create attributes for its inclusion within IS.
- Finally, the "Transition" (section 5) validates the process through follow up interviews. This stage explains the value and impact of the new paradigm: "IDM knowledge creation process scenario" for the organisation.

The AR approach used is focused on results and it values participation and the manufacturer's contribution, as it assumes their acceptance of the changes associated. In Information Technology applied to construction, AR has been proved useful for investigating IDM creation (Berard and Karlshoej, 2012). This methodology is used within this study to investigate how BIM could affect the interaction between manufacturers and the downstream agents of the building environment and consequently change the current reality of the organisation towards another paradigm not yet defined.

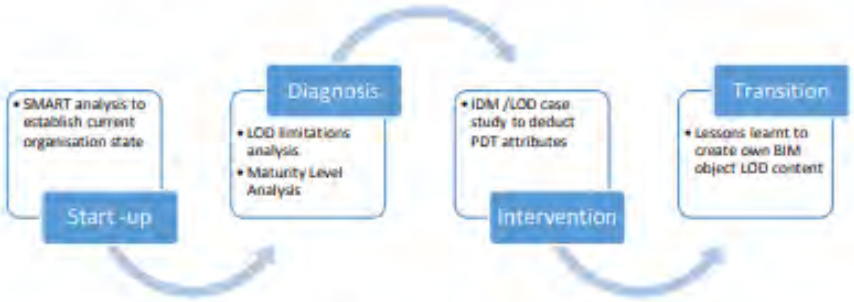


FIG 4. Organisational Development stages within the current research study.

3.1 Intervention stage case study Design

A case study is an empirical method aimed at "*investigating contemporary phenomena in their context*" (Benbasat et al., 1987, Robson, 2002, Yin, 2013). This includes trying to understand the phenomena from an interpretive research perspective, from the participants' point of view (Klein and Myers, 1999). The present case study uses a UK manufacturer to investigate the intricacies of the LOD to specify model element data using the IDM BPMN for its inclusion within manufacturers' IS. According to Robson's (2002) classification of interpretive studies, this case study is exploratory in nature. The research investigates the role of the manufacturing company BIM manager and looks to seek and generate new insights and ideas to create hypotheses for new research exploratory studies.

3.2 Case and subject's selection

The University of Birmingham invited Legrand Electric Ltd. to collaborate with this project in an initial interview. The selection of the company was arranged according to Benbasat's et al. (1987) and Flyvbjerg's (2006) recommendations. The company case study selected is revelatory and unique in the sense that the literature does not document any other approaches to LOD creation from the point of view of manufacturers and product specification data (see section 2.1). A process for specifying LOD data within the manufacturing industry is studied in context. Therefore, the chosen working group consists of a manufacturer BIM manager (responsible for BIM strategy, sales, and knowledge about products), who represents Legrand Electric Ltd. UK, an electrical engineer (responsible for electrical process supervision) from the same company and the researcher (IDM and academic monitoring) from the University of Birmingham, UK.

Berard and Karlshoej's (2012) study on the IDM functional behaviour, uses Supply Management Theory to classify manufacturing products. This classification will be used within this study to generalise the results and identify any limitations within the product studied. The classification is as follows: Made to stock (e.g. Cable tray or drywall), Made to order (e.g. windows) and Engineered to order (e.g. prefabricated concrete). Legrand Electric Ltd. UK Cable Management business unit cable trays, which generally corresponds to Made to Stock products

was studied. This product was studied in conjunction with cables because cable tray BIM models inherit properties from them. Made to Stock product were selected as per availability and easiness to deduct attributes.

4. RESULTS OF THE ORGANISATIONAL DEVELOPMENT PROCESS

4.1 Start-up stage

The target company (Legrand Electric LTD.) is a global electrical product manufacturer with presence in nearly 90 countries around the world. The research group consists of a BIM Manager, an electrical engineer and a doctoral researcher. A SMART analysis was conducted to establish the project boundaries. The conclusions of this analysis are the following: One of the company's objective is to educate itself in BIM processes relating to data exchanges, which in turn will ensure that Legrand can continue to be specified by their key stakeholders. In the case of the UK, the Government strategy requires Level 2 BIM for all public asset procurement (Cabinet Office, 2011). For 2016, the cable management business unit agreed to provide 3D models with non-graphical specification attached to them. To do so, the company engaged with the CIBSE initiative to provide Level 2 PDTs. These contain product attributes such as the ones found within the paper product specifications. Previous processes consisted of providing 2D CAD drawings and paper specifications to their clients, which is known as Level 1 BIM. It was understood that the aim of the meetings was to record the process and extract valuable lessons, drivers and barriers relating to the implementation of BIM using the OD strategy described in the methodology section. This is necessary in order to increase knowledge of their own BIM objects value, which has been found to be contractual support, interoperability support and software development support.

4.2 Diagnosis

This stage is set to share the understanding of the system involving the project and to decide if there is a potential need for change (Jones and Brazzel, 2014). From the outset of the project it was understood that BIM may change some of their processes. As the company's BIM Manger stated: *"BIM has already affected some of the ways in which we are looking at how we deliver data, which is the first step in BIM really, that's delivering that data"* (Gigante-Barrera, 2014). LOD is one of the most cited graphical and non-graphical standards within the literature (Staub-French and Khanzode, 2007, Eastman et al., 2011, Maria-Angeliki et al., 2014, Wood et al., 2014, Han et al., 2015, Hooper, 2015, Wu and Issa, 2015). This is the reason its usefulness for manufacturers has been analysed in section 4.2.1. However, other definitions are available depending on the country or institution which defines it. For example, in the UK, the PAS 1192: 2013 is the guideline used to define the BIM object information referred to as the Level of Definition (BIM4M2, 2014). Both concepts contain intrinsic constructs such as stage, LOD number of definitions and BIM use, which are compared for their inclusion within the IDM BPMN.

4.2.1 USA Level of Development and UK Level of Definition

The LOD to be included within the definition of a BIM object is a critical criterion for manufacturers (BIM4M2, 2014). The *"AIA G202-2013, Project Building Information Modelling Protocol Form"* was created by the "American Institute of Architects (AIA) California Council Integrated Project Delivery Task Force". The "AIA *G202-2013"* LOD allows for "Model Element" specification of content requirements and its associated uses. It is divided into five different progressive levels that specify the detail of completeness within the element (AIA, 2013). Similarly, the "Specification BIM Forum" in the *"Level of Development Specification 2015"* document (BIM Forum, 2015), utilises the AIA LOD definitions found in the "AIA *G202-2013"*. In contrast to the "AIA *G202-2013"*, it expands the AIA's LOD definition by including a LOD 350 required for coordination between disciplines (BIM Forum, 2015). Interestingly, the "*G202-2013"* propose several authorised uses such as "Analysis", "Cost", "Estimating" and "schedule", leaving room to assign other uses by the interested stakeholder (AIA, 2013). While the "*G202-2013"* LOD defines a basic standard, the *"Level of Development Specification 2015"* document, defines and illustrates LODs by product which help teams to specify deliverables. This specification addresses the definition of components by describing requirements. They can be included in contracts and can also help managers to explain to teams which information should be included in the project at different stages (BIM Forum, 2015). As an example, the *"Level of Development Specification 2015"* LOD's description for "Branch wiring System" elements is found below:

- LOD 100 - *"Schematic model element" and "Schematic layout".*

- LOD 200 - *"Schematic layout with approximate size, shape and location of equipment"; "Approximate access/code clearance requirements modelled"*
- LOD 300 – *"Modelled as design-specified size, shape, spacing and location of raceways boxes and enclosures; "Approximate allowances for spacing and clearances required for all specified hangers, supports and seismic control; actual access/code clearance requirements modelled".*
- LOD 350 – *"Modelled as actual size, shape, spacing, and location of raceways, boxes, enclosures"; "Actual size, shape, spacing, and location for supports and seismic control"; "Actual floor and wall penetrations are modelled".*
- LOD 400 – *"Supplementary components added to the model required for fabrication and field installation".*

Similarly, The PAS 1192: 2013 was created by the British Standards Institution in the UK (BSI, 2013). PAS 1192: 2013 includes BIM models descriptions that are articulated around Levels of Definition. These Levels of Definition, which includes narratives, describe the general information that should be included within BIM models. Differently to the "*G202-2013*", the Levels of Definition are linked to project stages, for example the CIC Scope of Services provides a standard classification. The definitions are as follows: Brief, Concept, Design, Definition, Design, Build and Commissioning, Handover and Closeout. TABLE 5 shows graphical 3D BIM models contained within the "Level of Development Specification 2015" and the PAS 1192:2013 respectively. While the first gives specific examples per product, the second provides a general description of what level to achieve at each project stage.

TABLE 5. Graphical comparison of AIA LOD and PAS 1192: 2013 LOD.

Level of Development Specification 2015					
LOD 100	**LOD 200**	**LOD 300**	**LOD 350**	**LOD 400**	
					
PAS 1192:2013					
Brief	**Concept**	**Definition**	**Design**	**Build and Commission**	**Handover and closeout**
					

While the "*G202-2013*" authorises 4 BIM uses and allows the user to define others, there are no authorised uses within the PAS 1192:2013. Nevertheless, the BIM protocol which helps to specify LOD data according to project stages and author, contains a choice of 30 BIM uses (CIC, 2013).

Some studies relate LODs with project stages with the aim of creating a structured process for sustainability design (Maria-Angeliki et al., 2014) or to satisfy energy analysis needs (Wu and Issa, 2015). These studies mainly relate to the idea of an LOD linked to a project stage such as the PAS 1192:2013. Conversely, a study on LOD model

progression using the AIA LOD concept, states that the LOD should be free of stage bindings (Hooper, 2015). Other studies suggest that the LOD depends on the BIM use or application (Staub-French and Khanzode, 2007, Eastman et al., 2011). For example, the "G202-2013" LOD binds the LOD concept to authorised uses as explained previously. From the manufacturers' point of view, BIM object level approaches to LOD are needed in order to take full advantage of BIM objects in terms of value, such as object-based software development (MVD), BIM contractual support (MVD and IDM and LOD) or interoperability collaboration (IFC). FIG 5 shows the variety of possibilities available depending on the LOD concept studied. Three main constructs (stage, number of definitions and BIM uses scope) define the LOD variances. Within the section "Intervention", the researcher used the *"Level of Development Specification 2015"* definitions as a starting point to match graphical and non-graphical information to generate LODs for different BIM uses. The reasons for using this LOD concept relays on its definition of graphical content according to specific products, its clarity on authorised uses and stage flexibility.

