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ENABLING LEAN DESIGN MANAGEMENT: An LOD BASED FRAMEWORK

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Abstract

Question: How can we use the Level of Development (LOD) concept to better develop BIM models under a Transformation, Flow and Value (TFV) perspective?

Purpose: The purpose of this study is to introduce a new LOD framework to relate the LOD value of a model element to its actual design context and to manage the design process according to the TFV theory.

Research Method: Review and analyze current LOD definitions and guidelines. Develop a new LOD framework and align its use to lean design management.

Findings: The new framework enables the application of lean design principles through a practical use of the TFV theory. The defined LOD variables, the LOD matrix, and the parametric nature of BIM models facilitate the integration of the TFV theory into the management of design workflow on BIM projects.

Limitations: The LOD framework needs to be applied experimentally to investigate its full potential.

Implications: The paper builds on the LOD and TFV theories. Researchers can employ current findings to develop new design management procedures and tools to ameliorate the quality of the design process as well as the final design product.

Value for practitioners: This study provides practitioners with a systematic and flexible procedure to define and manage LOD requirements inside BIM models. It also enables them to integrate lean design principles into the project's workflows.

Keywords: Lean Design, Building Information Modeling, Level of Development, Transformation, Value, Flow.

Paper type: full paper.

Introduction

The management of the design process is gaining more attention from the lean community. The nature of design, in addition to the impact design solutions and deliverables have on construction, operation and maintenance phases, are becoming

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clearer (Tilley et al. 1997; Ballard, 2000; Koskela et al. 1997). However, the application of lean theories in design, basically the TFV view and the Last Planner (LP^{TM}) system, is inspired by their implementation in construction; the fact that hinders their full integration (Bolviken et al. 2010; Freire and Alarcon, 2000; Koskela et al. 1997). Basically, these theories are employed to plan, schedule, and control Design Activities as per lean principles. This study investigates the implementation of the TFV theory from a different perspective focusing on the **Design Product** instead of **Design Activities**. The study benefits from the advancements of Building Information Modeling (BIM), and employs the Level of Development (LOD) concept to address the TFV application in design.

The proper management of design requires understanding and accepting its nature by all involved stakeholders. Design is an ill-structured process that does not have a clear destination and a clear path towards that destination. Had the design outcomes been recognizable early on, the design process would not be an adding value process (Ballard, 2000). In this context, design iterations are not only inevitable, but also necessary for designers and clients to better understand their project and increase its value (Reinertsen, 1997). Therefore, the iterative and multidisciplinary nature of design plays a major role in complicating its management, especially because detecting negative iterations and eliminating them is not easy. This fact remains true regardless of the platform running the design process. Whether using traditional 2D-CAD or BIM tools, the chaotic and vague nature of design is always a challenge.

Moreover, design should be understood at its micro and macro levels. At the micro level, design can be seen as a technique used by the designer (Architect, Engineer, etc.) to first formulate the problem, and then find ways to solve it under a set of constraints. This is the cognitive and creative nature of design (Kruger and Cross, 2006; Cross, 2004; Dorst and Cross, 2001). At the macro level, design takes place in a social environment that joins a number of stakeholders with different interests and experiences. This is the process nature of design. Meanwhile, the industry lacks managerial tools that can simultaneously address the micro and macro dynamics happening while the design is unfolding. This is an additional cause behind sub-optimal design management.

Recently, the construction industry is witnessing a new technological shift towards the implementation of Building Information Modeling (BIM). BIM could be described as an n-dimensional compilation of parametric data into central or combined local models. The proper adoption of BIM helps streamline design workflows and facilitate coordination among disciplines in a 3D environment (Barlish and Sullivan, 2012; Eastman et al. 2009; Hartmann, 2010). However, the definition and use of BIM are not stable yet and are far from standardization (Miettinen and Paavola, 2014). The use of BIM as a life-cycle management process is lagging behind its use as a production tool. Since BIM software are product oriented and do not necessarily impose procedural changes in design management, some practitioners switched from using 2D-CAD software to BIM software without changing the work process. Thus, BIM tools revolutionize the product design without necessarily guiding the design process.

