

LEVELS OF DETAIL, DEVELOPMENT, DEFINITION, AND INFORMATION NEED: A CRITICAL LITERATURE REVIEW

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SUMMARY: *The construction industry relies on precise building information for evaluating designs performance, collaboration, and delivery. For more than a decade, the Level of Development (LOD) is the most popular concept for describing the progression of geometric and semantic information across the design phases. The LOD is a domain language that aims to establish a common understanding of what each level means to facilitate communication and defining deliverables in contracts among the project participants. However, multiple similar standards are published worldwide for a similar purpose, such as Level of Detail, Level of Definition, and Level of Information Need. However, although they are similar at first glance, in many cases, they have numerous deviations in their fundamentals. This paper investigates the differences of the LOD standards and their interpretation by the scientific community through a thorough analysis. For this purpose, 58 LOD guidelines were reviewed, and a systematic literature review of 299 peer-reviewed publications was conducted. As a result, existing trends in using the LOD in research and the most widespread LOD naming conventions and specifications were identified. Additionally, the results highlight 16 common use cases for applying the LOD.*

KEYWORDS: *Level of Development, LOD, Level of Detail, Level of Definition, Level of Information Need, Literature Review.*

REFERENCE: *Jimmy Abualdenien, André Borrmann (2022). Levels of detail, development, definition, and information need: a critical literature review. Journal of Information Technology in Construction (ITcon), Special issue: 'The Eastman Symposium', Vol. 27, pg. 363-392, DOI: [10.36680/j.itcon.2022.018](https://doi.org/10.36680/j.itcon.2022.018)*

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1. INTRODUCTION

The processes conducted in the design and engineering of built facilities are typically multi-disciplinary and comprise various activities. Such activities include defining requirements, modeling design concepts, and evaluating their compliance and performance. These activities are connected and interdependent, representing the workflow necessary for delivering a functional asset with an adequate quality throughout its life cycle.

Building Information Modeling (BIM) is a method that uses digital information across the entire lifecycle of the facility under consideration. It is based on a comprehensive digital representation of the individual geometric and spatial elements, capturing their functional characteristics and dependencies (Borrmann et al. 2018). The utmost use of BIM is to provide a holistic and reliable basis for decision-making throughout the life cycle of a construction project. BIM facilitates collaboration across the different domain experts, which assists in reducing project costs and delivery time (Cheung et al. 2012; Kolltveit and Grønhaug 2004; Zanni et al. 2019). Typically, each domain expert has its own unique considerations, processes, and BIM tools. Hence, realizing the full potential of BIM requires a clear agreement of the modeled and exchanged information throughout the projects' life cycle.

The design process involves a set of interrelated activities that result in increasing the design solution knowledge (or reducing the uncertainty). A design solution is gradually elaborated, refined and detailed as the design evolves. Accordingly, the quantity and quality of the available information increases as the design becomes more mature.

It is crucial for the overall collaboration and coordination among the project participants to unambiguously define *what* information should be available at what milestone (*when*), which actor is supposed to deliver it (*who*), and to which end it is required (*purpose*). The exchange of BIM data within the Architecture, Engineering and Construction (AEC) industry is prescribed in legal contracts where the information for each specific model is specified, meaning that a common legal framework for organizing BIM data is required (Sacks et al. 2018).

Conventional construction planning heavily relies on the use of different drawing scales for defining geometric information needs regarding a suitable level of detail as well as a certain degree of maturity and preciseness (Farrelly 2008). The produced drawings evolve from sketches depicting the rough shape of the building and the floor plans to detailed workshop drawings presenting the precise design of individual elements, connection points, etc. Accordingly, a drawing's scale directly implies the degree of abstraction, vagueness and maturity of the design information conveyed, and typically, specific scales are requested in specific design phases. The concept of maturity is an essential requirement for supporting evolving design processes. As scale (as an indicator for maturity) cannot be applied for digital building models, an analogue concept is necessary.