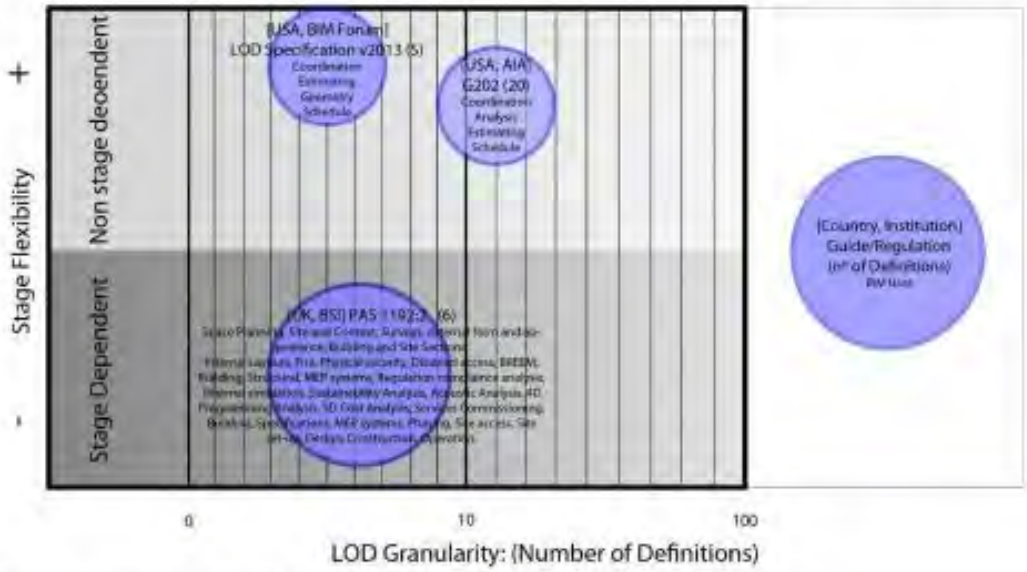


FIG 5. LOD BIM uses, n° of definitions and stage dependency compared.

4.3 Intervention

The OD Intervention stage is regarded as an *"iterative collaborative process of considering alternatives and clarifying the desired outcome"* (Jones and Brazzel, 2014). After presenting the previous research to the company's BIM Manager, the desired goal was to provide data that could support the client's life-cycle processes in a reliable and consistent manner. The process of specifying Level 2 cable and cable tray PDTs by using Level 3 standards such as the IDM was documented. The data was associated with the *"Specification BIM Forum 2015"* LOD in order to connect graphical and non-graphical information in a comprehensive and understandable manner for manufacturers.

A case study was carried out which involved deducting information from a client process (cable and cable tray sizing). The conclusions from the study were incorporated into the company BIM knowledge. The generated data exchanges and associated attributes were used to create a PDT for cable and cable tray manufacturer's products which contains attributes necessary for the electrical sizing use at different LODs.

4.3.1 IDM enabling LOD for Made to Stock products (electrical cable tray case study)

This section focuses on documenting the creation of a LOD for electrical BIM objects. It reviews the IDM specification used to document processes and attributes to advance BIM LOD standard for Made to Stock products. The IDM can capture business processes and the data exchanges associated with them (Chipman et al., 2013). Therefore, in the present research study, the IDM was the basis for data exchange development.

The IDM creation begins with the definition of "Process Maps" (PM) (see FIG 2). In the present research, the PM describes a particular flow of activities within the electrical cable sizing process. PMs are diagrammatically represented as single "pools" and the name of the pool describes the PM. The description and identification of the information from the data involved within the business processes at a particular stage of the project is depicted within "Exchange requirements" (ERs). The workflows scenarios and the ERs between the actors "architects" and "electrical engineers", are represented in single "lanes" contained within the PM "Pool"(Wix and Karlshøj, 2010). This is illustrated in the PM shown in FIG 7. The process of developing an IDM requires a first step of "process discovering and data mining" (Wix and Karlshøj, 2010). The *"Level of Development Specification 2015"* was used to create the case study. FIG 6 shows the geometric progression of a Cable Tray within this study.

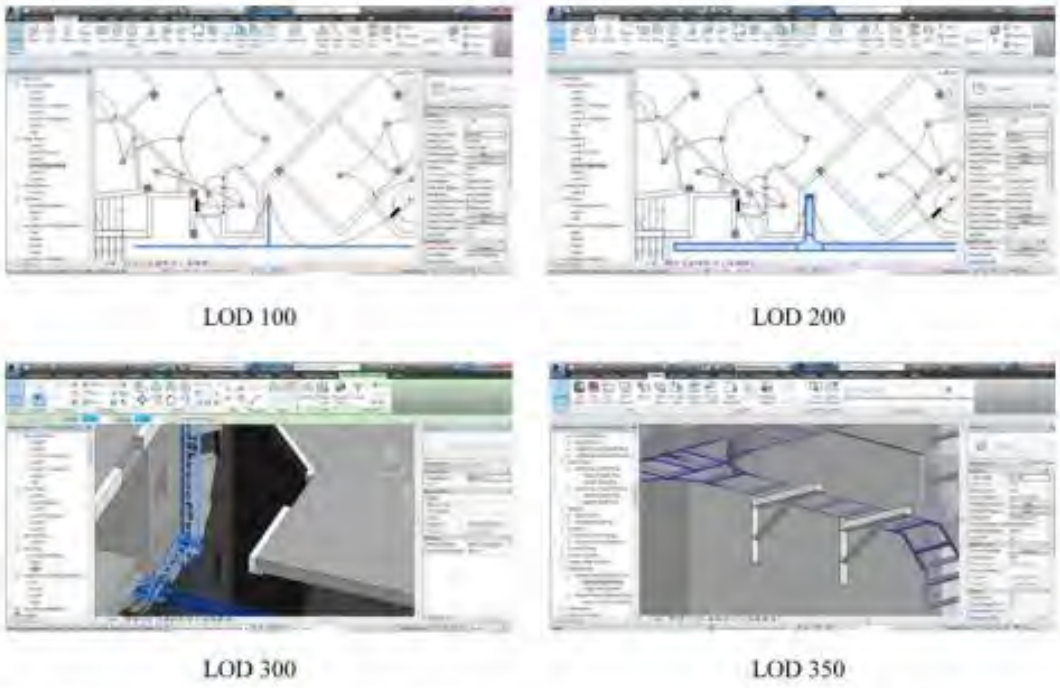


FIG 6. Revit Case study- Cable tray system LOD progression.

"Autodesk Revit 2015" was the proprietary software platform used to create the case study (see FIG 6), as it was found to be the most utilised software in the UK (BIM4M2, 2014). An educational license was obtained from the Autodesk website (Autodesk, 2015b). Cable sizing calculations were carried out by using standards based on the 1) "International Electrical Technical Commission" (IEC) *"IEC 60364 international regulation for residential and similar premises"* (AENOR, 2002, AENOR, 2004) and 2) Revit 2015 specific calculation methods (Autodesk, 2015a). Furthermore, for the Cable tray sizing, the "British Electrotechnical and Allied Manufacturers' Association" (BEAMA) *"Best Practice Guide to Cable Ladder and Cable Tray Systems Including Channel Support Systems and other Associated Supports"* has been consulted (BEAMA, 2014). Finally, in order to replicate the Revit 2015 case study, the research process was based on the UK document, *"PAS 1192-2 Capex"* (BSI, 2013). The process diagram for cable sizing has been depicted using the "Business Process Modeling Notation" (BPMN) (http://www.bpmn.org/) (see FIG 7), adopted by buildingSMART and the NIBS (Nawari, 2012).

The analysis of the "Electrical service and distribution system" sizing and specification, demonstrated that graphical information and non-graphical information are closely related. Both influence each other in an iterative process which involves calculations and the selection of the appropriate system. The connection between processes and the information required at a particular stage of the project is made through ERs. These ER are named by the prefix, which identifies the ER followed by the verb exchange. Lastly, the subject of the ER is expressed as a noun or phrase followed by further qualification of the exchange (Wix and Karlshøj, 2010). The ERs utilised in the case

study has been coordinated with the LOD cable definition from the "Specification BIM Forum Level of Development Specification" (BIM Forum, 2015). This helped to increase understanding of how BIM model's data progresses depending on its level of geometric development (see FIG 7).

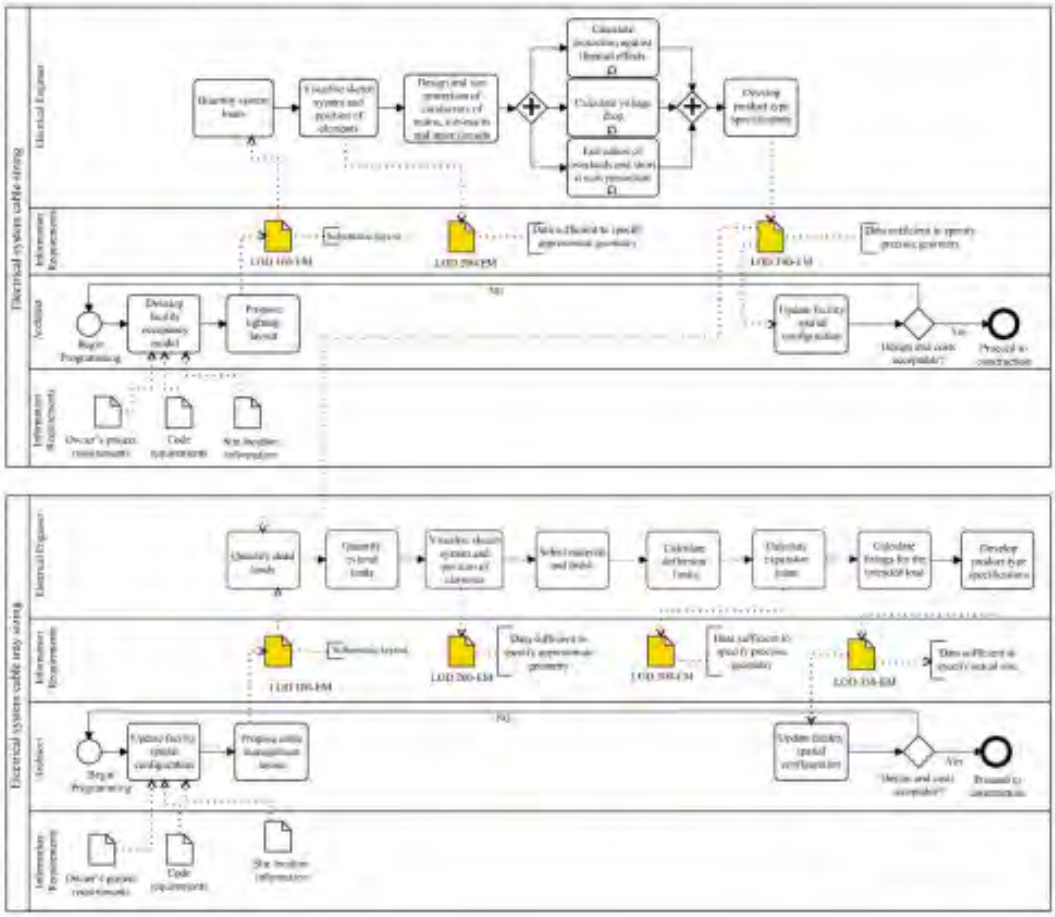


FIG 7. PM for cable and cable tray sizing.

The ER deducted from the case study are the following (see FIG 6 and FIG 7):

For the electrical System Cable sizing PM the following ER are defined:

- er_exchange_schematic_layout_model (LOD 100): Sufficient to create a schematic model.
- er_exchange_approximate_geometry_model (LOD 200): Sufficient to quantify system loads.
- er_exchange_precisse_geometry_model (LOD 300): Sufficient to calculate protection against thermal effects, voltage drops, overloads and short circuit protection.

