

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 draw recommendations for the behavioural and informational IDM perspective. In order to 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

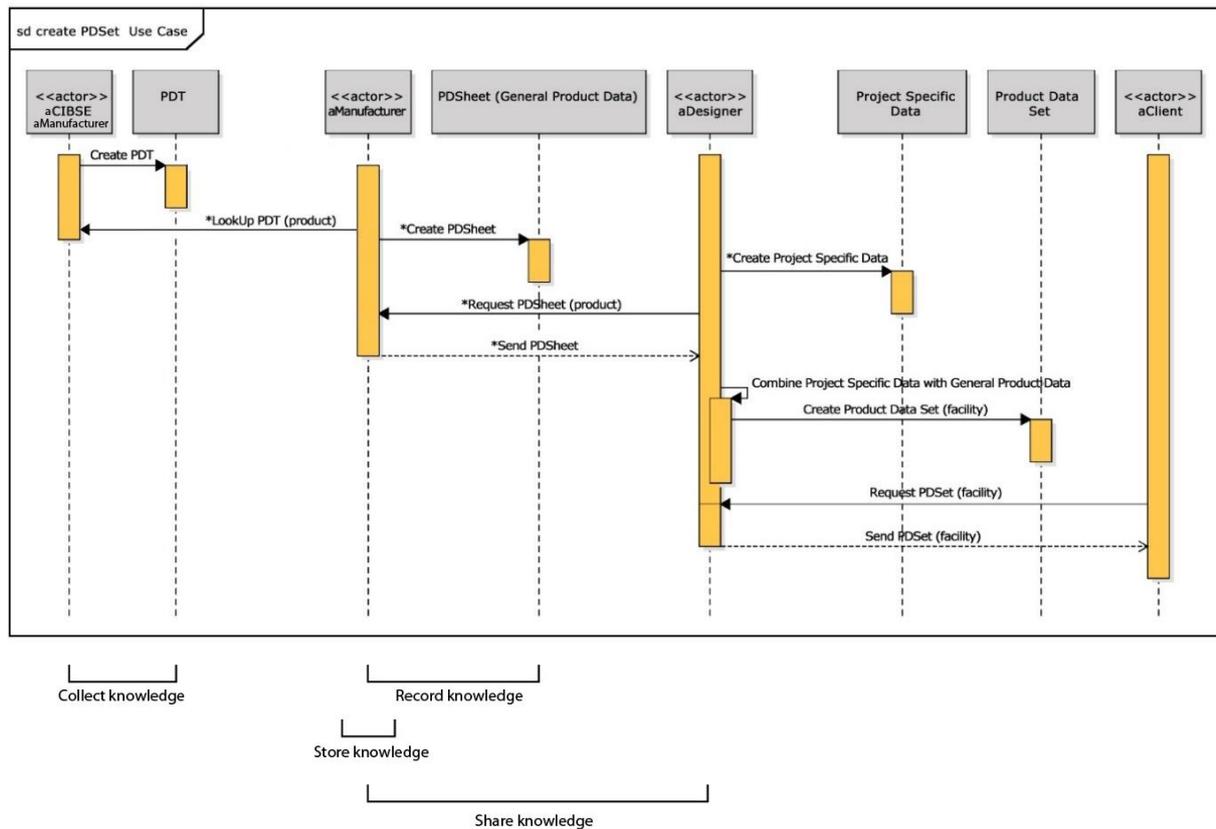


FIG 1. Sequence diagram of the PDT integration within the AEC IS.

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 Karlshøj (2012), IDM is a business process modelling language based on the Business Process Modelling Notation (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 Karlshøj (2012) sustain that the IDM language was proposed to overcome the BPMN 1.1 shortcomings.

