Automated model progression scheduling using level of development

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Automated model progression scheduling using Level of Development

Abstract

Purpose - Level of Development (LOD) is a key parameter for describing digital content in a Building Information Modelling (BIM) context. It is seen as an important vehicle for specifying information exchange throughout a facilities lifecycle. However, hitherto there has been little research examining how, beyond the theoretical concept, LOD can be being applied and smartly utilised in practice. This study seeks to unravel the concept and reveal new insights into its application from a design management perspective.
Design / Methodology / Approach - Following a literature and document review, two small-scale case projects were identified. The first to temper the state of the art theory and understand what happens in practice today – discovery led. The second, to drill down to the core of LOD utilisation to support planned model progression and test a plausible novel methodology to automate associated work-flow – theory led.
Findings - Results suggest that a lack of consistent understanding and utilisation exists and particular LOD errors are highlighted, but moreover that LOD can be so much more useful if integrated into a BIM-like workflow. Consequently, a new method of automatically comparing planned model progression with the current state of the model is presented.
Practical Implications - Advancement of the understanding of the concept and application of LOD and its usefulness has significant implications for design information management research.
Originality / Value - Fresh insights into LOD, concept and application are presented. The emerging proposed utilisation framework is novel and targets removal of known labour-intensive activities associated with LOD matrices whilst facilitating rich re-use of efficient model progression knowledge.

Keywords: BIM, Building Information Modelling, LOD, Level of Development, Model Progression.
Paper type: Research paper

Introduction

The concept and possible application of *Level of Development* (LOD) was pioneered by Vico and Webcor in 2005 as part of their Model Progression Specification (Vico, 2012). It was later refined by the AIA's IPD Task Force and adopted by the AIA in late 2008 (AIA, 2008). Versions of the same concept emerged around the world in BIM Standards and Guidelines about the same time: *Informationsniveauer*, BIPS (2009), *Detaljeringsgrad*, SIS (2008), *Model development Phases and Information Content Levels*, CRC (2009). The latest and perhaps most important publications advocating and explaining LOD are the AIA's new *G202-2013 Building Information Modeling Protocol Form* (AIA, 2013) which provides the basic LOD definitions together with a standardised responsibility matrix, and *Level of Development Specification* (BIM Forum, 2013) which attempts to clarify what the designations may mean for a comprehensive range of building systems.

Utilisation of LOD as object status identification parameter enables one to filter out which objects and object properties are relevant for particular purposes, in other words, that information required to carry out a specific BIM-Use. The expected benefits of using LOD as model parameter are improved effectiveness and efficiency in communicating and executing model development by allowing model content to be fully and clearly defined (Bedrick, 2013). However, current debates (McPhee and Succar, 2013a; McPhee, 2013b and McPhee *et al.*, 2013c; Kastell, 2013b) question its usefulness and furthermore, together with associated Model Progression Specifications (MPS) are critical of the labour-intensive, complicated schedules that are managed outside the BIM model. Nevertheless, it is claimed the sector needs LOD employed in a consistent way in order to benefit from automation (McPhee and Succar, 2013a). Moreover, if one is to allow that definitions of digital information deliverables be comprehensible by both man and machine, standardisation of methods to describe them seem an obvious boon. That is, by asserting better control of digital deliverables through LOD, one can improve accuracy of information exchanges by increasing knowledge about the reliability and specificity of a facilities digital representation.

Today where LOD and MPS are not utilised, (and hence scope of service content, extent and usability of deliveries left open to interpretation) downstream users of digital content use it at their own risk (Edgar, 2011). Mismatches occur resulting in confusion, frustration and missed opportunities (Hooper and Ekholm, 2012). Accordingly, a central issue is how to better facilitate adoption of LOD and associated responsibility matrices by improving their integration into BIM workflow. By viewing LOD as a linchpin to BIM - it is sits between the crucial systems of *Information Deliverables* and method to describe them and *Contractual Agreements and Responsibility for Information* – the aim of this research is firstly to uncover mechanisms facilitating and constraining utilisation of LOD to support information stewardship and secondly propose a method to automate model progression scheduling using LOD as pull parameter.

This objective was pursued by: 1) a review of the state of the art in LOD utilisation; 2) the study of a construction project in a major construction company where BIM has been used in an advance way; 3) development and exploitation of an experimental LOD model; 4) an analysis of empirical data and ratification of what is happening. This leads to the development of a promising new framework for integrating LOD utilisation into an automated workflow using model rule-sets and model checking tools.

Level of Development - Concept and Application

A literature review focusing on BIM and specifically the utility of LOD is provided to establish a context for the research. The concept and application of LOD in BIM projects is still relatively new, consequently there are limited existing studies to build on. This review therefore goes beyond academic publications to also include standards, guidelines and reports generated by government and other regulatory bodies, (AIA, 2008) (AIA, 2013a) (AIA, 2013b) (BIM Forum, 2013) (BIS, 2011) (CIC, 2013) (SIS, 2008) (Svensk Byggtjänst, 2011) current expert debates, (Kastell, 2013a) (Kastell, 2013b) (McPhee *et al*., 2013c) blogs, (McPhee and Succar, 2013a) (McPhee, 2013b) (Renehan, 2013) (Van, 2008) and articles published in respected online newsletters (Bedrick, 2008) (Bedrick, 2013) (Byggindustrin, 2013) that reflect the latest developments and philosophies of LOD in BIM.

Whilst technology has enabled a whole new level of collaboration through the use of proprietary BIM tools, the industry has some catching-up to do in terms of establishing common understandings of BIM concepts and applying consistent methodologies that may enable value-adding stewardship of digital information through construction project phases (Ekholm *et al*., 2013). A number of recent reports and standards (AIA, 2013; BIM Forum, 2013; Cuneco, 2012; Bedrick, 2013,) are advocating or reinforcing the importance of the concept of Level of Development (LOD) to support digital deliveries, however current debates (McPhee and Succar, 2013a, 2013b) (McPhee *et al*. 2013c) and (Kastell, 2013b), suggest both the concept and application of LOD today remains something of a theoretical and practical problem within the world of BIM.