For the electrical System Cable tray sizing PM the following ER are defined:

- er_exchange_schematic_layout_model (LOD 100): Sufficient to create a schematic model.
- er_exchange_approximate_geometry_model (LOD 200): Sufficient to calculate dead and imposed loads. Attributes providing from the "Electrical System Cable sizing".
  "er_exchange_precisse_geometry_model (LOD 300)" are needed, i.e. Cable Weight (kg/m).

- er_ exchange_precisse_geometry_model (LOD 300): Sufficient to select material and finish, to calculate deflection limits and expansion joints.
- er_ exchange_actual_geometry_model (LOD 350): Sufficient to calculate fixings for the intended load.

The ERs were documented using the "*Information Delivery Manual Guide to Components and Development Methods*". This documentation process is the foundation for IFC and MVD development (Wix and Karlshøj, 2010). As an example, the er_exchange_ approximate_geometry_model (LOD 200) for the cable sizing use is shown in TABLE 6.

TABLE 6. Electrical system cable sizing Exchange Requirement: er_exchange_ approximate_geometry_model (LOD200).

Name	er_exchange_approximate_geometry_model (LOD 200)
Overview	*The scope of this exchange requirement is the exchange of information to enable protection against thermal effects, voltage drop and overload protection calculations. Due to the iterative nature of the calculation process, predefined "Model element" generic attributes can be selected but are not valid to specify elements. Graphical information may be sufficient to specify approximate geometry (i.e. LOD 200).*
Information Requirements	Preconditions *Electrical systems loads will have been estimated. Prior requirement: er_exchange_loads_model (LOD 100)* Information Units: *Cable* *Provides relevant information about the cable* Attributes or properties that must be exchanged: *R= Conductor resistance measured in Ω/m at the service temperature. Reactance of the conductor on a frequency of 50Hz measured in Ω/m, Insulation material, γ: Conductivity (values of 48.11 m/mΩmm2 for cooper), Conductor material, S: section (mm2), Cable temperature. Iz: Current-carrying capacity of the conductor, Ambient temperature, Impedance (Z)*

The creation of BIM object information within this study entailed describing the name of the ER, overview and scope of the requirement and recording the attributes that must be exchanged. The results of this case study are shown in TABLE 7. This table represents the information that two separate Level 2 PDTs should contain for a Cable and Cable tray data exchange for sizing purposes using the PM represented in FIG 7.

However, for the creation of Level 3 standards such as the IFC, the definition of the data can be further developed by describing "Functional Parts", which requires a detailed technical specification of the exchange. IFC capabilities can be represented using the EXPRESS-G Graphical Form (ISO 10303 Part 11). This notation is used in IFC development because the solution provider or software developer can focus on a specific functional part instead of on the full IFC schema (Wix and Karlshøj, 2010). Consequently, the development of the IFC requires a clear definition of the ERs. However, the description of Functional Parts is not necessary for the aim of this study. After deducting the attributes, manufacturers can map them to existing MVDs, for example the SPARKie electrical design MVD (see TABLE 7). This can improve PDTs interoperability while finding paths for IFC development on an industry basis.

TABLE 7. Sizing use. Non-graphical information for Cable and Cable tray PDT.

Sizing use	Cable non-graphical information	SPARKie properties	Cable tray non-graphical information	SPARKie properties
LOD 200	R= Conductor resistance measured in Ω/m at the service temperature	✕	Z= Section modulus of the cross-section of the beam	✕
	X= Reactance of the conductor on a frequency of 50Hz measured in Ω/m	✕	l= Length of the beam (m)	✕
	γ: Conductivity (values of 48.11 m/mΩ.mm2 for cooper)	✕		
	S: section (mm2)	CrossSectionalArea		
	Iz: Current-carrying capacity of the conductor	CurrentCarryingCapasity		
	Insulation material	InsulationStandardClass		
	Conductor material	Material		
	Cable temperature	MaximumShortCircuitTemperature		
	Ambient temperature			
	Z= Impedance	NetImpedance		
LOD 300	Size (mm)	MaximumCableLength	E= Modulus of Elasticity (N/m^2)	✕
	Weight (kg/m)	Weight	I= Moment of Inertia (m^4)	✕
	Single-core or multi-core cable	NumberOfCores	Cable tray material	✕
	Installation method	InstallationMethod	Finish thickness (μm)	✕
			Finish galvanic series potential difference (Volts)	✕
LOD 350			E= Allowable movement expansion joint	✕
			K= Coefficient of linear expansion	✕

5. TRANSITION

The case study created using the "IDM knowledge creation process scenario" was validated in two stages: a quality test on information attributes and a follow-up interview on the usefulness of the BPMN for specifying product data. The participants were asked to review the informational perspective of the IDM BPMN. The data was shared with the Legrand's BIM manager and the Legrand's electrical engineer in XML format. They were asked whether the information from TABLE 7 was relevant to be included within manufacturer IS and was compared with previous PDT attributes deducted using the "PDT knowledge collection process scenario" (TABLE 8).

Furthermore, they were asked to give feedback on the behavioural and organisational perspective of the IDM BPMN for the implementation of the LOD.

5.1 Discussion

The Wix and Karlshøj's (2010) IDM BPMN method from BuildingSmart International was used within the present study to create manufacturer Made to Stock product data. The attributes were transcribed to an interoperable format such the XML. From this format, the data can be incorporated into any proprietary format such as Revit family files. The findings suggest the following steps (see FIG 8) towards the manufacturer's implementation of the IDM methodology for its inclusion within IS:

1) To select manufacturer product. If the product inherits properties from other products, the inheritance should be studied by creating a related process map. For example, cable and cable tray Process Map in FIG 7.
2) To select a BIM use.
3) To select a LOD based on its constituent constructs: stage, actor and number of definitions.
4) To set process map decision points based on product related regulations.
5) To link the chosen LOD with the corresponding set of attributes to create an ER.
6) To record the ER attributes using the *"Information Delivery Manual Guide to Components and Development Methods"*.
7) To include IDM deducted data to PDT (XML format) and find possible mappings to existing IFC data.
8) To select another use for the same product and repeat the process until all the product uses required have been considered.

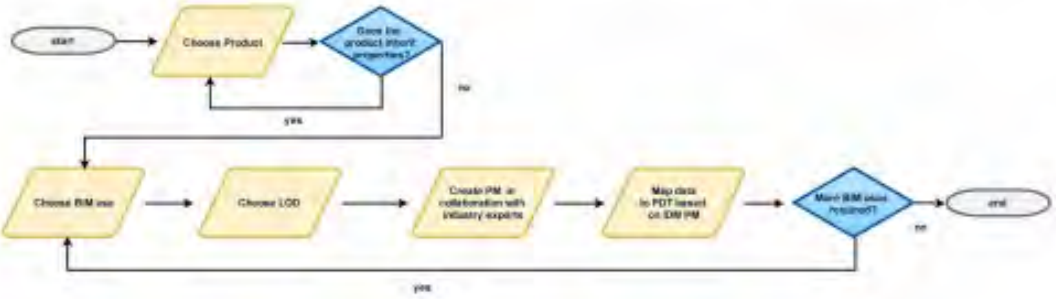


FIG 8. Process for IDM LOD creation.

The "Intervention" stage of the present research study has shown that the IDM can be used as a starting point for agreeing on the definition of the BIM object data. It has been demonstrated that the BMPN is able to capture data exchanges at certain LODs. However, the research group suggested that the IDM BPMN would require improvements in order for the LOD to be implemented within its structure.

Berard and Karlshoej (2012) suggested in their case study on building product data that data resulting from the IDM process should be free of IFC bindings (i.e. data should be exchanged as IFC, Revit files or unstructured documents). The present study agrees that manufacturers would benefit from a less complex process of data creation. Furthermore, we suggest that manufacturers can effectively incorporate IFC attributes to the interoperable XML format for its inclusion within proprietary software BIM models. The case study working group agreed that data value will increase as long as it can be used within proprietary software for data exchanges. That in turn will allow clients to include manufacturer data within contracts. Therefore, this study suggests that the mapping of the

deducted IDM data to existent MVD should be a task of manufacturers, leaving the task of transcribing free binding data to IFC format to software developers as suggested by Berard and Karlshoej (2012).

From the manufacturers point of view, the BIM object should incorporate attributes defined within a current MVD or those created using the IDM BPMN for its future inclusion within a MVD. For example, for the case study working group, it is more important to advance on interoperability of attributes rather than incorporate attributes from manufacturer paper specification which in turn might not be useful for data exchanges. TABLE 7 shows that 10 out of 13 attributes from the Cable product could be mapped to the SPARKie MVD. However, the cable tray attributes needed to design a cable tray were non-existent within the SPARKie MVD. This exercise was useful for raising concerns on the industry´s need to collaborate towards the creation of structured interoperable data for the definition of BIM objects attributes (i.e. cable tray attributes for design BIM use). The use of attribute guidelines such as those found in TABLE 1, together with Process Maps for specific products and BIM uses, would help to specify manufacturer LOD data. The Process Map can be used as a container of tacit data which can be reviewed for future updates, providing the framework that the attribute guidelines on its own did not provide.

However, Berard and Karlshoej´s (2012) study advises against the use of IDM BPMN on an industry basis due to its complexity therefore restricting its use to a project basis. Nevertheless, this study has proved that it could be applied on an industry basis for Made to Stock products. Although Berard and Karlshoej (2012) suggest that there might be thousands of multiple process maps, Made to Stock products design are based on prescriptive regulations such as the *"IEC 60364 international regulation for residential and similar premises"* used within the intervention stage of the present study. This regulation contains the processes needed to design an electrical component, shortening the multiplicity of process required to model the IDM.

Despite having an industry known BuildingSmart International IDM guideline, Wix and Karlshøj's (2010), Gigante-Barrera and Ruikar's (2016) and Lee et al.'s (2016) studies draw attention to the lack of a common standard for defining Exchange Objects. Gigante-Barrera and Ruikar (2016) and Lee et al. (2016) recommends using the LOD to avoid inconsistencies in the development of the IDM. The present study has proved that the LOD could be implemented within the BPMN for the definition of Exchange Models. However, the working group has found that the Wix and Karlshøj (2010) IDM guideline has some shortcomings within the Behavioural (project stages), and informational (attributes) perspective when implementing the LOD to define Exchange Requirements.

The information perspective requires a clear definition of the Exchange Models to deduct attributes consistently along process maps. Eastman et al. (2010) highlighted the difference between Exchange Models and Exchange Objects. Exchange Objects are not documented within the IDM guide and are defined as building blocks for defining Exchange Models. While the Exchange Models identifies the information set exchanged, the Exchange Objects are atomic definitions of the information sets that are to be exchanged. The Exchange Object definition might vary depending on the level of detail of the exchange object defined as per stage. While, Eastman et al.'s (2010) Exchange object definition process requires preparing the field for MVD development, thus overcomplicating the IDM development (i.e. defining functional semantics, relations and property sets for each exchange object), the present study proposes that it is kept relevant to property exchanges. We suggest that a simple method free of IFC bindings is beneficial to end users such as manufacturers as their interest remains only on defining consistent attributes agreed on across the industry.