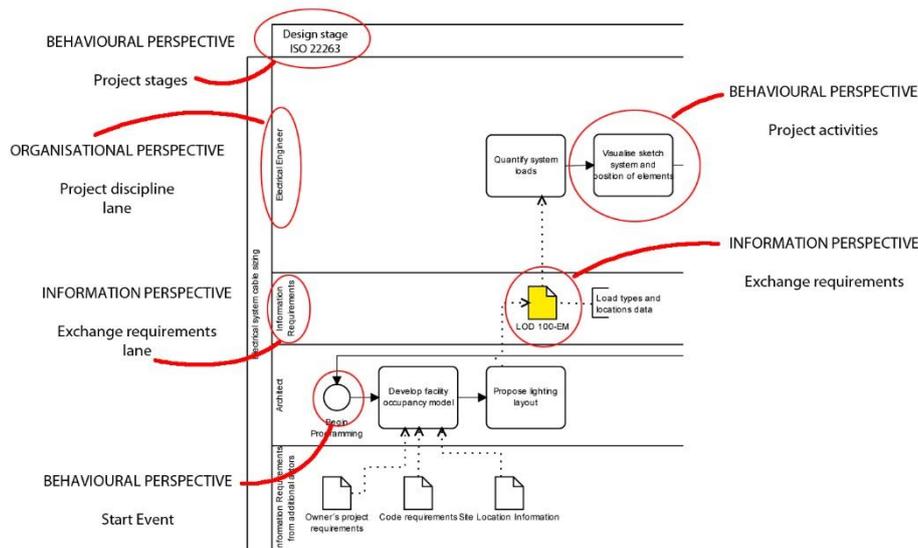


FIG 2. IDM BPMN perspectives adapted from Aram et al. (2010).

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.

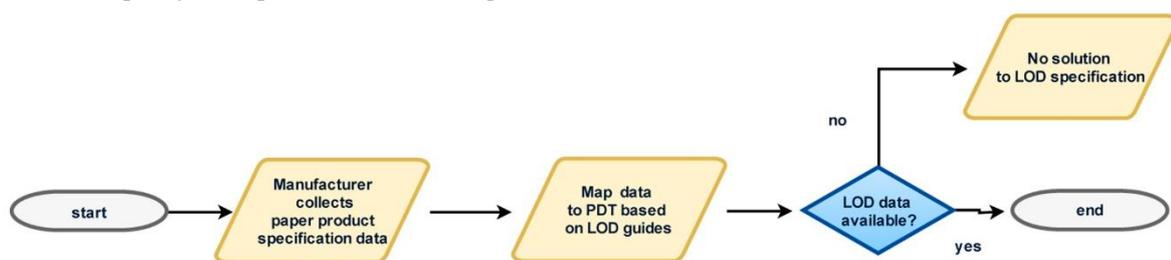


FIG 3. Process for PDT LOD data collection.

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 Karlshøj (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 Karlshøj (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.

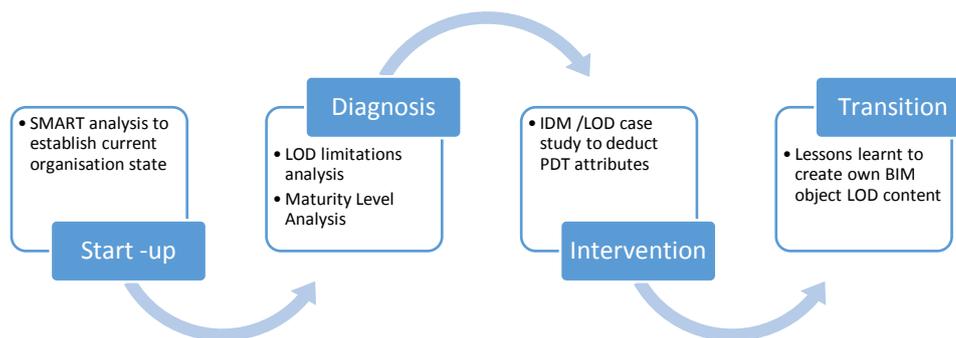


FIG 4. Organisational Development stages within the current research study.

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

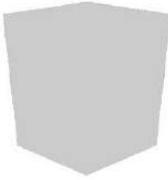
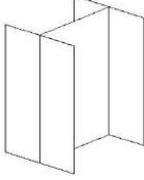
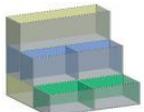
The LOD to be included within the definition of a BIM object is a critical criterion for manufacturers (BIM4M2, 2014). The *"AIA G202-2013, Project Building Information Modelling Protocol Form"* was created by the *"American Institute of Architects (AIA) California Council Integrated Project Delivery 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 relies on its definition of graphical content according to specific products, its clarity on authorised uses and stage flexibility.