To facilitate the use of BIM as a work process, research and industry efforts created the notion of Level of Development (LOD) to formalize the development of BIM models and authorize their possible uses (The American Institute of Architects, 2013; BIMForum, 2015). LOD, as defined by the American Institute of Architects (AIA), defines the minimum content requirements for a model's element and its authorized uses at five progressively detailed levels of completeness. Current classification systems range from LOD 100 to LOD 500, specifying the minimum graphical and non-graphical information an element should hold at each level, and its possible authorized uses. In this regard, LOD is viewed as a linchpin to BIM laying between the system of information deliverables and their descriptions on one side, and the corresponding contractual agreements and responsibilities on the other (Hooper, 2015). However, academics and practitioners have expressed several concerns around the LOD concept as it is currently understood and used. These concerns include:

- The fact that LOD is managed outside the BIM model and is labor-intensive (McPhee and Succar, 2013).
- Current classification systems are limiting the potential of the LOD concept since only five levels are used. This resembles the trial of painting a complex pictures with five colors allowed (McPhee and Succar, 2013).
- Current classification systems can only track elements at LOD milestones without detecting partial LOD levels witnessed throughout the design exercise (at one point, the LOD of an element may be neither 200 nor 300, but somewhere in between).
- LOD values are only descriptive and they are not related to the actual design context where elements pass through different statuses while converging to the desired LOD (for example: under design, pending approvals, design checks, under coordination, etc.).

To address the above mentioned gaps, this study introduces a new LOD framework based on variables related to design context. It also investigates the use of the framework in managing design workflows using the TFV theory. Accordingly, the aim of this research effort is to: (1) define design related variables that describe LOD, (2) link LOD to these variables using an LOD matrix, (3) use the new framework to manage design under the TFV theory.

Research method and limitations

The research method consists of three stages. The first stage targets the definition of LOD variables based on current LOD related literature and practical guidelines. Three variables: Graphical Detail Level (GDL), Information Richness (IR), and Confidence Index (CI) are introduced to formalize the understanding and use of LOD. While GDL and IR are inspired by current LOD guidelines, CI is used to link the reliability factor of LOD to the actual design context not only to authorized uses set by model authors. The second stage introduces a new LOD-Matrix to link LOD to the defined variables, and the third stage uses the new LOD framework to manage design under the TFV theory.

This effort tries to align the use of LOD in BIM projects with the application of the TFV theory in design management. The LOD framework presented in this paper is only theoretically developed at this stage. Future efforts can investigate the suggested framework on actual design projects to assess its practicality and potentials.

LOD variables

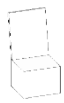
The investigation of current LOD definitions which are primarily inspired by AIA definitions reveals three major components of LOD: graphics, information, and reliability. While an element created in the model gains graphical and information characteristics (depending on how it is modeled and what data is attached to it), its reliability is separately assigned by the designer through the set of authorized uses provided at each LOD level. For instance, the designer can assign a low LOD level, say LOD 200, for a lighting fixture pulled from a library with high graphical detailing and with specific design data, to govern its downstream use by other stakeholders. LOD in this context helps designers communicate their model's content while imposing use restrictions.

Accordingly, three variables are introduced in this study to describe LOD and relate its value to the actual design context: Graphical Detail Level (GDL), Information Richness (IR), and Confidence Index (CI). While GDL and IR requirements can be associated with AIA definitions or other LOD classifications, CI is determined by the type of checks and coordination performed on a certain element, not only its authorized uses. Thus, LOD in this study is not only used as a modeling guide, but also as a design related metric. The LOD variables and LOD-Matrix are detailed in the following sections.

GRAPHICAL DETAIL LEVEL (GDL)

GDL targets the graphical representation of a model element. Four different graphical grades: schematic (G_0), generic (G_1), defined (G_2), and rendered (G_3) are adopted according to the UK BIM protocol described in Table 1.

Table 1: GDL variables: grades, description, and graphical representation

Grade (G) (AEC UK BIM Protocol V 2.0, 2012)	Description (AEC UK BIM Protocol V 2.0, 2012)	Graphical Representation
Schematic (G_0)	2D symbolic representation of model elements without 3D modeling/ or masses/or derived from other elements.	
Concept/Generic (G_1)	Simple place-holder with absolute minimum graphical detail level to be identifiable, e.g. as any type of chair	
Defined (G_2)	The element is more precisely modeled and sufficiently detailed to identify type of chair and element materials	
Rendered (G_3)	The element is modeled in a realistic manner. This type of representation is usually done by manufacturers	

Information Richness (IR)

Information Richness (IR) describes an element's richness in non-graphical information. IR can be categorized according to the type of information attached to the element. Five types of information are used in this paper: identification (I_1), dimensions

(I_2), performance/specification (I_3), installation (I_4), and lifecycle/sustainability information (I_5) (Weygant, 2011). These types of information cover almost all possible attributes that can be attached to a model element. Table 2 summarizes different IR categories and their descriptions.