Recker (2010) analysed the BPMN use and found that the BPMN 1.1 needed an approach to specify Pool and Lane meaning. Recker (2010) proposes workarounds such as restricting the meaning of the BPMN Pool and Lane constructs. While Berard and Karlshoej (2012) sustain that the IDM language was proposed to overcome the BPMN 1.1 shortcomings, the present study has found that an effort needs to be made on defining Exchange requirements in future releases. This is in line with with Gigante-Barrera and Ruikar's (2016) and Lee et al.'s (2016) research which recommends keeping the Exchange Requirements relevant to a standardised LOD. For example, the AIA or the PAS 1192 provides a standard way to express Exchange Models in a consistent manner. However, while the geometric information is well defined within the AIA, the PAS 1192 uses a more generic approach (see TABLE 5). Similarly, in both cases, the detail of the LOD non-graphical data (BIM object attributes) is either non-existent or insufficient to define exchanges (see TABLE 4). Therefore, a common industry solution should be given to define Exchange Requirements in a consistent way if the IDM aims to be deployed in an industry basis. As seen within the diagnosis stage, the selection of the LOD should take the following intrinsic constructs

into account: stage, number of definitions and actors (see FIG 5). The wide range of options could affect the behavioural perspective of the BPMN.

The behavioural perspective is well addressed within the BuildingSmart International IDM guideline (Wix and Karlshøj, 2010). In line with Recker's (2010) recommendations, the meaning of project stages was restricted. For example, to clarify project stages meaning, the IDM guide utilises a list of stages based on the Generic Process protocol (Wix and Karlshøj, 2010). However, this study uses the LOD as a standard to define Exchange Requirements. Therefore, the BPMN should adapt to this change. In order to reduce required Process Maps and for its ease of use on an industry basis, this study proposes keeping the Process Maps free of stage bindings. For example, the design of a product could take place during the design stage, construction or during the maintenance stage (Kreider and Messner, 2013). Trying to map LODs Exchange Requirement to project stages might overstrain the data specification process and require mapping more processes than required to find a general solution. Furthermore, Hooper's (2015) study on LOD model progression states that the LOD should not be restricted to project stages. For example, a cable tray LOD 100 might be specified during the design stage or during the construction stage. It is up to the project specifier to organise the data as the project progresses (CIC, 2010). Therefore, the IDM BPMN should be free of stage links when specifying LOD data on an industry basis. To accomplish this, the PM created should be specific enough to include only the product studied, related products (i.e. inherited attributes) and a defined BIM use (see FIG 8).

6. CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE RESEARCH

Manufacturers have difficulty in specifying BIM objects' data using the LOD (BIM4M2, 2014), which requires an in depth understanding of product content requirements (attributes) and BIM uses (ie. Facilities Management) (Van Kolck et al., 2012). Currently, Level of Development (LOD) data specification is not feasible as the method used to populate BIM objects with manufacturer data is based on compiling data from paper product specifications or LOD attributes guidelines which are not precise in terms of scope (BIM use) and content (attributes). UK manufacturers need to be capable of modelling business processes for their products using the LOD standard for data specification. The present research outlined the development of a novel approach to deduct parameters associated with the LOD. The study tested and validated the use of the Information Delivery Manual (IDM) to specify Product Data Templates (PDTs) attributes and its associated geometric data by linking Exchange Requirements (ERs) to a LOD standard. The case study carried out during the intervention section demonstrated that the IDM Business Process Modelling Notation (BPMN) developed by Building Smart is not completely suitable for modelling LOD data associated with Exchange Requirements due to the variety of the LOD intrinsic constructs and its impact on the informational and behavioural perspective of the IDM BPMN.

The aim of the present study is not to discredit previous efforts on LOD specification but to try to give a valuable tool which could be used by manufacturers to specify product data on an industry basis. For this reason, we have created a novel method validated within an exploratory case study to seek and generate new insights and ideas for future exploratory studies. Therefore, a case study on Made to Stock products (e.g. Cable tray and Cable) was developed to better understand the intricacies that affect the LOD creation using the BPMN. This in turn will help to add to the current knowledge on BPMN and allow manufacturers to model their product processes using the LOD specification. The creation of Process Maps for specific products will give the context that previous LOD attribute guidelines failed to provide (see TABLE 1 and TABLE 4).

In order to understand how the LOD specification could adapt to the current IDM BPMN, we simulated the inclusion of BPMN deducted data into a manufacturer's IS through a case study. The case study was carried out within an electrical product manufacturing company (Legrand Electric LTD.) and the unit of study was Made to Stock products (cable tray and cable) and the design BIM use. The case study entailed the collaboration of the Legrand's BIM manager and electrical engineer and a researcher from the University of Birmingham, UK. The case study was validated in two stages: a quality test on information attributes and a follow-up interview on the usefulness of the BPMN to specify product data. The informational and behavioural perspective of the BPMN was evaluated in relation to the LOD implementation.

Contrary to similar studies such as that of Berard and Karlshoej (2012) on the IDM BPMN functional perspective, the findings from the present case study has shown that the IDM could be applied on an industry basis if the product range is carefully selected and the BIM use can be supported with process prescriptive regulations. For

example, we propose the use of Made to Stock products for the design BIM Use using the *"IEC 60364 international regulation for residential and similar premises"* (AENOR, 2002, AENOR, 2004). Although it might be argued that it would be difficult to reach a common agreement on the process maps needed to define LOD attributes, this study has found that as far as process prescriptive regulations are used, the process map variability is reduced. Only the company studied counts with more than 2000 Made to Stock products which gives a measure of the scale of the solution. In order for it to be applied on an industry basis, manufacturers should keep the IDM BPMN simple. This should be free of IFC bindings which would make the IDM methodology less complex to implement. However, this should not exempt the manufacturer from mapping the deducted attributes to existing MVDs and recording them within XML format which in turn can be easily exported to any proprietary software format. This is valuable for manufacturers as their BIM object data will increase in interoperability and consequently will be included within contracts when used in projects. It has also been demonstrated that a common effort could help to find gaps within current MVDs thus finding paths for IFC extension.

This study has also demonstrated that the BPMN is able to capture data exchanges at certain LODs. However, both the informational and the behavioural perspective of the IDM BPMN should be improved if the LOD aims to be implemented on an industry basis. The BPMN can easily modify its structure to accommodate the LOD, for example an Exchange Requirement can be identified as a LOD BIM object (see FIG 6). The selection of a LOD standard is recommended to avoid inconsistencies when defining exchange requirements within the Process Maps. However, the LOD varies in terms of its intrinsic constructs (stage, number of definitions and actors) depending on the institution which defines it. Regardless of the LOD chosen, this study recommends keeping the LOD chosen free of stage bindings, this will in turn ease the complexity of process maps needed to define the data exchanges.

The present research does have some limitations to consider. First, the unit of analysis was discretised to Made to Stock products and the electrical design BIM Use. However, future research should investigate other BIM uses for Made to Stock products. This will help identify paths for further research and help to generalise the findings from this study. For example, sustainability or construction BIM uses within the PDT shown in FIG 5 and TABLE 8. Furthermore, the effectiveness of specifying BIM object's data from IDMs is limited due to the difficulty in gathering data for specific processes from multiple stakeholders. This has already been addressed by Berard and Karlshoej (2012). The present research acknowledges that the IDM should adapt its constituents to different LOD definitions complicating data gathering processes. In future studies, we aim therefore to explain the impact of the LOD constructs such as BIM use, stage, role or number of definitions on the IDM perspectives. Nevertheless, this exploratory study represents an initial attempt to standardise manufacturer's non-geometrical information for BIM data exchanges within Level 2 processes.

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APPENDIX

TABLE 8. Cable Ladder (Lengths) Product Data Sheet (Legrand Electric Ltd., 2016).

Template Category	**Cable Ladder (lengths)**			
Category Description	System component (length) used for cable support consisting of supporting side members, fixed to each other by means of rungs. Component utilises fittings to join, change direction, change dimension or terminate component runs.			
Information Category	**Parameter Name**	**Value**	**Units**	**Notes**
Manufacturer Data				
Specifications	Manufacturer	Legrand Electric Ltd	Text	
Specifications	Manufacturer Website	http://www.legrand.co.uk/home	URL	
Specifications	Product Range	Swifts Cable Ladder	Text	
Specifications	Product Model Number	Various	Text	Or Code
Specifications	CE Approval	Yes	Text	Number, Yes, No
Specifications	Product Literature	http://www.legrand.co.uk/downlo ds/Swifts_cable_ladder.pdf	URL	
Construction Data				
Specifications	Type	Cable Ladder	Text	This is a COBie field, other fields will be required in final PDTs
Specifications	Shape	Rectangular	Text	This is a COBie field, other fields will be required in final PDTs
Specifications	Material	Steel with zinc coating, Stainless Steel	Text	This is a COBie field, other fields will be required in final PDTs

Specifications	Finish	G - hot dip galvanised to BS EN ISO 1461, D - deep galvanised high silicon steel to BS EN ISO 1461, S - stainless steel to BS EN 10088 - 2 Grade 1.4404, E - powder coated to customer requirement	Text	This is a COBie field, other fields will be required in final PDTs
Specifications	Fittings/Accessories/Ancillaries	n/a	URL	Link to website
Specifications	Configuration	Supporting side members fixed to each other by means of rungs	URL	Link to website
Dimensional Data				
Specifications	Overall Length	3000, 6000	mm	Or Diameter. Minimum and maximum lengths available
Specifications	Overall Width (Internal)	150, 300, 450, 600, 750, 900	mm	
Specifications	Overall Width	190, 340, 490, 640, 790, 940	mm	Minimum and maximum widths available
Specifications	Overall Height	100, 125, 150	mm	Minimum and maximum heights available
Specifications	Gross Weight	12.1, ,30.8	kg	Equates to Operating Weight
Specifications	Rung Pitch (Standard)	300	mm	
Specifications	Cabling Area Depth	69, ,119	mm	
Performance Data				
Specifications	Reference Standard	BS EN 61537	Text	Load tests carried out to BS EN 61537
Sustainability				
Sustainable Material BREEAM etc.	Embodied Carbon	n/a	$kgCO^2$	Awaiting Industry Standard
Sustainable Material BREEAM etc.	Life Cycle Analysis	BREEAM	Number	Awaiting Industry Standard
Sustainable Material BREEAM etc.	Location Manufacturer	Scarborough, UK	GridRef	Awaiting Industry Standard
Sustainable Material BREEAM etc.	Green Guide for Specification	A	Enumeration	Awaiting Industry Standard
Sustainable Material BREEAM etc.	Environmental Product Declaration	ECO PASSPORT	Text	3rd Party Verification