In the scope of BIM, since more than a decade, multiple initiatives have been established with the focus of creating a consensus about what information should exist during the development of building elements during the life-cycle of a project (AIA 2013b; BIMForum 2020c; Claus Maier 2015; NATSPEC 2014; PROGETTIAMOBIM 2018; VA CFM 2010; VBI 2016; VicoSoftware 2005). The first initiative was with introducing the *Level of Detail (LoD)* for BIM objects (VicoSoftware 2005). Although at that time it was new in this AEC industry, the *Level of Detail* concept is a topic that has been discussed in computer graphics (Luebke et al. 2003) for a long time before. It is used to bridge complexity and rendering performance by regulating the amount of detail used to represent the virtual world. The LoD has been adopted and refined by the American Institute of Architects (AIA) to become the *Level of Development (LOD)*, referring to the completeness/reliability of the building elements information (AIA 2013b).

In computer graphics, the LoD concept is mainly concerned with rendering the geometrical detailing (from the visualization point of view, i.e. it does not provide information about the degree of elaboration and reliability of the model information). In the AEC industry, the LOD represents the availability and reliability of the geometric and semantic information, which takes into account the incremental availability of information during the design process. In addition to the specification of the geometric elaboration, it also includes requirements for the attribution, i.e. for the alphanumeric information to be specified. In contrast to the LoD, the LOD also determines the reliability of the geometric and alphanumeric information stored in the model element. This meta-information is an important basis for collaborating with other planning disciplines and for the assessment of the planning progress by the client and the construction companies.

The LOD is an essential part of any BIM project execution plan (BxP) (BIMForum 2020a) and is contractually binding in most cases (Abualdenien and Borrmann 2022). It clarifies the necessary efforts and milestone

deliverables, addressing the expectations of the involved domain experts. For more than a decade, practitioners rely on the LOD terminology to specify which information they need to deliver (Hooper 2015; Leite et al. 2011; van Berlo and Bomhof 2014). However, as the different LOD specifications are inconsistently defined (Bolpagni and Ciribini 2016; Gigante-Barrera et al. 2018; van Berlo and Bomhof 2014), each practitioner has a different interpretation of what a specific LOD means and which information should be present in the model. Such inconsistencies cause severe miscommunication and additional expenditure, which increases project risks (Abualdenien and Borrmann 2019).

This is the exact motivation behind the research presented in this paper. The aim is to highlight any deviations, misconceptions, and misinterpretations practitioners are confronted with when following the definitions provided by the variety of LOD specifications. For this purpose, a systematic literature review is conducted, where the most widespread LOD standards are reviewed and then their usage by practitioners is evaluated from multiple aspects. The contributions of this paper are threefold: (1) highlighting the differences between the different LOD standards and their applicability during a projects' life cycle, (2) providing insights on how practitioners interpret and apply the LOD concept in research, and (3) identifying common misinterpretations and use cases, and highlight common needs. Those contributions assist in unifying the usage of the different LOD specifications and emphasize the necessity of carefully considering the use of LODs in a way that complies with the intended purpose.

The paper is organized as follows: Section 2 presents the methodology followed in this literature review and the derived research questions. Section 3 provides an overview of the existing LOD guidelines and standards, describing their followed concepts and highlighting their deviations. Section 4 presents the setup and findings of the conducted bibliography analysis, and Section 5 discusses the outcomes of this study. Finally, Section 6 summarizes the findings and gives an outlook for future research.

2. METHODOLOGY & RESEARCH QUESTIONS

As stated above, this study aims to highlight any deviations, misconceptions, and misinterpretations practitioners are confronted with when following the definitions provided by the LOD specifications. To achieve this, we present our result in two main parts. First, 58 international LOD guidelines and standards are analyzed, focusing on their differences in terms of concept definition and references to the design process. Concept definition includes the use of concept name, abbreviation, and its applicability to the overall building model and the individual building elements. References to the design process include associations of specific LODs with specific design phases as well as linkage or analogy of the LOD levels to the scales of 2D drawings (such as 1:200 - 1:100 for LOD 200).

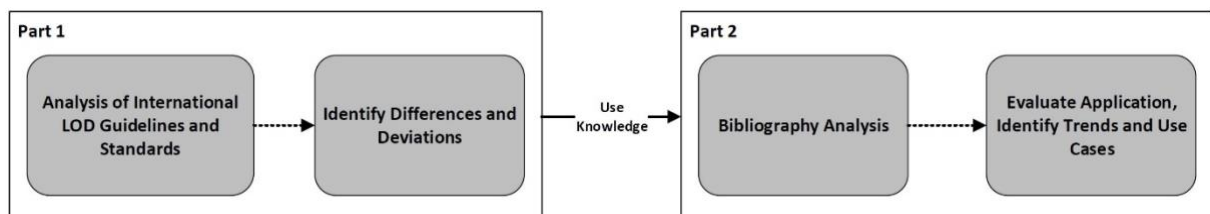


FIG. 1: High-level overview of the methodology followed in this literature review.