Table 2: IR variables: information types and description

Information Type	Description
Identification (I_1)	The information needed to identify the element used in the model (Weygant, 2011) (Ex: Mass, Structural Wall, Architectural Wall, Opening, Door, Duct, Light Fixture…etc.). The identification of elements varies according to design development. E.g., a door at early design stage could just be identified as "D1", however, it could be identified as "Single-Flush_800x2100" at a later stage where the design is being refined. An element not modeled in the model, can also be identified through other elements present in the model (ex: paint identified through walls).
Dimensions (I_2)	The size, shape, and location information that define the geometrical identity of the element used (Weygant, 2011)
Performance/ Specification (I_3)	Element qualification based on industry standards. This information helps the design and specification teams to determine why a product has been selected (Weygant, 2011). Nonetheless, this type of data is essential for major analysis tasks (Structural, Lighting, HVAC, etc.).
Installation/ Fabrication (I_4)	Covers any type of data related to element installation and fabrication. An element can hold information about the responsible contractor or fabricator, cost, installation time, installation procedures, or any other related data (Weygant, 2011).
Operation & Maintenance (I_5)	All data related to building or facility operation and maintenance (Weygant, 2011) E.g., maintenance schedule, replacement time, manufacturer information, etc.

Confidence Index (CI)

CI represents the reliability of each element used in the BIM model. CI is gained progressively with each positive iteration and after passing different types of checks and analyses performed within and across disciplines. The design checking process can be divided into two main categories: (1) reviews targeting client needs vs. building standards and (2) reviews targeting product's in-service requirements (Gray and Hughes, 2001), as highlighted in Table 3. CI can take ten different values (C_1 to C_{10}) according to each review type. The mentioned types are suggested to generally describe the checking process happening at the design stage.

Table 3: CI variables: review types and description

Review Type (Gray and Hughes, 2001)	Reliability Check Type (Gray and Hughes, 2001)
Reviews targeting client needs vs. building standards	C_1: Client needs vs. standard or innovative technical specifications. C_2: Compliance with building regulation, planning regulations, health and safety law, national and international standards. C_3: Building Performance under expected conditions of use. C_4: Design validation and coordination among different trades. C_5: Building safety and environmental compatibility.
Reviews targeting product's in-service requirements	C_6: Constructability. C_7: Permissible assembly tolerances. C_8: Failure modes and effects, and fault analysis. C_9: Reliability, serviceability, and maintainability of building elements. C_{10}: Labeling, warnings, identification, and traceability requirements of building elements.

LOD Matrix

A generic LOD-Matrix is developed to link GDL, IR, and CI variables to LOD as presented in Figure 1. Accordingly, project stakeholders can agree on specific GDL, IR, and CI requirements at each LOD level to plan and control the development of model elements.

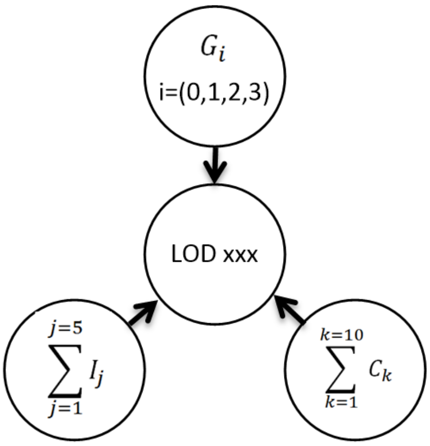


Figure 1: Generic LOD-Matrix

The minimum GDL and IR requirements can be associated with AIA LOD definitions, while CI can be inspired by the corresponding authorized uses. Table 4 highlights the applicable LOD variables for each LOD level as inspired by current AIA LOD definitions. Nonetheless, designers may choose to build their own project specific LODs by specifying a certain combination of GDL, IR, and CI variables.