Becerik-Gerber and Kensek (2010) highlight a lack of research on this topic and underline a need to research mechanisms [such as LOD] that may go some way towards providing standardised solutions to questions like: *what level of information is needed at each stage and who is responsible for it?* The AIA's Document E202-2008: Building Information Modeling Protocol Exhibit (AIA, 2008), recently updated as a set of digital practice documents (AIA, 2013b and 2013b), aims to address this question with a standardised protocol but it remains a high maintenance, stand-alone process that is created and managed outside the BIM.

In 2008, Bedrick highlighted that: *'at the core of architectural design is the process of moving from approximations to progressively more precise information. Representations of building elements in a BIM, though, are exact, whether they're intended to be or not, and can give a false indication of the precision actually known at a given point in the design process. Add to this confusion the fact that it is possible to use a BIM for many purposes (costing, scheduling, performance simulation, code checking, and visualization, to name just a few), some possibly not considered by the author of the BIM. The need for a framework for defining a BIM's precision and suitability for specific uses becomes obvious'* (Bedrick, 2008). From these circumstances the AIA's E202-2008 Building Information Modeling Protocol Exhibit (AIA, 2008) emerged as a stand-alone document designed to be appended to contract documents on BIM projects. Model Element Author (MEA) and Level of Development (LOD) arranged in associated model element classifications are cited as the 2 key ingredients that must be decided and recorded at the outset to avoid subsequent confusion and risk. Lighthart highlights LOD can be utilised as an alignment tool, then later in the process as means of checking contract compliance (McPhee *et al*., 2013c).

Since the AIA's first official publication of AIA E202, the concept of LOD has gone through further refinement. Expansion and clarification of the concept through description and graphic representation can be found in BIM Forum (2013). However, reports on the efficient application are few. It is known that the utilisation of MPS and associated LOD tables can be obscure, time-consuming, even difficult to relate to, but how has the research community responded? Leite *et al*., (2011) reports on the impact of Level of Detail (LoDt) on modelling effort through design development. However there is little research on LOD, or the impact on hours spent modelling and administrating model progression diligently and if / how processes could be streamlined to utilise LOD more effectively. Whilst Leite *et al*. (2011) highlights the impact of modelling effort to achieve various LoDt's and notes effects on modelling man-hours, they side-step the BIM LOD indices of *reliability* and *specificity*.

Choi *et al*. (2011) assumes a rather simplistic interpretation of LOD in their study of data interaction. Li *et al*. (2008) refers to LOD, but proposes a different nomenclature with similar taxonomy scale. He refers only to geometry. Neither object properties or the real meaning of LOD (*reliability* and *specificity*) surface. Chang and Shih (2013) are nearer the mark in reference to the AIA's standard definitions, though later regresses to project stages. However Chang and Shih do provide insight as to what a model with respective LOD's might contain and even suggests selections of functions a model at a particular LOD should be able to fulfil. But the question remains, as an alternative to manual personal checklists (which are emerging as a quick-fix solution), is there a way LOD utilisation could be better integrated into BIM workflow though automation?

Whilst the idea of LOD is not new, its meaning and application in a BIM context has created notable confusion which has manifested in ad hoc utilisation and regression to an understanding of it as simply quantity of detail instead of reliability and specificity of information. To move forward one must look again at current debates and how consultants are using LOD in practice. McPhee, for example, offers a number of problematic scenarios and argues both for and against its use (McPhee *et al*., 2013c). McPhee *et al*. (2013c) asks *what is LOD, is it useful or just another pointless deliverable*? Highlighting that even after the publication of the Level of Development Specification (BIM Forum, 2013), confusion remains about what LOD levels mean and how they should be used.

The argument deployed most often against the use of LOD and MPS, whether brokered by the AIA's Protocol Exhibit (AIA, 2013) or another system, is that its use implies high maintenance activities carried out outside the BIM. This position has been most famously advanced by McPhee and Succar, 2013a, 2013b and McPhee *et al*. 2013c in current debates involving industry experts. He articulates: '*All the BIM guides have some form of LOD table in them. They are invariably enormous complicated schedules that are managed separate to the BIM model'* (McPhee, 2013b).

Re-Occurring Issues: Confusion and Frustration

Collectively one can observe the re-occurrence of several emerging issues concerning LOD concept and application; moreover the main reasons why hitherto the application of LOD has been both inconsistent and weak can be assigned or designated to these same issues, namely: 1) a lack of consistent understanding and utilisation of LOD in practice; 2) scepticism over its usefulness; and 3) difficulty in integrating LOD and MPS into a BIM-like work flow, vis-á-vis a dissatisfaction with the management of it outside the BIM in high maintenance stand-alone documents. These issues are echoed by Lighthart (McPhee *et al*., 2013c) who reports widespread confusion as to how it can be applied, frustration over its high maintenance legacy and division over its usefulness. Even Guttman, subcommittee member of the action group that spawned the original AIA E202, expresses concerns about the practicalities of LOD: *'I have always been troubled by the way that we sometimes promote standards that are not really based on a history of industry practice'* (McPhee *et al*, 2013c). All this suggests a need for further investigation into firstly its usefulness and secondly it's integration into BIM work-flow. That way, given time, one may discreetly address the issue of inconsistent utilisation.

To the question: *'is it useful?'* Lighthart intimates it would be so much more useful if LOD in association with MPS could be used to automatically check planning progression against the status of the model (McPhee *et* *al*., 2013c). That way the concept can be applied and managed within the BIM. Here one can start to consider where contribution can be made to the current state of knowledge. But first where does LOD sit in relation to developments at buildingSmart? Formal grouping of model contents into *views* is one of the initiatives led by buildingSmart (BuildingSMART, 2014). The idea is that model view definitions (MVDs) groups model contents, expediently identifying objects and object properties to be used at a certain LOD, for example to perform energy calculations, an acoustic analysis and the like. This work is still under development, however more MVD's are emerging. Related to this are Cuneco's latest initiatives (Cuneco, 2012). Cuneco are developing a novel method of deploying LOD in Danish practice. Their Method and Structure for Information Levels (Cuneco, 2012) explains a discrete LOD concept and application and proposes its integration to their construction classification system (CCS) and implementation in IFC. This represents a bold step forward for the concept and application of LOD and testament to its importance as object parameter. This together with other Cuneco initiatives is set to push the Danish BIM standardisation efforts further to the forefront.