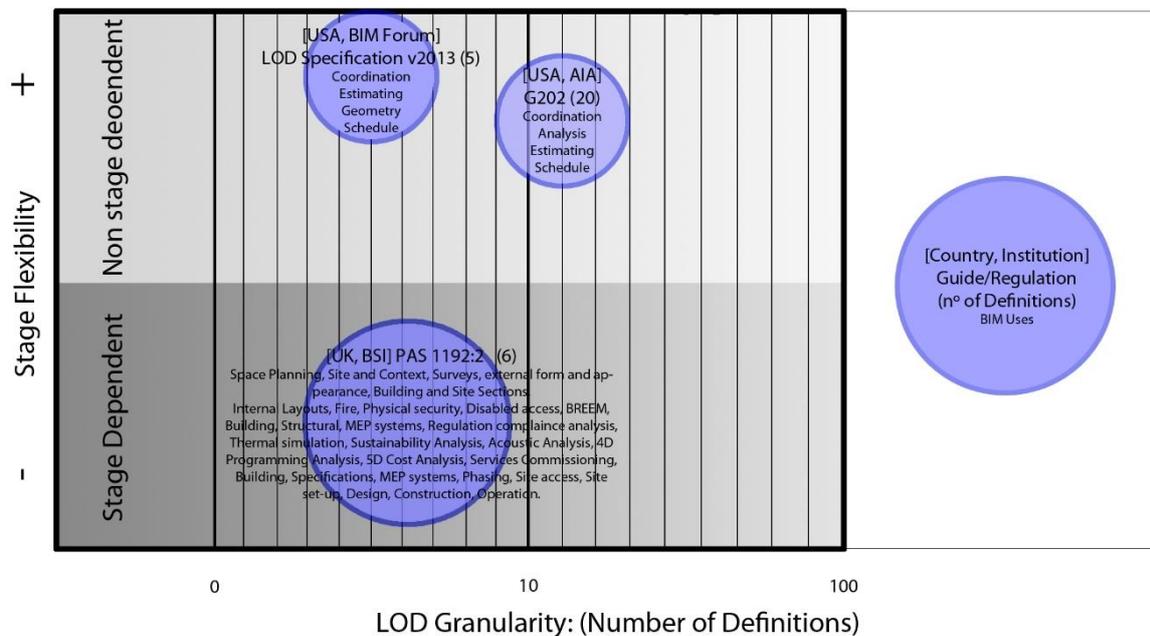


FIG 5. LOD BIM uses, n° of definitions and stage dependency compared.

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.

