A grounded theory based framework for level of development implementation within the information delivery manual

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INTRODUCTION

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 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).

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: the section 0 provides a brief introduction to the IDM environment. Section 0 discusses the methodology, and section **Error! Reference source not found.** 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 0 and 0 presents the findings that can make LOD susceptible to be standardised in a global context. The paper concludes with sections 0 and 0, containing the main conclusions and recommendations for future research on LOD standardisation.

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 **Error! Reference source not found.**): *process map (behavioural), narratives (organisational), exchange requirements (informational), and narrative business rules (functional).* The present study 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 **Error! Reference source not found.**):

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)

METHODOLOGY

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 **Error! Reference source not found.**). To carry out the coding stage (section **Error! Reference source not found.**), BIM guidelines and regulations were collected and reviewed from both government and private institutions from 9 different countries from North America and Europe 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 0). During the memo writing stage the theoretical constructs are systematically compared (see section 0). During the last stage called theoretical sampling (see section 0), 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 0). 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.

Figure 2. Grounded theory methodology

CODING STAGE - MEASUREMENT OF BIM MODEL PROGRESSION IN NORTH AMERICA AND EUROPE

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 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.

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

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.

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 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 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.

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

LOD Memo Taking and Theoretical Sampling Stage Combined

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.

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 to UK standard staged submission requirements such as for example the CIC scope of services stage definitions (BSI, 2013).

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, 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.

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 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.

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.

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, 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.

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.

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.

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.

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).

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.

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´ 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.

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	(Bips, 2007; BSI, 2013)	(VicoSoftware, 2016)	NA

	DAS, 2011; VicoSoftware, 2016)			
Classification → Building Elements	(AIA, 2008, 2013b; Bips, 2007; BSI, 2012b, 2013; Gravicon, 2012; VicoSoftware, 2016)			Positive support
Classification → Stage	(BSI, 2013)			NA
Classification → Attributes	(VA CFM, 2010)			NA

Error! Reference source not found. presents a LOD model which relates LOD constructs' pairwise comparisons and IDM perspectives from section 0 (LOD as a Process Oriented Standard). 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

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).

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.

CONCLUSIONS

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.

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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REFERENCES

ADEB-VBA. (2015). *Building Information Modelling – Belgian Guide for the construction Industry*. Brussel, Belgium: http://adeb-vba.be/the-guide-to-bim.pdf

AEC Infosystems Inc. (2010). *The VA BIM Guide*. National Institute of Building Sciences

AEC UK. (2009). AEC (UK) BIM Standard *A practical & pragmatic BIM standard for the Architectural, Engineering and Construction industry in the UK.*: AEC (UK) CAD & BIM Standards

AEC UK. (2012). AEC (UK) BIM Standard *Implementing UK BIM Standards for the Architectural, Engineering and Construction industry*: AEC (UK) CAD & BIM Standards

AIA. (2008). E202–2008 *Building Information Modeling Protocol Exhibit*: The American Institute of Architects.

AIA. (2013a). AIA Document E203–2013 *Building Information Modeling and Digital Data Exhibit*: The American Institute of Architects.

AIA. (2013b). AIA Document G202–2013 *Project Building Information Modeling Protocol Form*: American Institute of Architects.

AIA. (2013c). Guide, Instructions and Commentary to the 2013 AIA Digital Practice Documents *AIA Document E203™–2013, Building Information Modeling and Digital Data Exhibit*: The American Institute of Architects.

AIA Document G201™–2013, Project Digital Data Protocol Form: The American Institute of Architects.

AIA Document G202™–2013, Project Building Information Modeling Protocol Form: The American Institute of Architects.

Aram, S., Eastman, C., Sacks, R., Panushev, I., & Venugopal, M. (2010). *Introducing a new methodolgy to develop the information delivery manual for AEC projects.* Paper presented at the CIB W78 2010, Cairo, Egypt.

Berard, O., & Karlshoej, J. (2012). Information delivery manuals to integrate building product information into design. *ITcon, 17*, 63-74.

BIM Forum. (2013). Level of Development Specification *for Building Information Models*: Specification BIM Forum.

BIM Forum. (2014). Level of Development Specification *for Building Information Models*: Specification BIM Forum.