Research Gap and Contribution

In this respect, this study seeks not to re-invent the wheel, rather to explore alternative ways in which LOD can be used to support model progression. Hitherto, there is a lack of insight into how one might utilise LOD to ensure design information is being authored sequentially and make best use of both office resources whilst focusing on value-creating activities. Both Cuneco (2012) and BIM Forum (2013) describe the benefits of LOD employment in similar terms: to support information production and exchange. However there is little case evidence to support this, and it has not been within the scope of the guidelines or standards to offer examples. It is here, together with the offering of an alternative methodology, contribution can be made to the current state of knowledge.

Lighthart (McPhee *et al*., 2013c) suggest there is room for greater clarity, and implies something tangible to test: *is there a way of automatically verifying model content against intended use and programme, that could then be standardised and become a universally accepted norm?* This research takes this question and suggests, develops and tests a theoretical framework demonstrating how this might be achieved.

Research Methodology

The research design has been flexible from the start to enable a framework of reference to emerge during the study. The literature reviewed; current international debates, the emergence of new supporting documents (LOD Specification 2013, AIA G201 and 202 2013), together with consultant interviews and discussions revealed a real need for research in the rather specialised theme within the field of BIM: Level of Development. To move forward, two small scale but very different case projects were identified. The first to temper the state of the art theory and understand what happens in practice today – discovery led. The second, to drill down to the core of LOD utilisation to support planned model progression and test a plausible novel methodology to automate associated work-flow – theory led. The aim is to remove the mundane high maintenance activities currently associated with LOD tables by adopting standardised rule-sets to automatically check the model against planned progression.

Execution follows a number of sequential steps, namely: a review of the state of art in LOD utilisation; isolation of the issues, analyses of a strategic case project; ratification of what's happening and finally development of a possible framework for integrating LOD utilisation into an automated workflow (Figure 1). Conclusions reflect over the positioning of the results against the current state of knowledge.

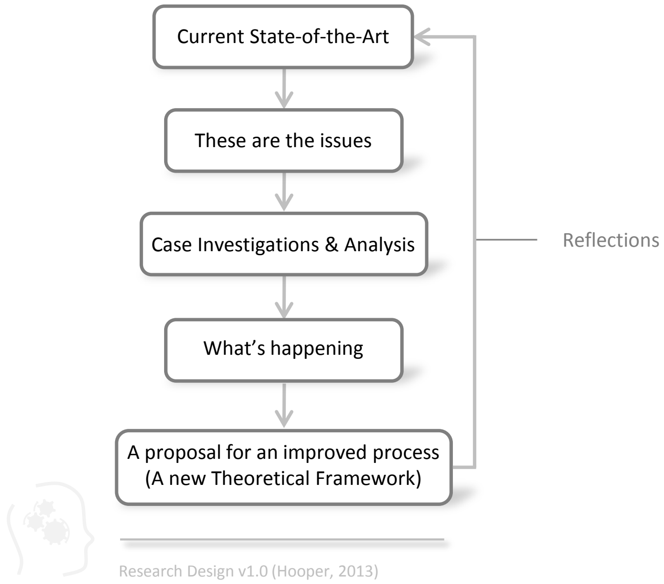

Figure 1: Research Execution

A qualitative approach was adopted from a critical realism perspective where acknowledgement is made to contextual factors (associated with case) whilst also arguing the phenomena under study can occur in similar settings (Saunders *et al*., 2009). Adoption of this approach supports the investigation in so far that it allows for the study of a complex and contemporary phenomena over which the investigator had little or no control (Yin, 2009). Data gathered has been deductively analysed to expose and interrogate the key components that influence the particular phenomena under study as described by Denscombe (2008). This enables a clearer understanding of both utilisation of LOD in context and provides insight into emerging possibilities that can be deemed relevant generally. In summary, a 'realistic' perspective was adopted because it supports research in practice and investigation into real world problems; employing a deductive approach because testing of theory was sought; and finally, a case strategy approach was engaged because it lends itself to discovery and theory-led research.

The literature review supported the formulation of a testable hypothesis which enables the study to stay within feasible limits (Yin, 2009). The data collection process started with an interview protocol, which was developed to increase consistency of the research (Yin, 2009). Accordingly, all interviews, associated with Case #1 followed similar case questions and collection procedures. The protocol focused on a narrow set of questions designed to unravel what happens in practice and facilitated the production of the Case #1 process map upon which is built a new LOD work-flow. Further empirical data was collected through documents, telephone and e-correspondence. Case #2 allowed breaking of new ground in developing a new theoretical framework for automated model progression scheduling using LOD. The case study's strength is its ability to deal with a full variety of evidence - documents, interviews, and observation - beyond what might be available through other research approaches (Yin, 2009).

A deductive approach is chosen for maximizing reliability and credibility in the results. The main unit of analysis is evidence of barriers and opportunities for LOD utilisation to support digital deliveries and model progression, with embedded units being the responses from interview sessions. Analysis began with transcribing interview responses into statements, abstracting and transforming the data into process-orientated events where evidence was convergent and corroborated. This enabled the development of a process-map recording what happened in Case #1. The emerging process-map is then re-worked to leverage LOD and feeds into the development of a new theoretical framework which is tested in Case #2.

Data Collection and Case Descriptions

The collection of empirical material has been assembled to firstly facilitate a deeper understanding of the circumstances and context that LOD as object parameter may be used, and secondly study model progression though the design and construction process and identify if and how automation is feasible. To meet these objectives a series of interviews with key personnel within design consultant and contracting organisations were carried out in a connection with a replacement bridge project where BIM is used in an advanced way (Bridge over Arbogaån near Röfors) together with the generation and examination of a controlled experimental model (The LOD Experiment).

Case #1: Bridge over Arbogaån near Röfors

In order to correlate state-of-the-art theory on LOD utilisation and understand how it might be adopted usefully in practice, a suitable case project was selected - Bridge over Arbogaån near Röfors, Sweden (Figure 2). The project, initiated and commission by the Swedish Transport Administration (Trafikverket), involved procuring a replica replacement 63.5m long bridge over a river near Röfors in Sweden. It was a small enough project to allow one to look closely at the content and purpose of information exchanges and understand what happens in practice. The project was a pilot where the team sought to break new ground with regards to integration of process, combined project tasks and data control utilising BIM. Significantly, the tender documents were let as a BIM model and digital documents instead of traditional drawings and specifications, and the contract documents hierarchy was amended to place BIM deliverables in the centre. The case is intrinsically interesting and a unique opportunity emerged to study it. The bridge was completed in August 2013.