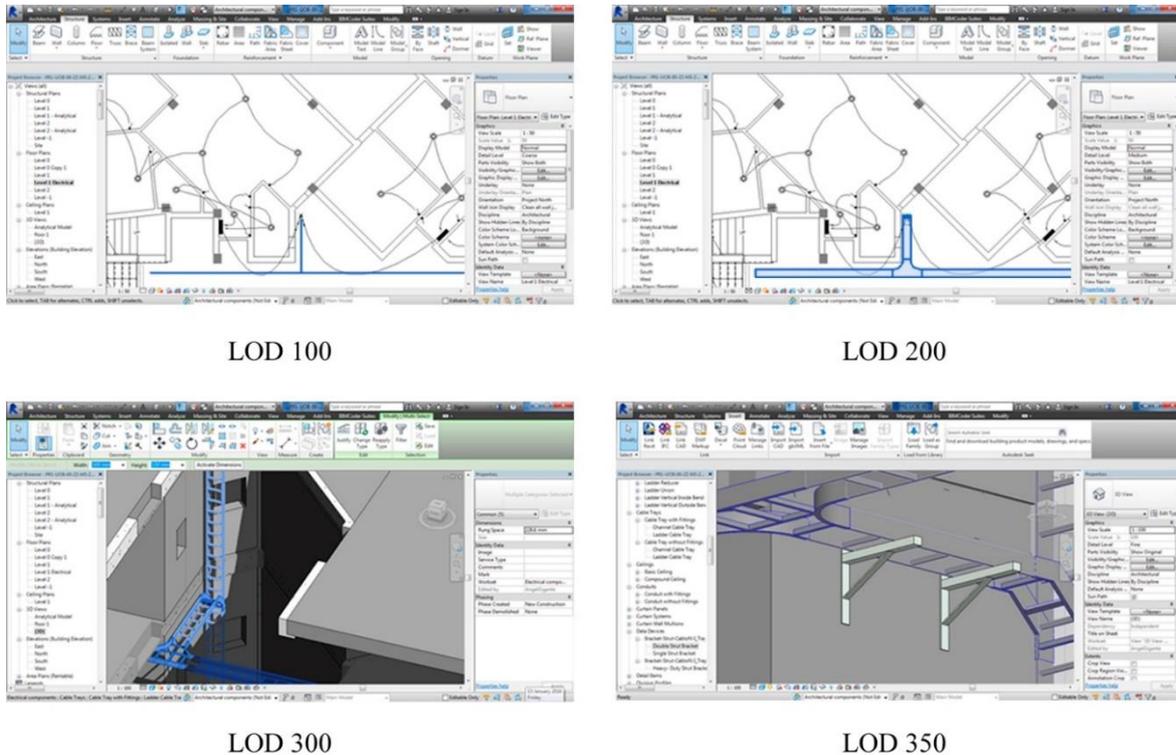


FIG 6. Revit Case study- Cable tray system LOD progression.

“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).