Sustainable Material BREEAM etc.	Responsible Sourcing of Materials	FSC	Enumeration	Awaiting Industry Standard
Sustainable Material ETL	Energy Technology List	n/a	URL	Hyperlink to ETL webpage for product
Sustainable Material LEED v.4	Responsible Extraction of Materials	n/a	Text	Awaiting Industry Standard
Sustainable Material LEED v.4	Material Ingredient Reporting	n/a	Text	Awaiting Industry Standard
Operations & Maintenance				
Facilities /Asset Management	O&M Manual	n/a	URL	Hyperlink to Manufacturer O&M Data
Facilities /Asset Management	Daily	n/a	Text	Maintenance tasks or SFG20 codes
Facilities /Asset Management	Weekly	n/a	Text	Maintenance tasks or SFG20 codes
Facilities /Asset Management	Monthly	n/a	Text	Maintenance tasks or SFG20 codes
Facilities /Asset Management	Quarterly	n/a	Text	Maintenance tasks or SFG20 codes
Facilities /Asset Management	6 Monthly	n/a	Text	Maintenance tasks or SFG20 codes
Facilities /Asset Management	Annually	n/a	Text	Maintenance tasks or SFG20 codes
Facilities /Asset Management	Bespoke Timeframe	Facilities routine maintenance schedule for electrical equipment	Text	Maintenance tasks or SFG20 codes
Facilities /Asset Management	Expected Life	n/a	Years	Maintenance tasks or SFG20 codes
Facilities /Asset Management	Warranty ID	n/a	Text	

Appendix E

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A Grounded Theory Based Framework for Level of Development Implementation Within the Information Delivery Manual

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ABSTRACT

The present study follows the progress of the level of development (LOD) specification from its inception in 2005 to its latest updates in 2018, a total of 42 guidelines from North America and Europe are reviewed. To organise the presented literature and to provide a comprehensive framework of LOD implementation within the information delivery manual (IDM), a LOD grounded theory-based taxonomy is introduced. The variables that constitute this taxonomy are BIM purpose, Stage, Role, Classification System, Attribute, Graphical information, Scale, LOD and Net benefits. The result of this exercise is a comprehensive view of the LOD construct impact on project performance which can be studied as a cumulative framework, where new research on the constructs can be added. Therefore, this allows a point towards the direction where further work is needed within the field of LOD-IDM implementation, such as the study of its use for data management among other uses.

KEYWORDS

Attribute, BIM Purpose, Building Information Modelling, Business Process Modelling Notation, Classification System, Data Management, Graphical Information, LOD, Net Benefits Role, Scale, Stage

1. INTRODUCTION

1.1. Background

In the Architectural, Engineering and Construction (AEC) industry, where several stakeholders from different organisations collaborate towards the completion of a project, having common standards and specifications to unify criteria and enhance collaboration is a fundamental driver. In 2005, Vico Software, a private software company-initiated work on an information management specification namely Level of Detail, used for coordinating modelling efforts between multiple parties (VicoSoftware, 2016). Later on, in 2008, the American Institute of Architects (AIA), refined the specification and adopted the name Level of Development (LOD) (AIA, 2008), which is the term most

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used worldwide for defining Building Information Modelling (BIM) object content progress along the different stages of the project. The exchange of BIM data within the AEC industry is prescribed in paper legal agreements where the information for each specific model is specified, meaning that a legal common framework for organising BIM data is required (CIC, 2013a).

LOD-supported electronic project data specification and management has the potential to enhance specification of model content and its utilisation with the project during design, construction and maintenance of the project (Hooper, 2015). The potential for greater information reliability is significant in an industry which historically has relied in paper-based specifications, which implies inefficient retrieval of information, classification and location of data during the project stages (East, Nisbet, & Liebich, 2013).

1.2. Research Motivation

Based on the initial findings of a comprehensive and systematic literature review, most of the related LOD research has approach it from an applied research perspective; documenting functionality extensions to the core principles of the specification (Wood, Panuwatwanich, & Doh, 2014), examining benefits of its implementation within projects (Fai & Rafeiro, 2014; Luth, Schorer, & Turkan, 2014) or including the LOD within business processes languages such as the Integrated Definition Methods IDEFO and IDEF3 (Maria-Angeliki, Robby, & Kirti, 2014). However, BIM requires defining information within the Industry Foundation Class (IFC) standard which allows for interoperability of data within proprietary software (Steel, Drogemuller, & Toth, 2012). Thus, enabling enhanced collaboration between AEC stakeholders. The creation of the IFC standard and its subsets called Model View Definitions (MVD) requires using the IDM methodology (Wix & Karlshøj, 2010).

The IDM uses the Business Process Modelling Notation (BPMN) language to record processes and to place AEC data into context (Berard & Karlshoej, 2012). Solihin and Eastman (2015) suggested that a LOD MVD based is needed to create automated rule checking approaches to data specification. The authors of the present study, Gigante-Barrera and Ruikar (2016) and other authors such as Lee et al. (2016), suggested associating LOD definitions to define each of the data sets within the BPMN also called Exchange Objects. Recently, Gigante-Barrera et al. (2017), tested and proved on his study on data specification for manufacturers that the LOD could be implemented within the BPMN for the definition of Exchange objects. This paper considers these authors' suggestion and differently from previous studies it focuses on the socio-technical process of LOD standardisation within the IDM. Of particular interest is the ongoing changes that the specification has suffered since its inception, the implementation context and characteristic variables that will make it useful for its deployment within the IDM context.

This paper is structured as follows: Section 1 provides a brief introduction to the IDM environment. Section 2 discusses the methodology, and Section 3 presents an analysis of the peculiarities of information management specification from 2005 to 2018 across 9 different countries from North America and Europe with a notorious interest in BIM standardisation. Section 4 and 5 presents the findings that can make LOD susceptible to be standardised in a global context. The paper concludes with sections 6 and 7, containing the main conclusions and recommendations for future research on LOD standardisation.

1.3. LOD as a Process Oriented Standard

The BIM Project execution Planning Guide from the US makes explicit the use of the IDM process maps, recommending their use as a method to specify project data. Thus, BIM model non-graphical data can be efficiently exchanged within the BIM workflow (NIBS, 2007). Berard and Karlshoej (2012), suggest that the IDM Business Process Modelling Notation (BPMN) language consists of the following perspectives (see Figure 1): process map (behavioural), narratives (organisational), exchange requirements (informational), and narrative business rules (functional). The present study

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uses Aram et al. (2010) and Curtis et al., (1992) description of the previous perspectives to study the LOD phenomena into the IDM context (see Table 1 and Figure 1).

2. METHODOLOGY

2.1. Research Methodology

Grounded theory is a method that help researchers to construct theory based on inductive reasoning (Charmaz, 2015). The method is qualitative in nature and establishes a systematic approach to data gathering, synthesis, analysis and conceptualisation (Charmaz, 2015). Coding, memo-taking and theoretical sampling methods were used as explained within Charmaz (2015) (see Figure 2). To carry out the coding stage (Section 3), BIM guidelines and regulations were collected and reviewed from both government and private institutions from 9 different countries from North America and Europe

Table 1. BPMN perspectives adapted from Curtis et al., (1992)

Perspectives	Question Answered About the Process Performed	Example
Behavioural	When or How the process is performed	Project stage (design stage) or project activities actions (quantify system loads)
Organisational	Who performs the process	Roles involved within the process such as architect or structural engineer
Informational	Informational output	Attributes exchanged such as height or voltage drop
Functional	What informational entity is relevant for the process	Attributes values such as window width

Figure 1. IDM BPMN perspectives adapted from Aram et al. (2010)

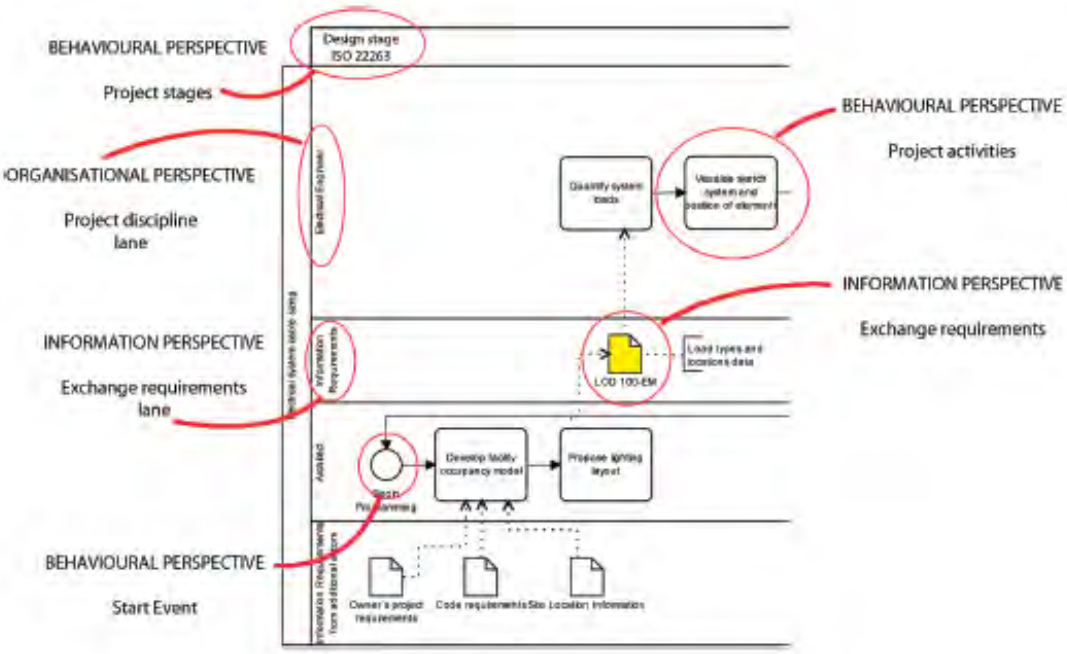
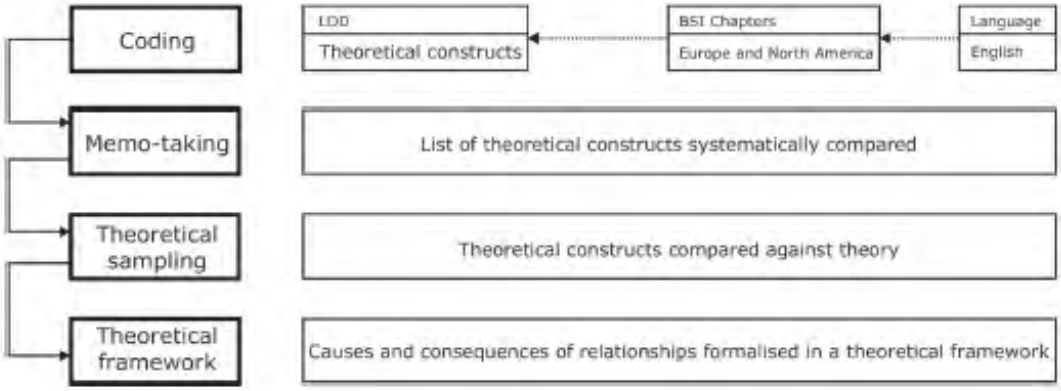


Figure 2. Grounded theory methodology



with an interest in BIM implementation. These countries are selected because their governments have a demonstrated interest on implementing BIM within their industry and because they agreed to implement open interoperable standards in relation to the Building SMART International initiative (BuildingSMART, 2016). However, it must be noted that 23 different countries have expressed an interest on developing open standards (BuildingSMART, 2016). Only public data available in English language was analysed but there is room for other researches to analyse publications in other languages. The review of the document sampling helped to focus our attention on LOD codes or theoretical constructs (see Section 4). During the memo writing stage the theoretical constructs are systematically compared (see Section 4.1). During the last stage called theoretical sampling (see Section 4.1), the theoretical constructs are compared against more theory to justify net benefits. Finally, Causes and consequences of theoretical relationships are sought and formalised in a theoretical framework (Section 5). Barney G. Glaser (1978, 1992), one of the creators of Grounded theory methodology supports that this methodology should be triangulated with quantitative data. The reason for this is that some researchers assume that qualitative data is subjective in nature (Petter, DeLone, & McLean, 2008). Meta-analysis is a recurrent quantitative approach to analyse literature. It is based on statistically significant results. However, Petter et al. (2008) has argued that a meta-analysis only shows correlation between constructs and are not suitable for establishing the boundaries of a theoretical framework. For example, it does not allow to show the direction of causality because the result is an effect size statistic adjusted for correlation between two variables.