Figure 2: Bridge over Arbogaån near Röfors (Photo: Sven Olof Ahlberg, Kulturbyggnadsbyrån)

Case #2: The LOD Experiment

The second case, The LOD Experiment (Figure 3), was initiated through the need to establish a platform to develop and test our theoretical proposition. The rational here is that a secondary case is established for the purposes of theory-building and theory-testing. This theoretical exemplar enabled experimentation with crucial object parameters and exploit the capabilities of modern model-checking tools. The digital project, based on a simple two storey dwelling, was created using a common BIM-Authoring tool and represented a necessary component of a research effort designed to produce both theoretical and practical results.

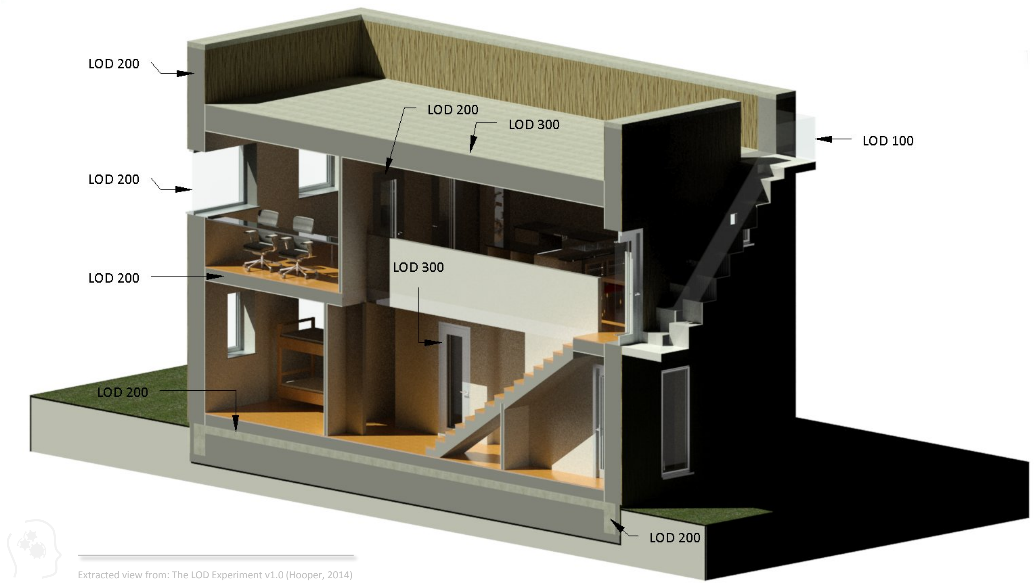

Figure 3: Extracted view from: The LOD Experiment (Source: Lund University)

A purpose-made rule-set was created to automatically interrogate model compliance with the delivery specification. The BIM-Use adopted was *3D Design Coordination* at *Scheme Design* stage.

Theory

Current theory suggests LOD is a key parameter for describing and aligning digital information content in a BIM context (Bedrick, 2013). On the one hand it represents an important component to describe a BIM-Info Deliverable (specificity and reliability of digital objects), and on the other, a unit to describe authorship responsibility connected to a party's contractual obligations. Figure 4 highlights LOD may represent something of a linchpin to BIM.

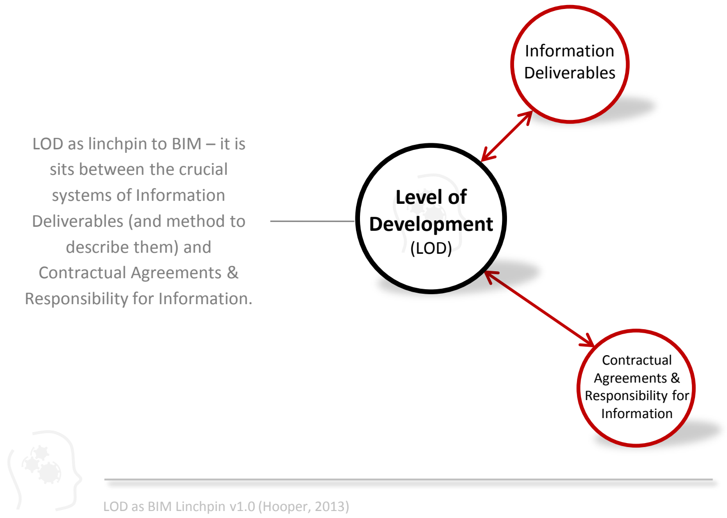

Figure 4: LOD as BIM Linchpin

Some object attributes are straight forward and can be readily automated and managed in the model including, *object author*, *object creation* and *last changed date*, and *object classification*, but others, for example *object status* and *Level of Development* are more awkward to handle. Whilst it is straightforward to stamp a drawing with a 'Preliminary' or 'Tender Document' or 'For Construction' status, in a BIM project it is less clear. Objects can have different statuses at particular project stages; whole models are unlikely to ever have one particular status (McPhee, 2013b). This is where the LOD parameter helps. It enables downstream users to understand the degree of completeness vis-á-vis how much they can rely on the information at object level (OpenBIM, 2013b).

Figure 5 illustrates key information deliverable parameters and where the LOD component fits in. Here one can understand what the relevant indices are, what they do and the potential to automate their production and management through model development phases.