Table 4: Applicable LOD variables for each LOD level as inspired by AIA definitions

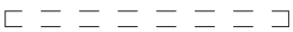
LOD	Applicable GDL Variable	Applicable IR Variables	Applicable CI Variables
100	G_0	I_1	C_1
200	G_1	I_1, I_2	C_1, C_2, C_4
300	G_2	I_1, I_2, I_3	C_1, C_2, C_3, C_4, C_5
400	G_3	I_1, I_2, I_3, I_4	C_1, C_2, C_3, C_4, C_5, C_6, C_7, C_8
500	G_3	I_1, I_2, I_3, I_4, I_5	C_1, C_2, C_3, C_4, C_5, C_6, C_7, C_8, C_9, C_{10}

Application Example

This section illustrates the use of LOD framework to determine the development of a model element in terms of GDL, IR, and CI variables. A concrete beam is examined in accordance to BIMForum LOD Specification (Section B1010.10 – Floor Structural Frame (Concrete)) (BIMForum, 2015). The beam is modeled in compliance to the corresponding specification guide under five different LOD levels presented in Tables 5 to 9.

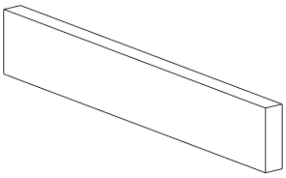
At LOD 100, presented in table 5, the beam is schematically drafted in 2D as double dashed lines (G_0). The beam is identified as a drop concrete beam with no dimensional information (I_1). The beam is checked against the client's needs and the corresponding technical specification (C_1: building framing cost, the suitability of concrete framing in the project case, etc.).

Table 5: LOD 100 Beam Modeling Example

<table>
<tr><th>LOD</th><th colspan="3">Description (BIMForum, 2015)</th></tr>
<tr><td rowspan="3">100
</td><td colspan="3">Assumptions for structural framing are included in other modeled elements such as an architectural floor element that contains a layer for assumed structural framing depth; or, schematic structural elements that are not distinguishable by type or material. Assembly depth/thickness or component size and locations still flexible.</td></tr>
<tr><td>GDL</td><td>IR</td><td>CI</td></tr>
<tr><td>G_0</td><td>I_1</td><td>C_1</td></tr>
</table>

At LOD 200, shown in table 6, the beam is modeled as a generic element (G_1), and is identified as a conventional concrete drop beam with approximate dimensions (I_1, I_2). The beam at this stage is checked against client's needs and the technical specifications (C_1: clear floor height, maximum allowable building height, total number of floors, etc.), studied in compliance to building standards (C_2: approximate nominal depth required), and is also checked with other disciplines to account for major clashes (C_4: mainly the architectural and MEP models).

Table 6: LOD 200 Beam Modeling Example

LOD	Description (BIMForum, 2015)		
200 	Element modeling to include: -Type of structural concrete system. -Approximate geometry (e.g. depth) of structural Elements.		
	GDL	IR	CI
	G_1	I_1, I_2	C_1, C_2, C_4

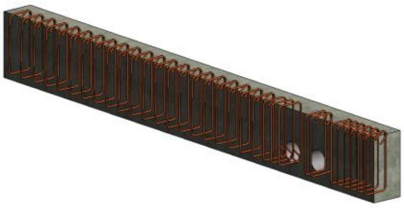
At LOD 300, presented in table 7, the design of the beam is more refined. It is modeled according to the determined concrete specifications with the materials defined (G_2), specific identification (I_1: ID or type), dimensions (I_2), and performance/specification information (I_3: concrete strength, required reinforcement, clear cover, hooks, concrete finish, typical details, section openings' location, etc.). The beam at LOD 300 is checked against: (1) client's needs and technical specifications (C_1: sustainability of concrete and adequate covers, concrete mix, surface slopes, etc.), (2) concrete /building standards (C_2: required section dimensions, allowable deflection, required reinforcement and minimum hook lengths, etc.), (3) building's performance (C_3: deflection under service loading, expected behavior under seismic risks, connection with supports, etc.), (4) other disciplines (C_4: architectural, MEP and façade models, etc.), and (5) building's safety and environmental compatibility (C_5: fire rating, contribution to building thermal performance, etc.).