BIM Forum. (2015a). Level of Development Specification *for Building Information Models*: Specification BIM Forum.

BIM Forum. (2015b). *Level of Development Specification* [LOD Attributes]: Specification BIM Forum.

BIM Forum. (2016a). Level of Development Specification *for Building Information Models*: Specification BIM Forum.

BIM Forum. (2016b). *Level of Development Specification* [LOD Attributes]: Specification BIM Forum.

Bips. (2006). Layer and Object Structures 2006 *(Lag- og objektstruktur 2006)* Ballerup, Denmark: Bips Digital Construction.

Bips. (2007). 3D Working Method 2006. Ballerup, Denmark: Bips Digital Construction.

BMVBS. (2013). *BIM Guidelines for Germany, Information and advice Final report (BIM-Leitfaden für Deutschland, Information und Ratgeber Endbericht),* Munich, Germany*: BMVBS.*

British Standards Institution. (2011). BS 8541-2:2011 *Library objects for architecture, engineering and construction. Recommended 2D symbols of building elements for use in building information modelling*: BSI. Standards Limited 2012.

BSI. (2012a). BS 8541-3:2012. In B. S. Institution (Ed.), *Library objects for architecture, engineering and construction. Shape and measurement. Code of practice*: BSI Standards Limited 2012.

BSI. (2012b). BS 8541-4:2012. In B. S. Institution (Ed.), *Library objects for architecture, engineering and construction. Attributes for specification and assessment. Code of practice*. : BSI Standards Limited 2012.

BSI. (2013). PAS 1192-2 *Specification for information management for the capital/delivery phase of construction projects using building information modelling* : BSI Standards Limited 2012.

BSI. (2014). BS 1192-4:2014 *Collaborative production of information Part 4: Fulfilling employers information exchange requirements using COBie – Code of practice.*: BSI Standards Limited 2012.

Building SMART Spanish Chapter. (2014). *BIM User's Guide (Guía de usuarios BIM)* : BuildingSMART Spanish Chapter.

BuildingSMART. (2016). Chapter Directory: BuildingSMART Retrieved from http://buildingsmart.org/chapters/chapter-directory/

Charmaz, K. (2015). Grounded Theory: Methodology and Theory Construction A2 - Wright, James D *International Encyclopedia of the Social & Behavioral Sciences (Second Edition)* (pp. 402-407). Oxford: Elsevier.

CIC. (2013a). Best Practice Guide for Professional Indemnity Insurance When Using Building Information Models. Great Britain: Construction Industry Council.

CIC. (2013b). Building Information Model (BIM) protocol, Standard Protocol for use in projects using Building Information Models (2013b). Great Britain: Construction Industry Council.

CIC. (2013c). Outline scope of services for the role of Information Management, (2013c). Great Britain: Construction Industry Council.

CIC RP. (2012). *BIM Planning Guide for Facility Owners*. University Park, PA, USA: Construction (CIC) Research Group at the Pennsylvania State University. Retrieved from http://bim.psu.edu

CIC RP. (2013). *BIM Planning Guide for Facility Owners*. University Park, PA, USA: Construction (CIC) Research Group at the Pennsylvania State University. Retrieved from http://bim.psu.edu

Eadie, R., Browne, M., Odeyinka, H., McKeown, C., & McNiff, S. (2013). BIM implementation throughout the UK construction project lifecycle: An analysis. *Automation in Construction*, *36*, 145-151. doi:http://dx.doi.org/10.1016/j.autcon.2013.09.001

East, E. W., Nisbet, N., & Liebich, T. (2013). Facility Management Handover Model View. *Journal of Computing in Civil Engineering, 27,* 61-67. doi:10.1061/(ASCE)CP.1943-5487.0000196

Ekholm, A., & Häggström, L. (2011). *Building classification for BIM–Reconsidering the framework.* Paper presented at the CIB W78-W102 2011: International Conference.

Fai, S., & 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*(5), 123.

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*. Paper presented at the Proceedings of the 16th International Conference on Computing in Civil and Building Engineering, Osaka, Japan.

Gigante-Barrera, A. n., 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), 22*(5), 80-103.