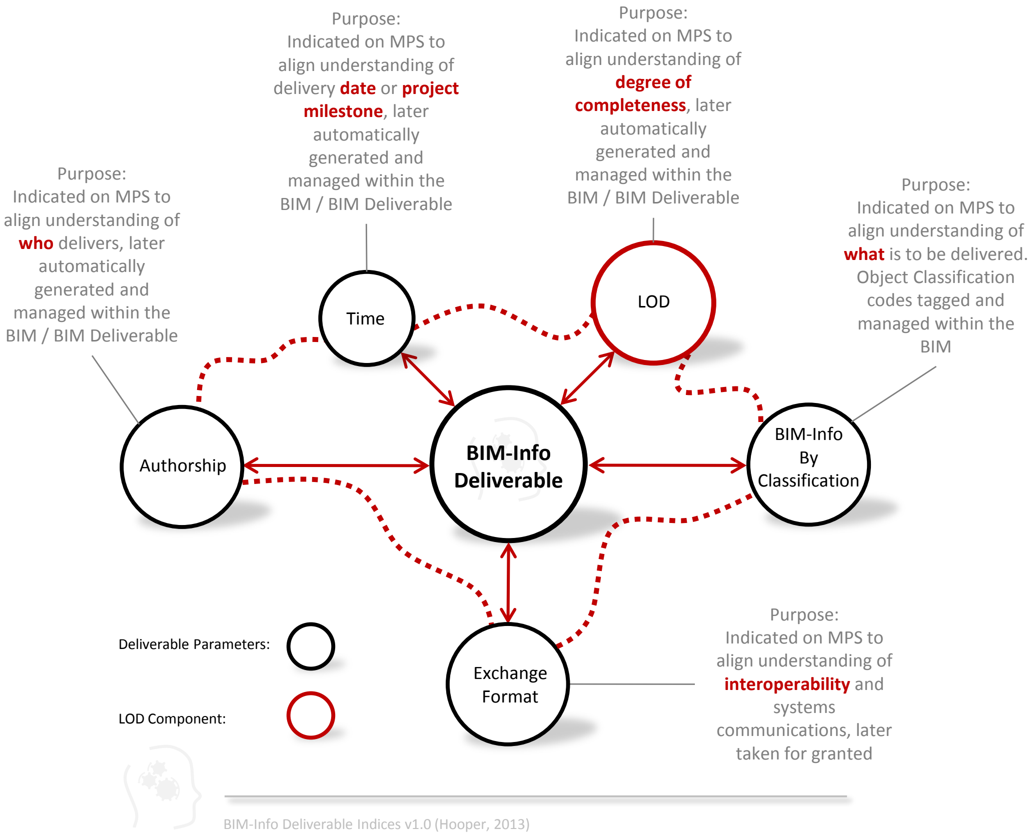

Figure 5: BIM-Info Deliverable Indices

Lighthart and Succar, further dissects LOD into 2 important indices: *reliability* - the degree to which users can rely of the information; and *specificity* – the degree of geometrical and information accuracy (McPhee and Succar, 2013a; McPhee et al., 2013c). Furthermore, in reference to the AIA's fundamental definitions of levels LOD 100-500, Succar points out that whilst it is awkward to assign anything but a round number LOD (100-500) without opening up a whole new can of worms as to what is meant, '*LOD tries to paint a complex picture with a single colour (5 shades allowed). It is an excellent way to make all pictures similar but adding extra colours can make the picture a little more expressive*' (McPhee and Succar, 2013a).

LOD can, however also be expressed through object class and attributes. For example, at a certain LOD an object may be classified as an Element according to ISO 12006-2 (ISO, 2002), stating that its function is determined. Another LOD may require that the composition of the object is determined (by classification), or that its U-Value or loadbearing capacity is determined (by additional attributes). Furthermore, IDM (Information Delivery Manual) based on ISO 29481-1 and 2 is an emerging method of defining information exchange requirements on a software implementation basis. Ratified through BuildingSmart, the IDM method uses the open interoperable data model (IFC) and the output is often a MVD (Model View Definition) containing a subset of the IFC data model (Bips, 2014). The whole depends on comprehensive software implementation.

However, even used in its crudest form (LOD 100-500); Level of Development forms a crucial component of a digital delivery specification (Figure 6). In the example below, BIM-Info Classification listed on the left, followed by Responsible Party, LOD, Author, Receiver and Delivery Format. The target LOD enables alignment of expectations, and if used as the AIA intends, can form the backbone to information exchanges between parties and processes.

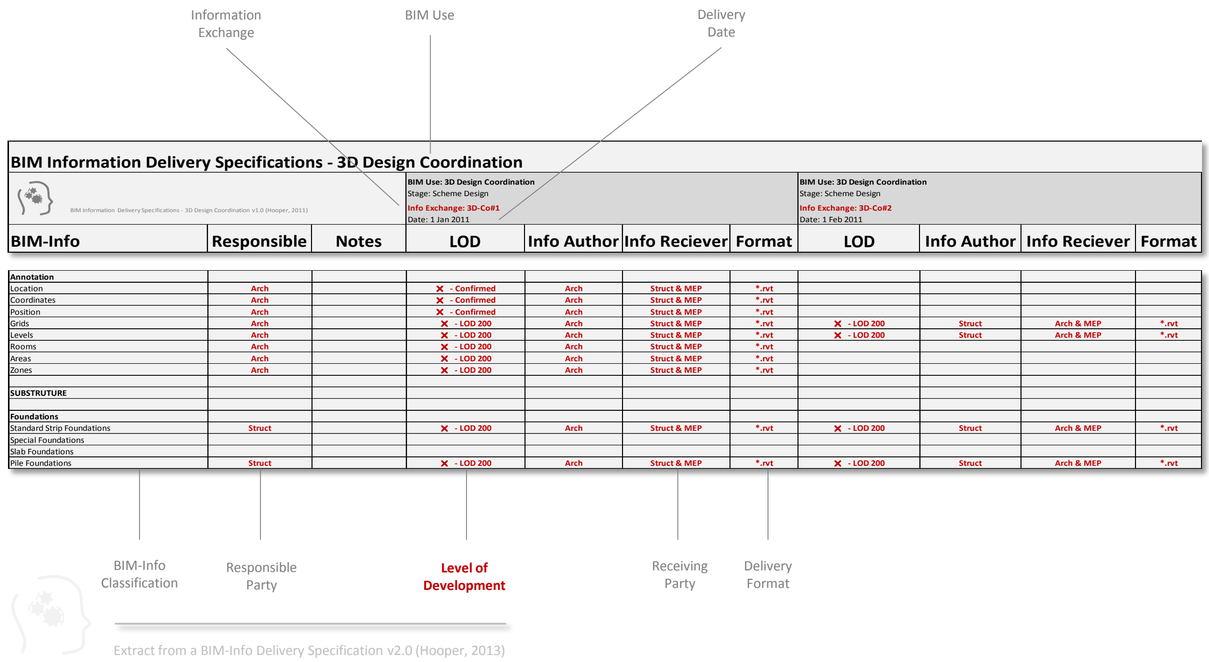

Figure 6: Extract from a Digital Delivery Specification (Source: Hooper and Ekholm, 2012)

It is conjectured that, in theory, it should be possible to exploit LOD deployed in delivery or model progression specifications (MPS) in a way that eliminates mundane manual tasks and assists authors in producing the right information at the right time, for the particular purpose. Figure 7, suggests a model of how this might be done using proprietary specification, modelling and validation tools. The delivery specification describes model content requirements using amongst others, LOD as object parameter. The BIM author populates the model accordingly and a rule checking tool is used to validate content. Non-compliances are highlighted for the BIM author to action.