Table 7: LOD 300 Beam Modeling Example

LOD	Description (BIMForum, 2015)		
300 	Element modeling to include: -Specific sizes and locations of main concrete structural members modeled per defined structural grid with correct orientation -Concrete defined per spec (strength, air entrainment, aggregate size, etc.) -All sloping surfaces included in model element with exception of elements affected by manufacturer selection Required non-graphic information associated with model elements includes: -Penetrations for items such as MEP/ Finishes, camber, chamfers, etc./ Typical details/ Embeds and anchor rods/ Aggregate/ clear clover/ Reinforcing spacing/ Reinforcing/ Live loads/ Shear reinforcing and stud rails		
	GDL	IR	CI
	G_2	I_1, I_2, I_3	C_1, C_2, C_3, C_4, C_5

The LOD 350 is created by BIMForum and is intended to account for the major kinds of coordination among the involved disciplines by modeling the required systems' interfaces. In this case, as presented in table 8, the beam is modeled with the required openings for mechanical pipes and showing the impacted shear reinforcement (G_2). Installation and fabrication information about the responsible contractor and construction sequence is added to the element (I_4). Constructability and assembly tolerances are also checked and coordinated among parties (C_6, C_7). LOD 350 is an example of a project-specific LOD where stakeholders agree on particular GDL, IR, and CI requirements to define a new LOD level.

Table 8: LOD 350 Beam Modeling Example

LOD	Description (BIMForum, 2015)		
350 	Element modeling to include: -Reinforcing Post-tension profiles and strand locations/ Reinforcement called out, modeled if required by the BIMXP, typically only in congested areas/ Pour joints and sequences to help identify reinforcing lap splice locations, scheduling, etc./ Expansion Joints/ Embeds and anchor rods/ **Penetrations for items such as MEP**/ Any permanent forming or shoring components/ **Shear reinforcing** and stud rails		
	GDL	IR	CI
	G_2	I_1, I_2, I_3, I_4	$C_1, C_2, C_3, C_4, C_5, C_6, C_7$

Finally, at LOD 400, highlighted in table 9, the element is modeled with exact geometry showing the finishing chamfers and all reinforcement detailing (G_3). Failure modes are also checked and various situations are considered such as construction sequence and the location of construction joints (C_8).

Table 9: LOD 400 Beam Modeling Example

LOD	Description (BIMForum, 2015)		
400 	Element modeling to include: -All reinforcement including post tension elements detailed and modeled -Finishes, camber, chamfer, etc.		
	GDL	IR	CI
	G_3	I_1, I_2, I_3, I_4	$C_1, C_2, C_3, C_4, C_5, C_6, C_7, C_8$

LOD: the TFV tripod

The new LOD framework is investigated as a tripod to the TFV theory of design management. Each component of TFV is addressed separately in the following sections.

Transformation

Several transformation aspects occur during design. While the most general one is the transformation of needs and requirements into the design product, other more specific transformations occur at the level of model elements. Design dynamics, whether at the micro or macro levels, are translated in elements gaining (or loosing) graphical detailing (GDL), information richness (IR), and design reliability (CI). Therefore, the element itself is transforming from one state to another during design. In this regard, the general transformation of needs into the design product can be seen as collective transformations of model elements throughout the design process.

The new LOD framework captures these kinds of transformations. It can track the GDL transformation of an element as more graphical detailing is added, its IR transformation as more design information is revealed, and its CI transformation as more design checks and coordination are performed. Therefore, the framework can track the transformation of a model element at the level of LOD as well as at the level of GDL, IR, and CI variables. For example, a concrete beam planned to be modeled according to LOD 200 requirements will gradually converge to this LOD by a number of transformations. The beam may be first created in the model with GDL of G_0 (schematic) and IR of I_1 (identification). At a later stage, the beam may be generically modeled (G_1) with dimension information (I_2). The element then gains C_2 when the structural engineer finishes the corresponding structural design required at this stage. The beam; however, will not gain C_1 and C_4 unless accepted by the owner and coordinated with other disciplines. Thus, the LOD 200 of the beam will not be attained until GDL, IR, and CI finish their required transformations.

Flow

A new design flow is defined in this study: the flow of model elements. At every instant of design, some new elements are created, other elements are further developed, and some elements are deleted or changed. Nonetheless, these elements witness several statuses throughout the design process: waiting, under design, inspection, rework, transfer, etc. Therefore, this new flow definition reflects design dynamics and can be used to streamline the generation and development of model elements as well as enhancing the overall design workflow.