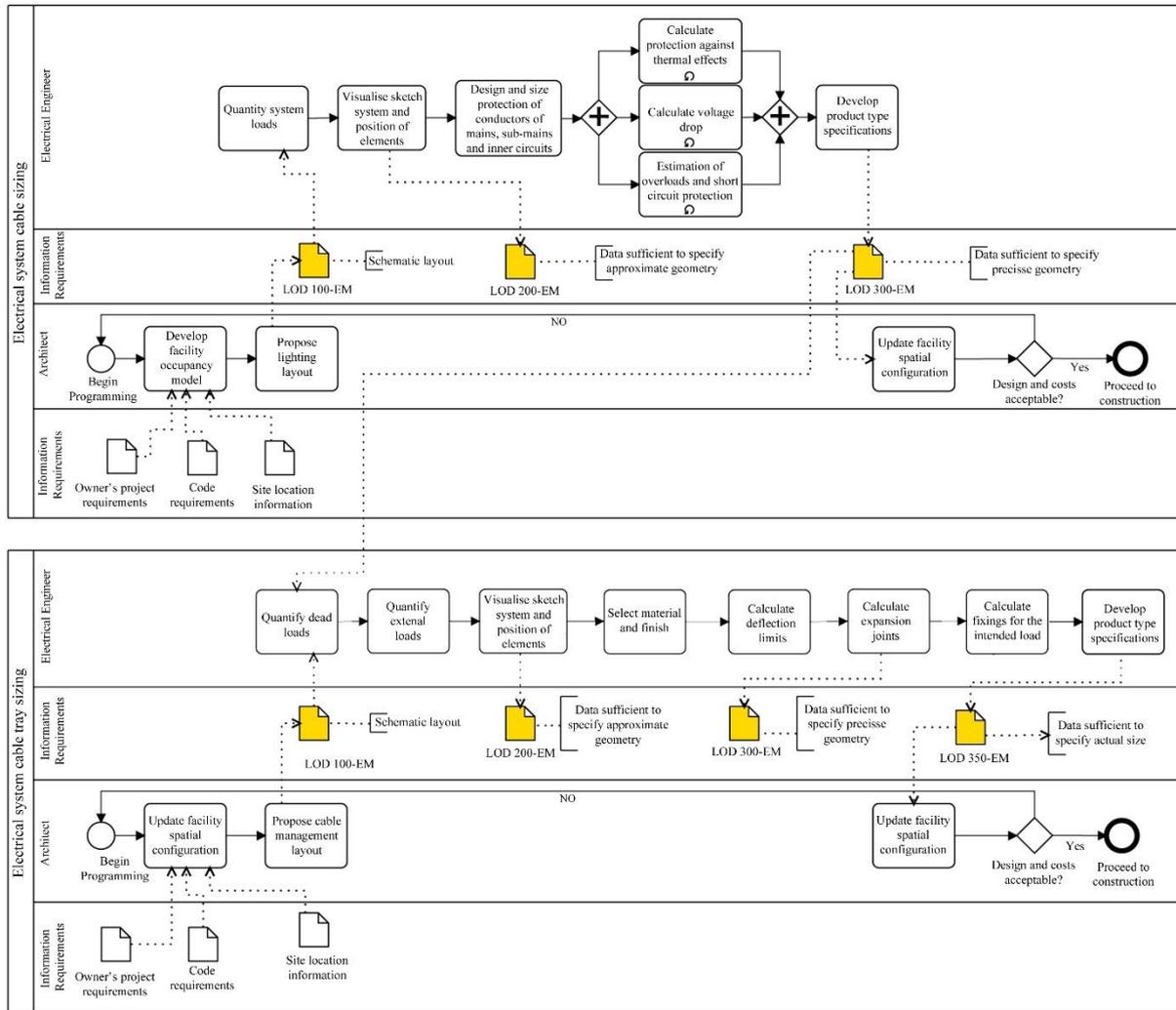


FIG 7. PM for cable and cable tray sizing.

The ER deduced 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	<i>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).</i>
Information Requirements	Preconditions <i>Electrical systems loads will have been estimated. Prior requirement: er_exchange_loads_model (LOD 100)</i> Information Units: <i>Cable</i> <i>Provides relevant information about the cable</i> Attributes or properties that must be exchanged: <i>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, I_z: Current-carrying capacity of the conductor, Ambient temperature, Impedance (Z)</i>

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/m Ω .mm ² for cooper)	×		
	S: section (mm ²)	CrossSectionalArea		
	Iz: Current-carrying capacity of the conductor	CurrentCarryingCapacity		
	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.

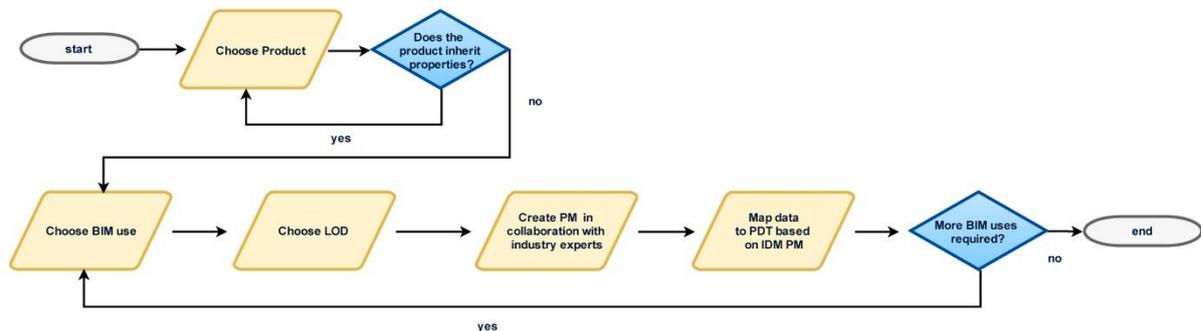


FIG 8. Process for IDM LOD creation.

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 BPMN 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 Karlshøj (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 Karlshøj'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 Karlshøj (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 Karlshøj (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 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 Karlshøj (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 Karlshøj (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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REFERENCES

- AENOR (2002). Reglamento Electrotécnico para Baja Tensión e Instrucciones Técnicas Complementarias (ITC) BT 01 a BT 51 [Electrotechnical Regulation for Low Voltage Systems and Complementary Technical Instructions BT 01 to BT 51]. Spain: AENOR. (In Spanish).
- AENOR (2004). Electrical installations of buildings. Part 5: Selection and erection of electrical equipment. Section 523: Current-carrying capacities in wiring systems.
- AIA (2013). AIA Document G202–2013. Project Building Information Modeling Protocol Form. American Institute of Architects.
- Aram, S., Eastman, C., Sacks, R., Panushev, I. and Venugopal, M. (2010). Published. Introducing a new methodology to develop the information delivery manual for AEC projects. CIB W78 2010, 2010 Cairo, Egypt.