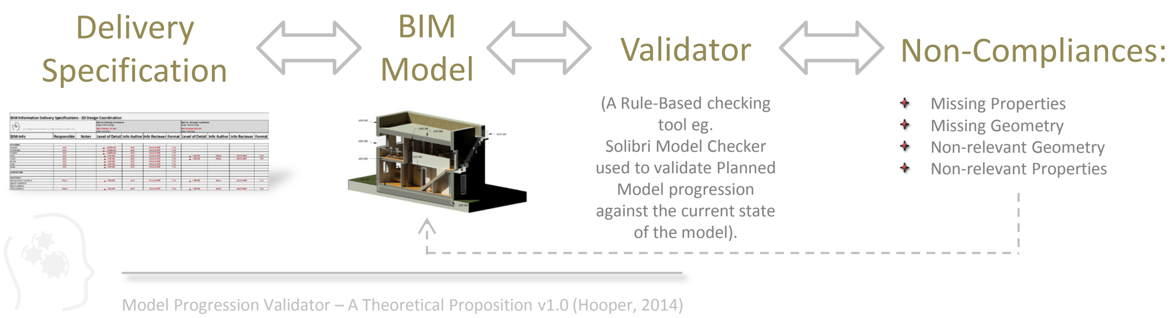

Figure 7: Model Progression Validator – A Theoretical Proposition

Results

Taking the resultant model development process from Case #1, a new LOD utilisation framework was designed to exploit LOD and guide the model development process more effectively that was tested in Case #2. The intentions were to develop an automated mechanism that may ensure the project was on track and enable implementation of optimal BIM-Uses along the way, thereby adding value to the process and maximising opportunities to leverage the data behind the virtual building.

Case #1: Observations

The main result of the Bridge over Arbogaån case study is an annotated process map (Figure 8) which firstly attempts to reveal what happened, and secondly inform us how practitioners may improve and better leverage LOD.

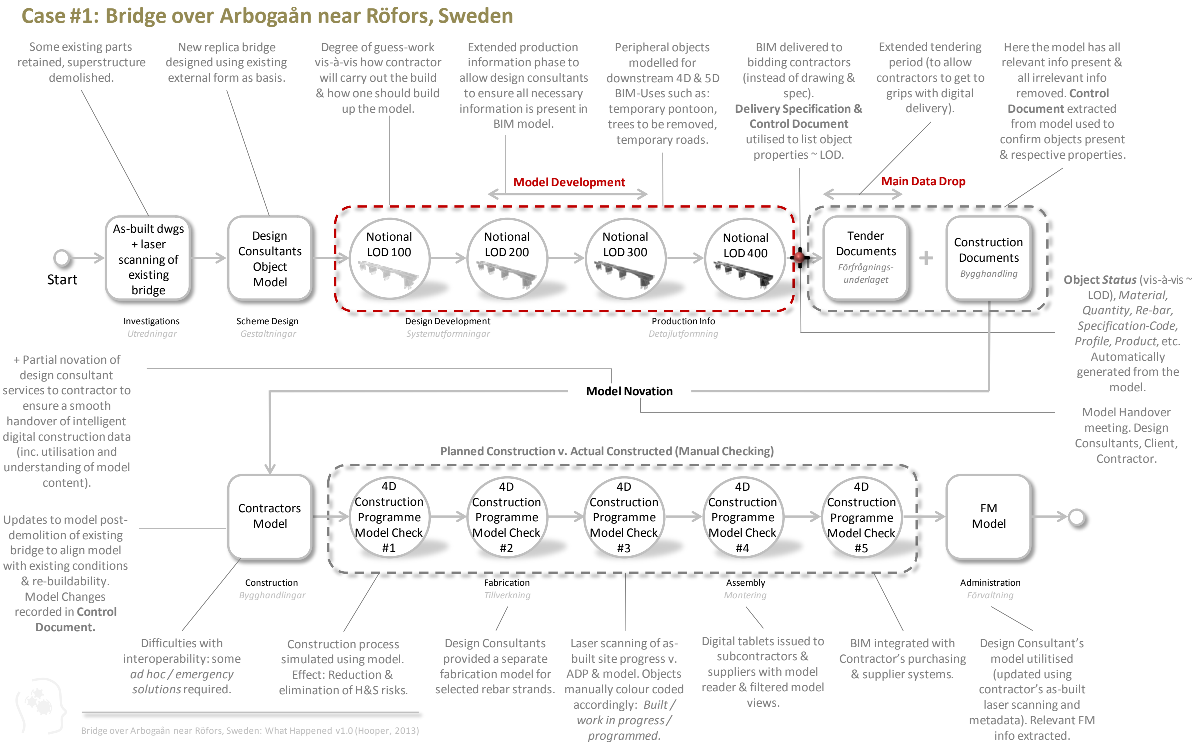

Figure 8: Bridge over Arbogaån near Röfors: What Happened

Whilst the intended benefits of delivering digital information to site and later for FM were realised, it is noted that utilisation of LOD (per the AIA's nomenclature) was only notionally observed through the crucial model development stages. The main reason for this was that there was no need or desire for design iteration - the bridge was simply to be a replica of the existing, whilst adopting current road safety standards and increased bearing capacity. The challenge was to incorporate all this into the existing external geometry and deliver a digital product model for tender and construction (OpenBIM, 2013a).