The gained knowledge from the first part is subsequently used for the literature review presented in the second part. The second part focuses on the analysis of literature produced by scholars through the most prominent and influential journals in the field of *Building Information Modeling* during the period 2000 - 2020 using a set of keywords (discussed in detail in Section 4). Then each paper is evaluated against LOD relevance criteria; papers not fulfilling the criteria are discarded, while others are selected to be thoroughly reviewed (more details about the relevance and exclusion criteria is provided in Section 4).

The conducted literature review follows the guidelines provided by Kitchenham (2004), which comprise three main phases: planning, conducting, and reporting. Based on Kitchenham's guidelines, the following three research questions were derived, representing the focus during the assessment of the individual literature papers:

- **RQ1:** Is there a trend of increasing the application of the LOD concept? Is the LOD terminology required and preferable by practitioners in their different use cases? The focus here is to identify the use of LODs

through time by the different domains, which emphasizes the increasing need for a standardized LOD guideline. This paper investigates this RQ through the investigation of scientific research; further investigation that is focused on industry application can complement this analysis and is planned for the future.

- **RQ2:** Which LOD specification is the most popular among researchers? The question identifies which of the common LOD specifications (see Section 3.1) is preferred by scholars in their research.
- **RQ3:** What are the primary use cases that require the LOD concept? This question aims to evaluate the relevant purposes for applying the LOD in the AEC industry, such as quantity take-off, visualization, simulations etc.

The content of each relevant paper is analyzed from the perspective of answering those research questions. The analysis results are then collected and used in statistical analysis, including counts of referenced terms, abbreviations, and guidelines through the years. This helps in identifying existing trends, the most common LOD standards, and the applicable use cases. Figure 2 illustrates the process in detail.