- Autodesk. (2015a). About wire sizing [Online]. Available: <http://knowledge.autodesk.com/support/revit-products/learn-explore/caas/CloudHelp/cloudhelp/2016/ENU/Revit-Model/files/GUID-0F801DCD-18CD-4B7A-A64F-D4D9E8A4CEA9-htm.html> [Accessed 23/02/2015].
- Autodesk. (2015b). Free software download for students and educators [Online]. Available: <http://www.autodesk.com/education/free-software/revit> [Accessed 24/02/2015].
- BEAMA. (2014). BEAMA best practice guide to cable ladder and cable tray systems Including channel support systems and other associated supports. Available at: <http://www.beama.org.uk/resourceLibrary/beama-best-practice-guide-to-cable-ladder---cable-tray-systems.html> [Accessed 02/08/2015].
- Benbasat, I., Goldstein, D. K. and Mead, M. (1987). The case research strategy in studies of information systems. *MIS quarterly*, 369-386.
- Berard, O. and Karlshoej, J. (2012). Information delivery manuals to integrate building product information into design. *ITcon*, 17, 63-74.
- BIM4M2. (2014). BIM Adoption by Product Manufacturers. Available at: http://bim4m2.co.uk/wp-content/uploads/2015/02/BIM4M2-BIM-Adoption-by-Product-Manufacturers_03Feb.pdf [Accessed 02/07/2015].
- BIM Forum (2015). Level of Development Specification for Building Information Models. Specification BIM Forum.
- BIM Forum. (2016). LOD [Online]. Available: <http://bimforum.org/lof/> [Accessed 12/02/2016].
- BIM Task Group. (2014). Frequently asked questions [Online]. Available: <http://www.bimtaskgroup.org/bim-faqs/> [Accessed 10/09/2015].
- BSI (2013). PAS 1192-2 Specification for information management for the capital/delivery phase of construction projects using building information modelling. British Standards Institution.
- Cabinet Office (2011). Government Construction Strategy (GCS). Cabinet Office.
- Chipman, T., Fallon, K. K., Feldman, R. A., Williams, G. and Fadojutimi, O. (2013). Ontology for Life-Cycle Modelling of Electrical Distribution Systems: Model View Definition. In: Kristine Fallon Associates, I. (ed.). Washington: US Army Engineer Research and Development Center, Construction Engineering Research Laboratory (ERDC-CERL).
- CIBSE. (2015). Product Data Templates and Product Data Sheets [Online]. Chartered Institute of Building Services. Available: <http://www.cibse.org/knowledge/bim-building-information-modelling/product-data-templates> [Accessed 07/01/2016].
- CIC (2010). Project Execution Planning guide version 2.0. The Computer Integrated Construction Research Group and The Pennsylvania State University.
- CIC (2013). Building Information Model (BIM) protocol, Standard Protocol for use in projects using Building Information Models In: (CIC), C. I. C. (ed.) 1 ed. London: Construction Industry Council
- Curtis, B., Kellner, M. I. and Over, J. (1992). Process modeling. *Communications of the ACM*, 35, 75-90.
- Eastman, C., Jeong, Y., Sacks, R. and Kaner, I. (2010). Exchange Model and Exchange Object Concepts for Implementation of National BIM Standards. *Journal of Computing in Civil Engineering*, 24, 25-34.
- Eastman, C., Teicholz, P., Sacks, F. and K., L. (2011). *BIM Handbook - A Guide to Building Information Modeling for Owners Managers Designers Engineers and Contractors*, Wiley - Blackwell.
- Fai, S. and Rafeiro, J. (2014). Establishing an Appropriate Level of Detail (LoD) for a Building Information Model (BIM)-West Block, Parliament Hill, Ottawa, Canada. *ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, 2, 123.
- Gigante-Barrera, A. (2014). Level 2 BIM maturity implementation within the UK construction industry: A critical approach for designer. Dissertation, University of Birmingham.