Glaser, B. (1978). Theoretical sensitivity Sociology Press. *Mill Valley, CA.*

Glaser, B. G. (1992). Basics of grounded theory: Emergence vs. forcing. *Mill Valley, CA.*

Gravicon. (2012) COBIM Commin BIM Requirements 2012. *Vol. version 1.0. Series 3 Architetcural Design*. Finland: Parties to the © COBIM project.

Hooper, M. (2015). Automated model progression scheduling using level of development. *Construction Innovation, 15*(4), 428-448. doi:doi:10.1108/CI-09-2014-0048

Kreider, R. G., & Messner, J. I. (2013). *The Uses of BIM, Classifying and Selecting BIM Uses*. University Park, PA, USA: Construction (CIC) Research Group at the Pennsylvania State University. Retrieved from http://bim.psu.edu/uses/the_uses_of_bim.pdf

Lee, Y.-C., Eastman, C. M., & Solihin, W. (2016). An ontology-based approach for developing data exchange requirements and model views of building information modeling. *Advanced Engineering Informatics, 30*(3), 354-367.

Luth, G. P., Schorer, A., & Turkan, Y. (2014). Lessons from Using BIM to Increase Design-Construction Integration. *Practice Periodical on Structural Design and Construction, 19*(1), 103-110. doi:doi:10.1061/(ASCE)SC.1943-5576.0000200

Maier C. (2015). *Building Information Modeling. Grundzüge einer open BIM Methodik für die Schweiz (Principles of an open BIM methodology for Switzerland),* Zurich: Ernst Basler + Partner.

Maria-Angeliki, Z., Robby, S., & Kirti, R. (2014). Defining the sustainable building design process: methods for BIM execution planning in the UK. *International Journal of Energy Sector Management*, *8*(4), 562-587. doi:10.1108/IJESM-04-2014-0005

NIBS. (2007). *United States – National Building Information Modeling Standard*, DC, USA: National Institute of Building Sciences.

NIBS. (2013). *United States – National Building Information Modeling Standard v3_2.7*. Washington, DC, USA: National Institute of Building Sciences.

NYCDDC. (2012). *BIM Guidelines*. New York City Department of Design + Construction. Retrieved from http://www.nyc.gov/html/ddc/html/home/home.shtml

Ohio DAS. (2011). *State of Ohio Building Information Modeling Protocol,* Ohio Department of Administrative Services. Retrieved from http://das.ohio.gov/Portals/0/DASDivisions/GeneralServices/SAO/pdf/SAO-BIMProtocol.pdf

Petter, S., DeLone, W., & McLean, E. (2008). Measuring information systems success: models, dimensions, measures, and interrelationships. *European journal of information systems, 17*(3), 236-263.

Rgd. (2012). Rgd BIM Standard *Rgd BIM Norm*. The Hague: The Netherlands: Rijksgebouwendienst Ministry of the Interior and Kingdom Relations.

Solihin, W., & Eastman, C. (2015). Classification of rules for automated BIM rule checking development. *Automation in Construction, 53*, 69-82.

Steel, J., Drogemuller, R., & Toth, B. (2012). Model interoperability in building information modelling. *Software & Systems Modeling, 11*(1), 99-109. doi:10.1007/s10270-010-0178-4

TPA of NY & NJ. (2012). *E/A Design Division BIM Standard Manual*, USA: The port authority of NY & NJ,.

UF. (2011). *BIM Execution Plan-BIM Guidelines and Standards v 1.1*, USA: University of Florida

USACE. (2014). *Minimum Model Element Matrix M3 v1.3*, USA: US Army Corps of Engineers.

USC. (2012). *Building Information Modeling (BIM) Guidelines v 1.6*, USA: USC Capital Construction Development and Facilities Management Services

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).

VicoSoftware. (2016). BIM Level of Detail: VicoSoftware / Trimble Retrieved from http://www.vicosoftware.com/BIM-Level-of-Detail

Wix, J., & Karlshøj, J. (2010). *Information Delivery Manual Guide to Components and Development Methods*: BuildingSMART International. Retrieved from http://idm.buildingsmart.com

Wood, J., Panuwatwanich, K., & Doh, J.-H. (2014). Using LOD in Structural Cost Estimation during Building Design Stage: Pilot Study. *Procedia Engineering, 85*, 543-552. doi:http://dx.doi.org/10.1016/j.proeng.2014.10.582