The impact of unambiguous digital information deliverables, defined through alternative parameters such as specification codes had a positive effect on the project outcome. Not just in hard terms: on time, on budget, but significantly on working relations. Colleagues became closer and more focused as a result of the new way of working (purposefully exploiting the digital asset) and common goals emerged from better defined, richer and more accessible deliverables. A key member of the design team was novated to the contracting team to enable a smooth transition of design information to the contractor domain. A significant effect of delivering contractual documents digitally instead of in paper form was that it *enabled* downstream BIM processes to be executed without quibble about responsibility for accuracy and correctness, avoiding the scenario of downstream users utilising the intelligent digital information at their own risk which hitherto has been an issue in Sweden (Edgar, 2011).

However, observations suggest that a lack of consistent understanding and utilisation of LOD exists and, in concurrence with the literature, discussions implied certain scepticism over its usefulness and reveal difficulties in managing object status and LOD expediently.

Unravelling Misconceptions about LOD

Whilst earlier findings on digital authorship (Hooper and Ekholm, 2012) suggest: 1) a tendency to focus on authoring the wrong information to the wrong LOD for BIM deliverables on the information delivery critical path; 2) abortive work and laborious effort on carrying out changes; 3) a tendency for BIM authors to wait till the other has reached a certain LOD till they commence their BIM contribution; 4) wasted opportunities, and delays in arriving at genuinely optimised solutions. Here, emerging from case investigations and more open discussions are 4 rather fundamental *LOD errors* which can be paraphrased into the following observations:

- LOD Error #1 - *We can't see the wood for the trees*: A serious consequence of a lack-lustre attention to level of development is the dire effects of content hoarding - models laden with irrelevant, wrong or out-of-date information making it simply not possible to see the wood from the trees.

- LOD Error #2 - *Using objects that may cover all eventualities*: Whilst it may seem a good idea to adopt objects that appear to cover all eventualities, they may come to serve as a hindrance to down-stream users. The information, the object, instead of being smart and actually meeting the needs of all users, becomes clumsy and un-usable, suggesting conflict between *versatility* and *usability*.

- LOD Error #3 - *Quick-Fix, reactionary ad hoc solutions in emergency situations*: A lack of industry-wide pre-defined standard solutions prevails. Fumbled, quick-fix solutions are often favoured to get deliverables issued on time, prioritised ahead of developing robust solutions and re-using knowledge which may render the process of model development more efficient, and improve output quality.

- LOD Error #4 - *Individual checklists v. Standardisation*: Working in a BIM mode demands a level of standardisation in both concepts, routines, processes and data formats (Ekholm *et al*, 2013). Whilst use of individual checklists is one way to organise one's own work and move ahead in earnest, digitalising and re-use of knowledge associated with routine activities can be seen as obvious benefit supported by BIM.

From Case #1 emerged a process map illustrating what may happen in practice today in a typical BIM project of its type. It provides clues as to where improvements can be made in a process where joined-up thinking is a key ingredient for success.

Outcome from Case #2
Moving forward, The LOD Experiment, a digital test-bed project, was established to examine the plausibility of the testable hypothesis that: *if there is a way of automatically comparing planned model progression with the current state of the model, MPS can be better integrated in to BIM work flow, LOD can be more useful, and mundane tasks can be eliminated.*

Emerging from in-house trials is a possible new framework, presented as a sequence of process steps, for integrating LOD utilisation into an automated workflow (Figure 9). This figure presents a refined illustrated documentation of the workflow tested. In step 1 one establishes and selects the applicable BIM-Use, and in step 2 deploys the associated Model Content, Structure and LOD Parameter Guide (MCSLPG). (As a more robust alternative to personal checklists, a standardised, re-usable model content specification was created. It is used to guide authors in what material to author – facilitating re-use of knowledge). In step 3 BIM authors proceed with creating the object-orientated 3D model, which is then automatically validated in step 4 using a rule-based model checking tool and a machine readable version of the MCSLPG. The validation process highlights *'bad objects'* ie, those objects that are not fit for purpose, being for example incorrect level of development for the BIM-Use. Step 5 allows for the release of an automatically generated burn-down chart (Scrum theory see Schwaber and Sutherland, 2013) illustrating planned model progression v. the actual state of the model. This can be viewed as a valuable contribution to the model development process and supports both BIM authors, project managers and stakeholders in understanding the current status and outstanding effort. Completed and remaining tasks are listed which can then be actioned in step 6. Finally, a lean, compliant model emerges in step 7.

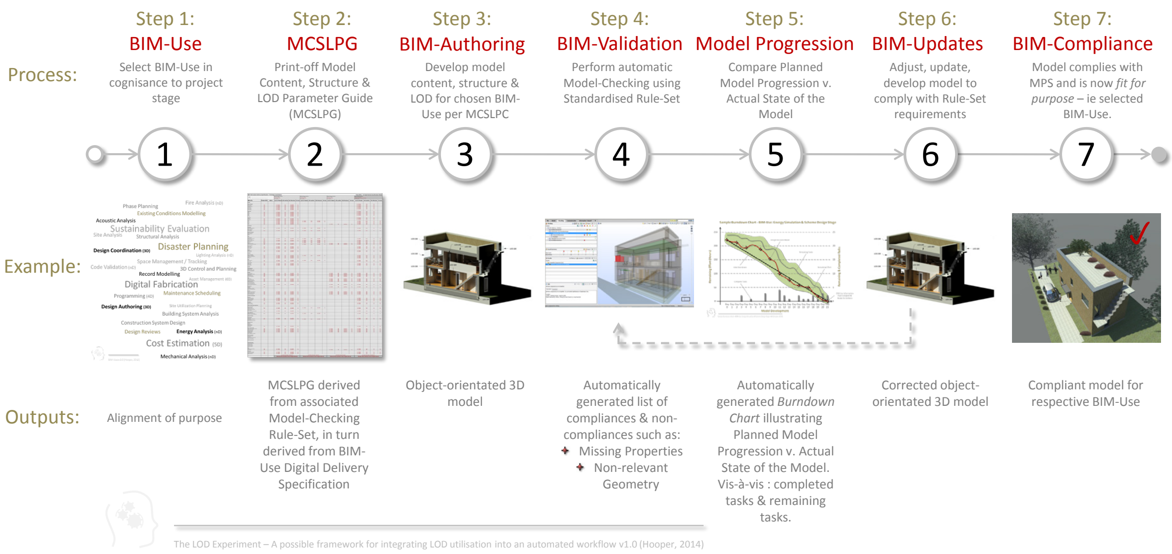

Figure 9: The LOD Experiment – A possible framework for integrating LOD utilisation into an automated workflow