This preliminary framework is able to show the boundaries of the framework and its causal directionality. A qualitative documentary analysis was used to carry on the code phase of grounded theory. Therefore, only relevant LOD documents were examined to create the framework. Notwithstanding, the researchers encourage to complement this inductive reasoning with a future abductive stage. This is testing the framework hypothesis and creating both qualitative and quantitative results (for example meta-analysis) which will modify this preliminary framework. This will only be possible when the industry has reached an adoption and maturity stage favourable enough to gather high quality quantities of meta data.

3. CODING STAGE: MEASUREMENT OF BIM MODEL PROGRESSION IN NORTH AMERICA AND EUROPE

3.1. BIM Model Element Definitions in North America

In the United States, diverse companies and institutions have proposed different definitions in order to effectively describe Model Element progression among AEC projects. By the year 2018, 24

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Specifications, Protocols, guides and manuals were created from private companies, universities, state agencies and professional associations. As shown in Table 2 three standards define the Model Element progression as Level of Detail, whereas twenty define it as Level of Development and one as Accuracy and Grade.

3.2. BIM Model Element Definitions in Europe

Europe, in the same trend as the United States has approached the definition of the LOD from different perspectives. As at 2018, 16 standards and guides published in English are available from companies, governments, and professional associations. As shown in Table 3, the LOD in Europe acquires several definitions such as Degree of Detailing, Level of Development or BIM content levels. In addition, only in the UK it is defined as Grade and Level of Detail, Level of Attributing, Level of Detail and Level of measurement and Level of Definition which is divided into Level of Model Detail and Level of Information Detail.

4. LOD THEORETICAL BASE

In reviewing the various approaches that standardisation institutions have taken in developing the LOD specification, the following observation has emerged in relation to the following Berard and Karlshoej (2012) IDM perspectives: process map (behavioural), narratives (organisational), exchange requirements (informational), and narrative business rules (functional). The guidelines studied offer some insight which might increase our understanding of the LOD phenomena. The most recurrent LOD constructs found within the Table 2 and Table 3 documents organised as per IDM perspectives include:

- Behavioural perspective (process map):
  - **BIM Use:** Kreider and Messner's (2013) defines BIM uses as a "… method of applying Building Information Modelling during a facility´s lifecycle to achieve one or more specific objectives…" (Kreider & Messner, 2013);
  - **Stage:** According to Eadie et al.'s study (2013), stages can be understood as the project lifecycle phases. For example, "…project inception, feasibility, design, construction, handover, operation, maintenance and eventual demolition."
- Organisational perspective (narratives):
  - **Role:** Within this study, the several stakeholders who are contributing to the development of a BIM project;
  - **Building Classification System:** The terminology and semantics which need to be utilised within the AEC industry to describe the building entities and processes during the project lifecycle (Ekholm & Häggström, 2011).
- Informational perspective (exchange requirements):
  - **Graphical Information:** The 3D virtual representation of a BIM model;
  - **Scale:** Within the literature context this refers to a specific ratio relative to the actual size of the model;
  - **LOD:** 3D and associated information progression of a BIM model along the project lifecycle.
- Functional perspective (business rules):
  - **Attributes:** The explicit information that describes the graphical information as well as the specification and behaviour of an object in relation to the LOD;
  - **Net Benefits:** Within this study, this refers to the extent to which LOD constructs impact on the current use of BIM Information systems.

The previous constructs provide a theoretical base for developing a model for LOD implementation. The relationships between constructs are grouped based on the expected causal relationships between

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Table 2. LOD standards in North America

Year	Organisation and Standard Name	Model Element Definition	Inherited From
2005	[VS] Model Progression Specification v1 (VicoSoftware, 2016)	Level of Detail	Not Found
2008	[AIA] E202-2008 BIM Protocol Exhibit (AIA, 2008)	Level of Development	[VS] v1 2005
2010	[VA] The Veteran Affairs BIM Guide v1.0 (AEC Infosystems Inc., 2010)	Level of Development	[AIA] 2008
2010	[VA]The VA BIM Object Element Matrix Manual Release v1.0 (attributes) (VA CFM, 2010)	Level of Development	[AIA] 2008
2010	[VS] Model Progression Specification v2 (VicoSoftware, 2016)	Level of Detail	[VS] v1 2005
2011	[VS] Model Progression Specification v3 (VicoSoftware, 2016)	Level of Detail	[VS] v2 2010
2011	[OD o AS] State of Ohio BIM Protocol (Ohio DAS, 2011)	Level of Development	[AIA] 2008
2011	[UF] BIM Execution Plan v1.1 (UF, 2011)	Level of Development	[AIA] 2008
2012	[NYC DDC] BIM Guidelines (NYCDDC, 2012)	Level of Development	[AIA] 2008
2012	[PSU] BIM Planning Guide for Facility Owners v1.0 (CIC RP, 2012)	Level of Development	[AIA] 2008
2012	[TPA of NY NJ] E, A design division BIM standard manual (TPA of NY & NJ, 2012)	Level of Development	[AIA] 2008
2012	[USC] Building Information Modeling (BIM) Guidelines v1.6 (USC, 2012)	Level of Development	[AIA] 2008
2013	[AIA] Document G202™–2013, Project BIM Protocol Form (AIA, 2013b)	Level of Development	[AIA] 2008
2013	[AGC, AIA, BIM Forum] Level of Development (LOD) Specification v2013 (BIM Forum, 2013)	Level of Development	[AIA] 2013
2013	[AIA] E203-2013 BIM and Digital Data Exhibit (AIA, 2013a)	Level of Development	[AIA] 2013
2013	[AIA] Guide, Instructions and Commentary to the 2013 AIA Digital Practice Documents (AIA, 2013c)	Level of Development	[AIA] 2008, [AIA] 2013
2013	[NIBS] National BIM Standards US v3_2.7 (NIBS, 2013)	Level of Development	[AIA] 2013, [AIA] 2013, [AGC, AIA, BIM Forum] 2013
2013	[PSU] BIM Planning Guide for Facility Owners v2.0 (CIC RP, 2013)	Level of Development	[AIA] 2013
2013	[PSU] The uses of BIM Classifying and selecting BIM uses v0.9 (Kreider & Messner, 2013)	Level of Development	[AIA] 2013
2014	[AGC, AIA, BIM Forum] Level of Development (LOD) Specification v2014 (BIM Forum, 2014)	Level of Development	[AIA] 2013, [AGC, AIA, BIM Forum] 2013
2014	[USACE] Minimum Model Element Matrix M3 v1.3 (attributes) (USACE, 2014)	Level of Development (accuracy) and grade	Not Found
2015	[AGC, AIA, BIM Forum] LOD Specification v2015 (BIM Forum, 2015b)	Level of Development	2013 [AIA], [AGC, AIA, BIM Forum] 2014
2015	[AGC, AIA, BIM Forum] LOD Specification v2015 (attributes) (BIM Forum, 2015b)	Level of Development	2013 [AIA], [AGC, AIA, BIM Forum] 2014
2016	[AGC, AIA, BIM Forum] LOD Specification v2016 (Draft) (BIM Forum, 2016b)	Level of Development	[AIA] 2013, [AGC, AIA, BIM Forum] 2015

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Table 3. LOD standards in Europe

Year	Organisation and Standard Name	Model Element Definition	Inherited From
2006	[Denmark, BIPS] Layer and Object Structures 2006 (Lag- og objektstruktur 2006) (Bips, 2006)	Not in English	
2007	[Denmark, BIPS] 3D Working Method 2006 (Bips, 2007)	Degree of Detailing (Information levels)	Not Found
2009	[UK, AEC] BIM Standard v1.0 (AEC UK, 2009)	Grade, Level of Detail (Scale)	Not Found
2012	[Netherlands, Rijksgebouwendienst] Rgd BIM_Standard v1.0.1 EN 1.0 (Rgd, 2012)	Level of Development	[AIA] 2008
2012	[UK, AEC] BIM Standard v2.0 (AEC UK, 2012)	Grade, Level of Detail (Scale)	Not Found
2012	[UK, BSI] BS 8541-3-2012 Library objects for architecture, engineering and construction (BSI, 2012a)	Level of Detail and Level of Measurement	Not Found
2012	[UK, BSI] BS 8541-4-2012 (BSI, 2012b)	Level of Attributing	Not Found
2012	[Finland, COBIM] Common BIM Requirements 2012 Series 3 Architectural Design (Gravicon, 2012)	BIM Content Levels	Not Found
2013	[Germany, BMVBS] BIM Guidelines for Germany (BIM-Leitfaden für Deutschland) (BMVBS, 2013)	Not in English	
2013	[UK] PAS 1192-2-2013 (BSI, 2013)	Level of Definition (level of model detail + level of information detail)	Not Found
2013	[UK, CIC] Best Practice Guide for Professional Indemnity Insurance When Using BIMs v1 (CIC, 2013a)	Level of Detail	[UK] PAS 1192-2-2013
2013	[UK, CIC] Building Information Model (BIM) Protocol v1 (CIC, 2013b)	Level of Detail	[UK] PAS 1192-2-2013
2013	[UK, CIC] Outline Scope of Services for the Role of Information Management v1 (CIC, 2013c)	Level of Detail	[UK] PAS 1192-2-2013
2014	[UK, BSI] BS1192-4_Collaborative production of information Part 4 (BSI, 2014)	COBie	Not Found
2014	[Spain, uBIM] Guía de Usuarios BIM (Building SMART Spanish Chapter, 2014)	Not in English	
2015	[Belgium, ADEB-VBA] Building Information Modelling – Belgian Guide for the construction Industry (ADEB-VBA, 2015)	Level of Development	[AGC, AIA, BIM Forum] 2013
2015	[Switzerland, Ernst Basler + Partner] Building Information Modeling. Principles of an open BIM methodology for Switzerland (Maier C, 2015)	Not in English	

LOD constructs. Examining the literature review using this relationship structure, helps us to understand the reasons behind its adoption or refusal and its impact within the framework. Table 4, includes a total of 13 pairs of LOD constructs' relationships analysed within the present research.