The LOD framework is used to describe the flow of model elements and to track their status change over time. Every element can be tagged by GDL, IR, and CI variables, along with corresponding LOD values. In this regard, the design workflow can be addressed as a flow of several categories of elements (partitions, windows, doors, beams, etc.) towards a set of planned LOD levels. For instance, at a certain phase in design, partitions may be planned to reach LOD 300, while doors and windows to reach LOD 200. Design managers can at any point in time check the actual LOD value of an element, define what LOD variables are missing or underdeveloped, and then take adequate actions to remove bottlenecks and keep the element flowing toward its planned LOD.

Value

Under the TFV theory, design is perceived as a process that generates value to the customer (Koskela, 2000). In BIM, the customer's value can be directly captured and managed inside the model throughout the project life cycle: from early concepts to the operations and maintenance (O&M) phases. This is in fact the target of BIM use in construction. Practically, customer's value is translated into model elements that evolve during design before converging to a final design product which is the BIM model.

The new LOD formulation targets the value aspect of design by introducing the variables CI. CI includes a set of design checks that target client's value against the corresponding design context (C_1, C_2, C_3, C_4, C_5) on one hand, and against the product's in-service requirements (C_6, C_7, C_8, C_9, C_{10}) on the other. Customer's value then is captured at the level of every model element and can be tracked and managed throughout the design process. Moreover, the new LOD framework serves a self-checking guide used by designers to ensure the quality of BIM deliverables as the LOD of an element is clearly checked against GDL, IR, and CI requirements.

Discussion

A new LOD framework is developed in this study to relate the LOD of a model element to the actual design context. The paper also investigates the use of the framework in implementing the TFV theory in design management. This section discusses the major aspects of the framework and its possible uses.

The framework enables designers build and use specific LOD levels that meet their needs. For instance, designers may agree to model the AC chillers generically (G_1) without struggling with graphical detailing, while providing all necessary data (I_1, I_2, I_3, I_4, I_5) using an online link, and performing all types of design checks (C_1 to C_{10}). This modeling flexibility helps designers better meet client's needs while avoiding over production and unnecessary work. Designers may also use the framework in compliance with current LOD guidelines by aligning GDL, IR, and CI requirement of each LOD level to the corresponding LOD definitions and descriptions.

The purpose of using the LOD classification systems is protected in this study. First, the contractual use of LOD, manifesting in planning LOD requirements and assigning authoring responsibilities, can be associated with the new LOD framework. Moreover, the contract may include specific GDL, IR, and CI requirements for each LOD level. Second, the use of LOD to formalize the development of BIM models and authorize their use is also taken into consideration. The new framework helps in building systematic modeling procedures by setting the specific GDL, IR, and CI requirements of each LOD level. Designers therefore have clear LOD requirements to be met. Nonetheless, the reliability of model elements is not just controlled by the set of authorized uses; it is clearly related to the design context by the variable CI.

The new framework enables the use of LOD for design management purposes. LOD, as presented in this study, is not just a descriptive index, but also a design related metric. LOD as discussed in previous sections captures the TFV aspects of design from a design product perspective. The transformation of inputs to outputs, the flow of information, and the client's value can be monitored during the design process by tracking GDL, IR, CI, and LOD values of model elements. Accordingly, the use of LOD in BIM projects can be aligned with the application of the TFV theory to manage the design process.

Conclusions

This research paper introduces a new LOD framework and uses it to employ the TFV theory in design management. The paper consists of three major parts: the first part introduces three LOD variables (GDL, IR, and CI) related to the actual design context. The second part develops a generic matrix to link LOD to the defined variables, and the third part investigates the use of the new LOD framework in managing design under the TFV theory.

LOD in this paper is presented as a design related metric that changes and progresses over time. The importance of this approach lies in explicitly relating LOD to its GDL, IR, and CI components regardless of the LOD number. Knowing what is actually contributing to the LOD value, in a specific design context, is more important than the LOD value itself. Moreover, the presented framework seems to help design managers better implement the TFV theory in design management. Therefore, The LOD framework can be used to capture the TFV aspects of design.

Finally, this research presents a theoretical framework to enhance the implementation of LOD in BIM projects. It also investigates the use of LOD to employ the TFV theory in design. Future efforts can further develop the suggested framework, and can also target its practical application over BIM platforms. Actual case studies can also be conducted in the future to validate the proposed framework and reveals its practical implications.

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