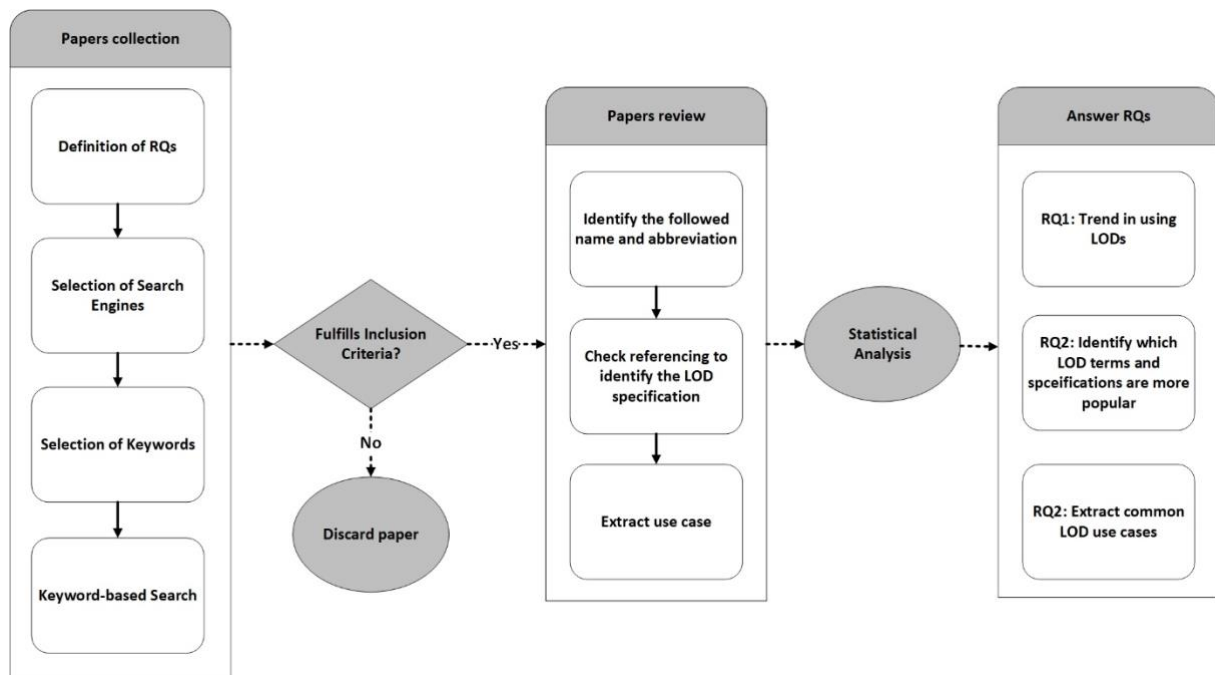


FIG. 2: Search method: first scientific databases were searched via a set of keywords. The collected publications were then filtered by reviewing the title, abstract, and conclusions. The selected publications were then reviewed in detail with the aim of answering the previously defined research questions. Finally, a statistical analysis was performed to identify existing trends.

3. ANALYSIS OF LOD STANDARDS

The BIM industry is wealthy with different concepts and terms. Therefore, it is important to differentiate between their applicability and usage. In this section, the LOD concept, along with other related concepts, are described and discussed.

3.1 Level of Development (LOD)

The *Level of Detail* (LoD) concept is an old topic that existed in computer graphics for bridging the graphical complexity and performance by regulating the amount of detail used to visualize the virtual world (Luebke et al. 2003). In 2005 VicoSoftware (Trimble 2013; VicoSoftware 2005) published the first LOD specification for the AEC Industry when they introduced the *Level of Detail (LoD)*, describing the necessary semantic and geometric information with a set of five levels.

In 2008, the American Institute of Architects (AIA) built upon the LoD definitions and introduced the *Level of Development (LOD)*, which also comprises five levels starting from LOD 100 and reaching LOD 500. From 2013, the BIMForum working group has investigated the AIA definitions in detail and introduced LOD 350 (BIMForum 2020c). The BIMForum subsequently has published updated versions of the *Level of Development Specification* in a yearly cycle with the aim of providing a common understanding of the expected information at every LOD. The first level, LOD 100 (conceptual model), is limited to a generic representation of the building, meaning no shape information or geometric representation. The second level, LOD 200 (approximate geometry), consists of generic elements as placeholders with approximate geometric and semantic information. At LOD 300 (precise geometry), all the elements are modeled with their quantity, size, shape location, and orientation. Next, to enable the detailed coordination between the different disciplines, such as clash detection and avoidance, LOD 350 (construction documentation) is introduced, including the interfaces between all the building systems. Reaching LOD 400, the model incorporates additional information about detailing, fabrication, assembly, and installation. Lastly, at LOD 500 (as built), the model elements are a field verified representation in terms of size, shape, location, quantity, and orientation.

Figure 3 clarifies the progression of the design across the LODs with an elevator example. This example was modeled according to the BIMForum's specification (Abualdenien and Borrmann 2022). At LOD 100, the elevator's material, dimensions, and even location are still flexible. LOD 200 provides a generic envelope representation and travel paths. At LOD 300, any associated equipment and structural support are modeled. Sizing, tracks, rails, and access zones are modeled and fixed at LOD 350. Finally, all connections, supports, framing, and other supplementary components are modeled at LOD 400 (BIMForum 2020c).