4.1. LOD Memo Taking and Theoretical Sampling Stage Combined

4.1.1. Scale → BIM Use

The relationship support between Scale and BIM Use within the guidelines is scarce. For instance, the Architectural, Engineering and Construction (AEC) UK BIM Standard (2009) guideline proposes a transition from CAD to BIM (AEC UK, 2009). The UK, AEC BIM Standard v1.0 sets a positive relationship between scale and BIM uses (AEC UK, 2009). The guideline contains references to typical drawing scales for a total of 12 BIM uses such as fabrication, sequencing, energy analysis among others. The guideline proposes that the model scale must be prepared to suit the purpose the project is going to serve. For example, for energy analysis, it sets a preferred scale of 1:200 and a maximum

Table 4. Proposed LOD constructs relationships for the inclusion within the LOD framework

Scale	→	BIM Use
Project Stage	→	BIM Use
Project Stage	→	LOD
Role	→	LOD
LOD	→	Attributes
LOD	→	Geometry
LOD	→	Scale
BIM Use	→	Attributes
BIM Use	→	Geometry
BIM Use	→	LOD
Classification	→	Building Elements
Classification	→	Stage
Classification	→	Attributes

scale of 1:100. This would help to manage detail levels above the maximum recommended. When this happens, the guideline recommends drawing them in 2D while using 3D views as metadata.

4.1.2. Project Stage → BIM Use

An example of a moderate support relationship between project Stage and BIM use is the AIA G202. The AIA G202 finds it useful to define different LODs for different uses at the same project milestone. This is freely assigning the model element per BIM use at a project stage (AIA, 2013b). However, this can result in a fractal effect as the MPSv2 review suggests (VicoSoftware, 2016). The main difference between the AIA G202 and the MPSv3 is that the combination of BIM use, BIM element, LOD on a project stage can be managed at the project level when using the AIA G202 (AIA, 2013b). However, the MPSv3 predefine a rigid set of constructs which in turn will be beneficial to maintain a standardised library of components with attached information (VicoSoftware, 2016), but detrimental for project innovation and flexibility of specification.

4.1.3. Project Stage → LOD

There are a few standards that encourage using Project Stages linked to the LOD. The Danish 3D working method 2006 degree of Detailing binds the Danish DBK project stages to the LOD classification (Bips, 2007). However, this can be considered moderate support as it also recommends its use within other stages.

Negative support between the Project Stage and LOD relationship is seen in the Vico Software specification (VicoSoftware, 2016), the AIA G202 (AIA, 2013b) or the AIA E202 Model Element Table (AIA, 2008), which recommends LOD management and its specification within a project stage or a percentage of the project stage. Differently from the Danish DBK, Vico software and the AIA G202 acknowledges that there might be more than one model version per design phase. Thus, enabling the review of the model at various project milestones. Similarly, the BIM forum Level of specification (BIM Forum, 2013, 2014, 2015a, 2016b), assumes that when the BIM model elements and systems are not individually managed, the project incurs significant waste in terms of time, cost and human resources.

On the contrary, the PAS 1192 is a pure example of a positive relationship between LOD and project stages as the LOD is unequivocally coincident with the project stages making easier alignment

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to UK standard staged submission requirements such as for example the CIC scope of services stage definitions (BSI, 2013).

4.1.4. Role → LOD

There is lack of studies which investigate the Role and LOD relationship. The Danish 3D working method 2006 classifies the degree of detailing by actors i.e. architecture (Bips, 2007). Later, BIM uses would be attached to this definition. This can be considered as a moderate relationship as it is understood that more than one professional might be responsible for common building elements pertaining different roles.

4.1.5. LOD → Attributes

The Vico Software LOD and Attributes relationship can be considered as moderate. Vico Software MPSv3 proposes creating a historical database for the cost and schedule which could be associated with a LOD definition (VicoSoftware, 2016). However, the VICO Software specification does not regulate the attributes and values needed to do such a study.

Examples of strong relationships where attributes have been specified as per LOD include the following: The Veteran Affairs BIM Object Element Matrix provides a list of BIM elements with its correspondent attributes based on the AIA E202 LOD classification (VA CFM, 2010). Other guides such as the NYCDDC BIM guidelines propose required attributes per building system which would be a more generic approach than the previous guideline example (NYCDDC, 2012). The USACE Minimum Model Element Matrix M3 provides a list of attributes based on their own LOD specification which has had little followers within the industry (USACE, 2014). Finally, the BIM Forum Level of Development 2015 and 2016 recommends a list of attributes based on the AIA G202 LOD specification and is also accompanied by a list of illustrations per model element which leaves little room for human error (BIM Forum, 2015b, 2016a).

Version 2 of the AEC UK BIM Standard breaks the binding within geometric and non-geometric descriptions of the model (AEC UK, 2012). It recommends that the information is managed for its intended purpose, meaning that there should not be a straight link between Attributes and LOD. Thus, the relationship should be considered as negative.

The BSI also created BS 8541-4-2012 Library objects for architecture engineering and construction – Part 4: Attributes for specification and assessment – Code of practice. This guide proposes a definition for level of information called Level of Attributing. This guideline encourages using the IFC property sets, attributes and units of measure. This allows for internal and external database consistency. Although the guideline encourages using attributes, it does not specify them, therefore the Attribute and LOD relationship could be considered as moderate.

In the United Kingdom (UK), the PAS 1192-2:2013 defines the Level of Definition (LOD). The document includes the Level of Model Detail which describes graphical information and the Level of Information Detail. The second, on the contrary stands for the content description of non-graphical models (BSI, 2013). However, there is not any reference to attribute information. Thus, the relationship could be considered as moderate.

4.1.6. LOD → Geometry

Vico Software describes how the 3D shape should be represented for different LODs (VicoSoftware, 2016). For example, it describes the type diversification of an object, its geometry, penetrations and connections. However, it does not provide a guide of requirements per object, thus the relationship could be considered as moderate.

The BIM Forum Level of Development specification is intended for professionals engaged in BIM element creation. The guide helps these professional to rely on the kind of model they are sharing or receiving in terms of usability (BIM Forum, 2013, 2014, 2015a, 2016b). It provides an

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image per LOD and a short description of what the image should include as the model progresses. The link between Graphical information and LOD is considered as positive.

4.1.7. LOD → Scale

The UK, AEC BIM Standard v1.0 and v2.0 provides a general example of illustrations per LOD and scale (AEC UK, 2009, 2012). The guidelines recommend creating fit to purpose models to ensure the most efficient use of the PC processing power, therefore the relationship can be considered as positive.

4.1.8. BIM Use → Attributes

The BSI created the BS 8541-4-2012 Library objects for architecture engineering and construction – Part 4: Attributes for specification and assessment – Code of practice which establishes a positive link between BIM uses and attributes such as the Construction Operation Building information exchange (COBie) MVD attributes (BSI, 2012b).

4.1.9. BIM Use → Geometry

Within the AIA G202 (AIA, 2013b), which is the newest version of the AIA E202 document (AIA, 2008), a coordination use is specified. It must be noticed that the coordination use can only be applied after the model has been detailed enough to allow for clash detection purposes. Therefore, the BIM Forum Level of Development Specification (BIM Forum, 2013, 2014, 2015a, 2016b) introduces a by-step LOD in between the 300 and 400 LOD for coordination purposes. This LOD is called the LOD 350 and its graphical representation is provided to coordinate modelling efforts.

4.1.10. BIM Use → LOD

Guidelines provide moderate support for the BIM Use and LOD relationship. Some guidelines propose authorised uses which are closely related to the LOD definition. This means that these guidelines are only reliable under the recommended uses. The Vico Software Level of Detail (MPSv1) (VicoSoftware, 2016) defines Geometry (modelling or visualisation), Scheduling and Estimating as reliable data outputs when using their specification. A positive relationship between these two concepts is described: One important lesson learnt from the MPSv1 is that when the LOD is not followed by an authorised use, the specification becomes too general and it is subject to interpretation by the designer. However, a negative example of this relationship is found within the MPSv2. Differently from the MPSv1, this specification defines different levels of model progression per BIM use. When this is defined for each building model element, it creates an iteration problem for model elements, BIM uses and levels of definitions, which might be counterproductive for the generalisation of LOD definitions. We have illustrated this problem using the following formula:

$$Total\ LOD\ definitions = (no.\ of\ Classes^{no.\ of\ Aspects})no.\ of\ Building\ elements$$

The updated Vico software proposal for the definition of model elements is the MPSv3. Within this specification, the previous problem is acknowledged and the combination of Building element, BIM use and level of model element progression dependent on the BIM use was standardised and its relationships pre-set as a library of definitions. Therefore, a positive relationship between LOD and BIM use was established.

Both the AIA E202 and the AIA G202 documents support the studied relationship (AIA, 2008, 2013b). The AIA Document E202 defines authorised uses such as construction, analysis, cost estimating and schedule as per LOD. Similarly, in the AIA G202, which is the newest version of the document, a coordination use is added and a previously defined construction use is subtracted.

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A positive relationship between BIM Use and LOD is explained within the State of Ohio BIM Protocol (Ohio DAS, 2011). This guideline uses the AIA E202 to define required uses for building permission purposes as the model progresses. However, it does it independently of project stages.

Differently from the USA, in Europe, narrative descriptions have been created to describe the LOD. For example, the 3D Working Method 2006 in Denmark contains a narrative description of model progression which includes non-authorised uses such as modelling, estimating coordination, planning, logistics, operations and maintenance and fabrication performance (Bips, 2007). Non-authorised uses within this study are uses which are linked to a very general level of detail giving rise to the authors interpretation. Therefore, the relationship support could be considered as moderate.

The *BS 8541-3:2012* establish a positive relationship between three different levels of detail which attend to different BIM uses each one such as coordination, quantity take off and visualisation (BSI, 2012a). Furthermore, it combines a level of measurement which will set the basis for a detailed definition of the model element and its preparation for quantity take offs purposes. Meaning that for a model element to be used for a specific BIM use, it must be detailed to purpose.

The PAS 1192-2:2013 defines the Level of Definition (LOD) and introduces a narrative for each level of model progression from which the following BIM uses can be deducted (BSI, 2013): Design, Analysis, Coordination, Sequencing, Estimating, fabrication, capture of as installed information, operation, maintenance and performance. This implies a moderate relationship between the LOD and BIM Use relationship. Similarly, the Common BIM Requirements 2012 introduces textual descriptions per level of model progression where certain BIM uses can be deducted from. For example, communication and collaboration, energy analysis, construction, scheduling and contractor purchasing.

4.1.11. Classification → Building Element

There are few initiatives considering the relationship between classification and Building Element categories. Vico software establish a positive relationship between classification and building elements as it uses a classification system to describe a building object in more detail as the project progresses (VicoSoftware, 2016).

Similarly, in Finland, the Common BIM Requirements 2012 encourages agreeing on the information beforehand using the Architect's Model content requirements table which uses the Talo 2000 classification (Gravicon, 2012). This gives the designers the free will to organise the BIM content level per stage. The guide demonstrates that the product naming evolves with the object, for example for Level 1, building parts are named using a description of the object, whereas for Level 2 there is a clear naming convention and cost information can be inferred from the model.