- Gigante-Barrera, A. and 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. and Makanae, K. (eds.) Proceedings of the 16th International Conference on Computing in Civil and Building Engineering. Osaka, Japan: ICCCB2016 Organizing Committee.
- Gilmore, T., Krantz, J. and Ramirez, R. (1986). Action Based Modes of Inquiry and the Host-Researcher Relationship. *Consultation: An International Journal* 5, 160-176.
- Han, K. K., Cline, D. and Golparvar-Fard, M. (2015). Formalized knowledge of construction sequencing for visual monitoring of work-in-progress via incomplete point clouds and low-LoD 4D BIMs. *Advanced Engineering Informatics*, 29, 889-901.
- HM Government (2015). Digital Built Britain, Level 3 Building Information Modelling - Strategic Plan.
- Hooper, M. (2015). Automated model progression scheduling using level of development. *Construction Innovation*, 15, 428-448.
- ISO (2010). ISO 29481-1. Building information modelling – Information delivery manual – Part 1: Methodology and format, International Organization for Standardization. Geneva, Switzerland.: International Organisation for Standardisation.
- Jones, B. B. and Brazzel, M. (2014). *NTL Handbook of Organization Development and Change: Principles, Practices, and Perspectives (2nd Edition)*, Somerset, NJ, USA, Center for Creative Leadership.
- Klein, H. K. and Myers, M. D. (1999). A set of principles for conducting and evaluating interpretive field studies in information systems. *MIS quarterly*, 67-93.
- Kreider, R. G. and Messner, J. I. (2013). The Uses of BIM, Classifying and Selecting BIM Uses. In: Construction (CIC) Research Group at the Pennsylvania State University (ed.). University Park, PA, USA.
- Lee, Y.-C., Eastman, C. M. and Solihin, W. (2016). An ontology-based approach for developing data exchange requirements and model views of building information modeling. *Advanced Engineering Informatics*, 30, 354-367.
- Legrand Electric Ltd. (2016). SWIFTS® Cable Tray Product Technical guide. In: UK, L. E. L. (ed.).
- Luth, G. P., Schorer, A. and Turkan, Y. (2014). Lessons from Using BIM to Increase Design-Construction Integration. *Practice Periodical on Structural Design and Construction*, 19, 103-110.
- Maria-Angeliki, Z., Robby, S. and Kirti, R. (2014). Defining the sustainable building design process: methods for BIM execution planning in the UK. *International Journal of Energy Sector Management*, 8, 562-587.
- Nawari, N. (2012). BIM Standard in Off-Site Construction. *Journal of Architectural Engineering*, 18, 107-113.
- NYCDDC (2012). BIM Guidelines. New York City Department of Design + Construction.
- Recker, J. (2010). Opportunities and constraints: The current struggle with BPMN. *Business Process Management Journal*, 16, 181-201.
- Robson, C. (2002). *Real world research*. 2nd. Edition. Blackwell Publishing. Malden.
- Shahin, A. and Mahbod, M. A. (2007). Prioritization of key performance indicators: An integration of analytical hierarchy process and goal setting. *International Journal of Productivity and Performance Management*, 56, 226-240.
- Staub-French, S. and Khanzode, A. (2007). 3D and 4D modeling for design and construction coordination: issues and lessons learned. *ITcon* 12, 381-407.
- Steel, J., Drogemuller, R. and Toth, B. (2012). Model interoperability in building information modelling. *Software & Systems Modeling*, 11, 99-109.
- USACE (2014). Minimum Model Element Matrix M3 v1.3 US Army Corps of Engineers.

- VA CFM (2010). The VA BIM Object Element Matrix Manual Release v1.0 (attributes) U.S. Department of Veterans Affairs (VA) Office of Construction & Facilities Management (CFM).
- Van Kolck, M., Hodkinson, B. and Needham, C. (2012). Australian and New Zealand Revit Standards. ANZRS.
- Wix, J. and Karlshøj, J. (2010). Information Delivery Manual Guide to Components and Development Methods. BuildingSMART International.
- Woo, J.-H., Clayton, M. J., Johnson, R. E., Flores, B. E. and Ellis, C. (2004). Dynamic Knowledge Map: reusing experts' tacit knowledge in the AEC industry. *Automation in Construction*, 13, 203-207.
- Wood, J., Panuwatwanich, K. and Doh, J.-H. (2014). Using LOD in Structural Cost Estimation during Building Design Stage: Pilot Study. *Procedia Engineering*, 85, 543-552.
- Wu, W. and Issa, R. (2015). BIM Execution Planning in Green Building Projects: LEED as a Use Case. *Journal of Management in Engineering*, 31, A4014007-4014001 - A4014007-4014018.
- Yin, R. K. (2013). Case study research: Design and methods, Sage publications.

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/downloads/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	3 rd 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	