This seven step BIM-Use orientated workflow was tested using proprietary BIM applications (Autodesk Revit and Solibri Model Checker). Two commonly deployed BIM-Uses were tested: *3D Design Coordination* at *Scheme Design Stage*, and *Energy Simulation* at *Design Development Stage.* A corresponding delivery specification is exported from a standardised model-checking rule-set crucially detailing, *BIM-Info Classification, LOD*, and *BIM-Info Author*. These rule-sets were created within Solibri Model Checker for the pilot and can be re-used. To control the experiment and validate compliance of the resultant model, the BIM was manually checked. Despite only 2 BIM-Uses were tested, the principle displays robustness and potential to support other applications. However, to be of wider function, a broader range of rule-sets should be created to support alternative parallel processes such as cost analysis.

Discussion

It is conjectured that if one substitutes this kind of work-flow during the model development stages, implementing multiple BIM-Uses in parallel, it is possible to assume a greater level of information leverage, and benefit from not only model development efficiency gains, but also better quality authorship and information exchanges.

Today the MPS with specified LOD participant outputs or exchanges exists as stand-alone documents (McPhee *et al*. 2013c) - not very BIM. Furthermore, industry experts question the usefulness of LOD and its suitability as BIM content descriptor (McPhee and Succar, 2013a). This research examined the concept and application of LOD in a BIM context and presents a novel method of exploiting it to support the information production process through utilisation of standardised model rules enabling automatic checking of model progress against planned model development. Whilst Case #1 exhibited little substantive utilisation of LOD (since, amongst other things, a single discipline model was all that was required), it did enable identification of where potential for improvement lay. In Case #2 the key research proposition is tested and verified allowing for tentative conclusions to be drawn. First, that better integration and automation is possible and second, that there is great potential to re-use knowledge-based processes and leverage value through efficiency gains and improved information quality. Although the cases explored where dissimilar in type, the relevant aspects in digital information management were common. The patterns observed are deemed typical and therefore can be seen to strengthen and broaden the application of the emerging results.

An attempt has been made to develop a new scenario where LOD may be more useful in BIM projects. This is done with BIM-Use delivery specifications translated into re-usable model checking rule-sets supported by LOD definitions. The LOD utilisation framework serves the following purposes in facilitating model progression:

- To facilitate accurate representation of actual model status v. planned model progression;
- To capture and reuse knowledge;
- To enable a platform for quality control;
- To leverage existing BIM tools;
- To maximise automation and remove mundane, labour intensive tasks in which if errors occur, present adverse cost consequences;
- To facilitate and encourage sequential model development through standardised milestone gates;
- To facilitate a logical information maturity with reusable tools.

These findings are important; they indicate that greater and more consistent knowledge is required about new industry concepts whilst presenting an application where success has been realised and common errors mitigated. It is acknowledge that it is difficult to generalise from case studies where verification cases are lacking. One size does not fit all however the framework described incorporates sufficient flexibility to have universal application. Replication can be problematic in quantitative research, however Robson (2006) argues that one may nonetheless be at liberty to capitalise on original studies where there are relatively strong findings giving support to a particular theory suggesting the operation of certain mechanisms in the context of the study.

Conclusions

The concept and application of LOD has been studied, its use in practice, attempted to unravel misconceptions about it and through the new LOD utilisation framework sought to reduce the possibility of LOD frustration through automation of process. This work has therefore contributed with first, a literature and case review of LOD in practice and second, a novel method of employing LOD that may reduce or remove the known labour-intensive activities associated with MPS and help design authors focus on creating critical path information. It is also expected to improve the construction industry's potential for reuse of knowledge across stakeholders. Furthermore, it is conjectured that the framework and associated rule-sets will support the systematic creation of digital design information on BIM projects and enable greater opportunities for design authors to exploit the digital asset through deployment of multiple and sequential BIM-Uses through the design development stages.

Although such a method could also be used on traditional, manually controlled projects, it shows great potential to support BIM project participants and reuse of intelligent processes in a way that is readily transferable. This is seen as crucial in promoting the industry's productivity performance. The quality, success and value of automated model progression scheduling using LOD must now be developed through further practical testing, implementation in real projects and further adaption based on feedback from practical application.

To the original research question: *is there a way of automatically verifying model content against intended use and programme that could then be standardised,* one can now reference a method that does just that. Furthermore, the framework may function not only as a method to compare planned against actual model progression, but as an early-warning mechanism to guide the design consultants to author the right objects and properties on the BIM-Use critical path, avoiding expensive man-hours engaging in pointless finesse. To get started one needs only to create a specific BIM-Use delivery specification and associated model checking rule-set.

The main contribution is insight into how LOD can be applied expediently and awareness of the need to structure digital content to facilitate real-time cross-checking with scheduled deliverables. This knowledge is important in order to enable BIM information authors to align information deliveries or data-drops with the expectations of downstream users. Vico, a construction costing and programming software company, highlight that one does not need to meticulously plan model progression if one is simply using the digital model for visualisation, however, where exploiting 3D coordination, 4D Programming, 5D Cost Analysis and 6D Asset Management functionality, utilisation of LOD in association digital delivery specification and model progression is essential (Vico, 2012). Here the proposed framework represents a flexible model for integrating LOD into a BIM-like workflow, whilst facilitating rich re-use of information content knowledge. This work can also be viewed as a contribution towards BuildingSmart's IDMs / MVDs insofar as it offers a tentative business case for automated model progression. However, in the first instance represents a *here and now* proposition to current difficulties in model authoring control.

The idea behind the use of LOD to support model development is that by attaching an LOD status attribute to objects in conjunction with standardised re-usable checklists (detailing BIM-Use content), one can with much greater certainty guarantee a certain quality of information at a given point in time (Kastell, 2013b). Other disciplines have then the possibility of organising their respective contributions around status-marked LOD objects in a way that allows recognition of object specificity and reliability.

A further step to reach standardisation and dissemination into practice may be possible through buildingSmart. Further research could be in transforming and combining this effort into an IDM / MVD together with extended validation cases. A whole the process could be improved by integrated software implementation.

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