Within the AIA Document E202TM – 2008 BIM Protocol Exhibit (Level of Development) (AIA, 2008), a model element defines a component, system or assembly within a building and these are represented by the Construction Specification Institute (CSI) UniFormatTM classification system. However, the Guide, Instructions and Commentary to the 2013 AIA Digital Practice Documents (AIA, 2013c), recommends using a different classification system if required according to the complexity of the classification system, the number of different users, familiarity with the classification and evaluation of the Model use and translation to required software. For example, Masterfomat and Omniclass are recommended. Similarly, The BIM Forum Level of Development Specification uses the AIA G202-2013 Level of Development definitions using the CSI Uniformat 2010 (BIM Forum, 2013, 2014, 2015a, 2016b).

Furthermore, within the Denmark_3D Working Method 2006 (Degree of Detailing), it is encouraged that the DBK national classification is used to define the building model (Bips, 2007).

The PAS 1192 is an example of a regulation that stablishes a link between systems or product with a classification system such as Uniclass and the cost plan (BSI, 2013). The BSI also created the BS 8541-4-2012 Library objects for architecture engineering and construction – Part 4: Attributes for specification and assessment – Code of practice (British Standards Institution, 2011). This guide recommends using measure naming conventions based on the BS ISO 80000-1.

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4.1.12. Classification → Stage

There is a scarcity of guidelines recommending best practice to address the classification stage relationship. However, the PAS 1192-2:2013 suggests using the CIC scope of services stage definitions (BSI, 2013).

4.1.13. Classification → Attributes

A different trend helps to classify attributes per classification system. For example, the Object Element matrix, which is a compendium of BIM model attributes for each building element is referenced using the OmniClass and Uniformat classification system. The attributes evolve in line with the AIA E202 LOD definition (VA CFM, 2010). The attributes are classified according to different BIM uses such as costing requirements, construction logistics or asset management among others. The model author would choose the appropriate element and LOD for the required BIM use and would populate its BIM model with the described attributes.

5. THEORETICAL FRAMEWORK RESULTS

The guidelines' support for the relationships between LOD constructs are summarised in Table 5. We replicated Petter et al.'s (2008) methodology used to create a model for Information Systems Success with slight modifications to adapt the methodology to the current study. However, it should be noted that the present study does not base its conclusion on other studies'

Table 5. Summary of LOD guidelines relationship support

Relationship	Positive	Moderate	Negative	Result
Scale → BIM Use	(AEC UK, 2009)			NA
Project Stage→ BIM Use	(VicoSoftware, 2016)	(AIA, 2013b)		NA
Project Stage → LOD	(BSI, 2013)	(Bips, 2007)	(AIA, 2008, 2013b; BIM Forum, 2013, 2014, 2015a, 2016b; VicoSoftware, 2016)	Negative support
Role → LOD		(Bips, 2007)		NA
LOD → Attributes	(BIM Forum, 2015b, 2016a; NYCDDC, 2012; USACE, 2014; VA CFM, 2010)	(BSI, 2012b, 2013; VicoSoftware, 2016)	(AEC UK, 2012)	NA
LOD → Geometry	(AEC UK, 2009, 2012; BIM Forum, 2013, 2014, 2015a, 2016b)	(AIA, 2008, 2013b; VicoSoftware, 2016)		NA
LOD → Scale	(AEC UK, 2009, 2012)			NA
BIM Uses → Attributes	(BSI, 2012b)			NA
BIM Use → Geometry	(AIA, 2013a, 2013b)			NA
BIM Use → LOD	(AIA, 2008, 2013b; BSI, 2012a; Ohio DAS, 2011; VicoSoftware, 2016)	(Bips, 2007; BSI, 2013)	(VicoSoftware, 2016)	NA
Classification → Building Elements	(AIA, 2008, 2013b; Bips, 2007; BSI, 2012b, 2013; Graviton, 2012; VicoSoftware, 2016)			Positive support
Classification → Stage	(BSI, 2013)			NA
Classification → Attributes	(VA CFM, 2010)			NA

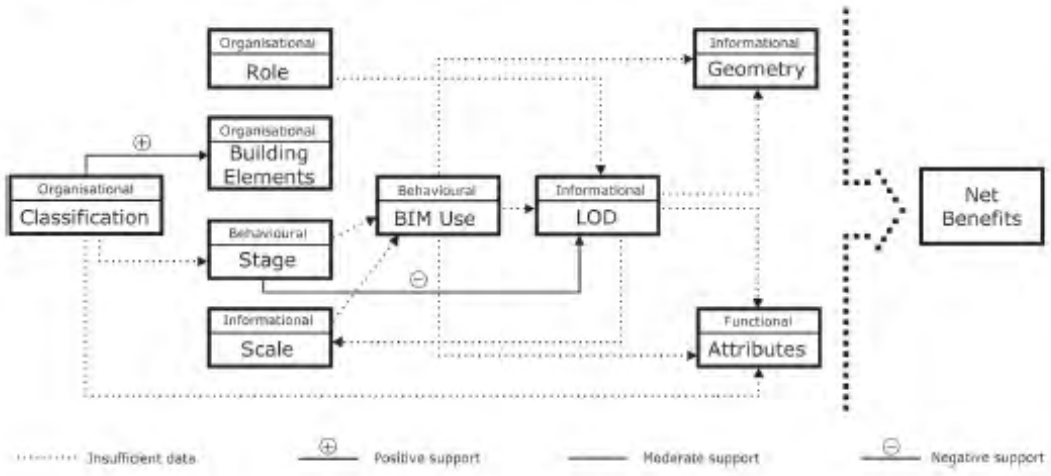
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empirical data as the scientific research on the LOD field constructs is non-existent. On the contrary, a wide range of LOD guidelines exist. Therefore, after a qualitative analysis of the LOD pair of constructs' relationship was carried out, we summarised the level of support as positive, moderate and negative. We assigned values of 1.0 point to each of the previous categories respectively. The total points summed up for each of the relationship's support was divided by the total of studies. In order to classify the relationship between strong support, moderate support, or negative support, a percentage distribution was proposed. Positive, moderate or negative support was assigned when the percentage of papers with a positive, moderate or negative support respectively result was in the range of 70-100%. We choose a high percentage to measure significant results as if we had chosen percentages close to 50-100% or 60-100%, it would have been easy to assign significant results to a category with a similar significant number of labelled categories. When there were less than 5 guidelines describing the relationship or results in the range of 0-69.9%, the result was categorised as having insufficient data to draw a conclusion (NA). In the same trend as Petter et al.'s research, this study does not aim to provide a mere quantitative approach, but to suggest areas where the LOD construct relationship needs to be researched further.

Figure 3 presents a LOD model which relates LOD constructs' pairwise comparisons and IDM perspectives from section 1.3. The model intends to provide a framework to determine causal influences in defining Net Benefits arising from its usage in projects.

The quantitative study shows that there is insufficient data to draw conclusions for most of the unit of analysis (see Table 5). However, there is strong support for the following relationships: Negative support for the LOD → Project stage and Positive support for the Classification → Building Element. There is not sufficient data to establish a direct link between Net Benefits and the studied relationships. However, the net benefits found within the literature have been summarised in Table 6 for future framework validation. For example, it would be useful to investigate whether LOD definitions that closely define building elements per classification yield greater reliability of external and internal databases. Similarly, one could also investigate whether the LOD definitions that bind LOD per project stages leads to poor value engineering performance.

Figure 3. IDM-LOD framework. Support for interrelationships between LOD constructs.



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6. IMPLICATIONS AND DISCUSSION

The researchers acknowledge that it might be difficult to isolate the impact of one construct on the overall LOD performance within a project. However, the study of the previous pairs of relationships will help researchers to qualitatively assess Net benefits as shown in Table 6. The measures of Net benefits have been classified per pair of constructs and negative (-) and positive (+) impact on LOD performance. For example, a project stage closely linked to a LOD definition might lead to poor value engineering performance. However, as stated previously, the proposed relationships and consequent net benefits should be tested to validate the proposed conclusions.

7. CONCLUSION

A grounded theory methodology has been carried out to create a framework for LOD implementation within the IDM which will facilitate future research on LOD implementation in Information Systems. The theoretical constructs that conform the framework can be classified as follows: BIM Use, Lod, Project Stage, Role, Building Element, Classification, Scale, Attributes, Net Benefits. Moreover, these construct combinations have an overall impact on the LOD performance, when measuring performance as Net Benefits. By studying the interrelations between pairs of constructs, it has been possible to suggest Net benefits from LOD implementation such as Increased Model Reliability, Enhanced Value Engineering, Enhanced Attribute Validation, Reliability of External and Internal Databases, e- Submission, Lean Design among Others such as Risk, Cost and Schedule Prediction. However, the key performance indicators needed to measure the suggested Net Benefits are out of the scope of this research. The creation of case studies using the described cumulative framework will help to set valuable key performance indicators to be used by information managers to evaluate the impact of different LOD approaches on a BIM managed construction project.

Table 6. Net benefits associate to pairwise relationship constructs

Scale	→	BIM Use	+ Transition From CAD to BIM (AEC UK, 2009).
Project Stage	→	BIM Use	-A project stage does not constraint a BIM use as it will affect negatively the freedom of use choice (Kreider & Messner, 2013).
Project Stage	→	LOD	+Alignment to country submission standards (BSI, 2013). -Value engineering (VicoSoftware, 2016). -Waste time, cost, human resources (BIM Forum, 2013)
LOD	→	Attributes	+Attributes validation (Solihin & Eastman, 2015), Historical database link (VicoSoftware, 2016), Avoids waste of time, money and resources during design (BIM Forum, 2015a).
LOD	→	Geometry	+Avoids waste of time, money and resources during design (BIM Forum, 2015a).
LOD	→	Scale	+ Transition from CAD to BIM (AEC UK, 2009).
BIM Use	→	Attributes	+Attributes validation (Solihin & Eastman, 2015), Historical database link (VicoSoftware, 2016)., Avoids waste of time, money and resources during design (BIM Forum, 2015a).
BIM Use	→	LOD	+ Model reliability (VicoSoftware, 2016). - Fractal effect if defined per each BIM use (VicoSoftware, 2016).
Classification	→	Building Elements	+Reliability of external and internal databases (VicoSoftware, 2016).
Classification	→	Stage	+Reliability of external and internal databases (VicoSoftware, 2016).
Classification	→	Attributes	+Reliability of external and internal databases (VicoSoftware, 2016).

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The constructs introduced within this paper and the framework for LOD implementation described could be considered a tool for future research development for the following reasons. First, it provides a comprehensive view of the LOD constructs' impact on project performance. Second, it compiles a broad range of research and guidelines which tend to be dispersed and makes it coherent for its holistic study. Third, the depiction of the LOD using the IDM language will help researchers and professionals to find paths for Information Systems implementation improvement. Fourth, the present study can be studied as a cumulative framework, where new research on the constructs can be added, thus allowing researchers to point towards directions where further work is needed.

The present research compiles a limited amount of LOD guidelines from America and Europe. For example, guidelines which were not written in English were discarded. Furthermore, Asia and Australasia were excluded from the analysis as the researchers found the studied guidelines enough to fulfil the sense of saturation. Furthermore, only qualitative results were gathered. The authors of this study encourage to test the framework generated hypothesis in both a qualitative and quantitative way. This will redefine the direction and strength of the LOD constructs´ pairwise relationships within the presented framework and consequently will allow its use for future LOD research.

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