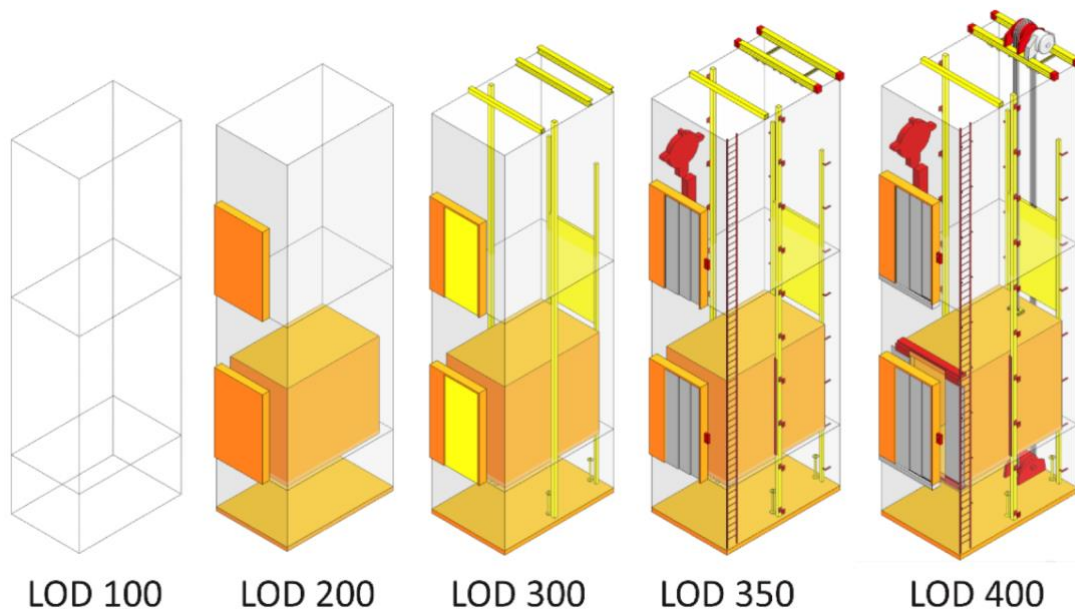


FIG. 3: Illustrating the progression of design across the LODs with an example of Elevator. This example was modeled according the BIMForum's specification (Abualdenien and Borrmann 2022; BIMForum 2020c).

Since then, many efforts have been invested in the U.S., Europe, Asia, and Australia to develop a suitable and practical standard assisting the delivery of the industry projects. Besides the BIMForum's definitions, the U.S. Department of Veterans Affairs (V.A.) has published a comprehensive spreadsheet, the *Object Element Matrix*, that provides a list of the expected LOD attributes for the building components throughout the building life-cycle (VA CFM 2010), which encourages the concept's applicability in the industry. Additionally, the U.S. General Services Administration (GSA) published an LOD guideline (U.S General Services Administration 2018), where they used the Level of Design, Development, and Detail as synonyms and represented as LOD. In the case of GSA, the guideline provided a mapping of the different elements to the corresponding discipline (like Architecture, Structural Engineering, HVAC etc.) and to the design phases.

Most of the countries, especially in Europe, have proposed different terms for their regions. In the UK, the *Level of Definition* (BSI 2012a) has been introduced. It consists of seven levels and introduces two components: Levels of Model Detail, representing the graphical content of the models, and Levels of Model Information, representing the semantic information. The Danish definition includes seven *Information Levels* that correspond roughly to the traditional project life-cycle phases (van Berlo and Bomhof 2014).

In Germany, the concept of *Modelldetaillierungsgrad* (MDG) (VBI 2016) introduced by the German Engineering Consultancy Association VBI is a common alternative to the BIMForum's LOD. The MDG comprises ten levels (010, 100, 200, 210, 300, 310, 320, 400, 510, 600) that correspond to the HOAI project life-cycle phases (HOAI 2013). In this regard, the MDG specification is defined according to the maturity demanded by each phase. This is a key difference to the LOD concept since the LOD has by purpose no connection to the design phases (BIMForum 2020c). However, the MDG specification provides a mapping to the BIMForum's LOD, where the MDG levels 100, 200, 300, 400, and 500 correspond to the LODs with the same level. The rest of the MDGs have no correspondence to the LOD.

The Italian LOD definition adopts the BIMForum's specification while adjusting it to seven levels with letters in an ascending order from *LOD A – LOD G* (PROGETTIAMOBIM 2018). In Switzerland, the LOD concept is based on the BIMForum's definitions, but at the same time, it is assigned to projects life-cycle phases (Claus Maier 2015). Similarly, in Norway, the concept of *Model Maturity Index* (MMI) is commonly used as an equivalent to the LOD. The MMI has adopted the same scale as the BIMForum's LOD, 100 – 500, and is applicable for both the elements and building model level (H. W., Skeie, G., Uppstad, B., Markussen, B. and Sunesen 2018). However, MMI focuses more on developing and controlling the design process than on geometric specification. It facilitates, among others, the determination of milestones in the project.


















In Australia, the American LOD concept was utilized in its current state, describing the maturity of the individual elements without any mapping to the life-cycle phases (AIA 2014). Additionally, the NATSPEC National BIM Guide (NATSPEC 2013) adopted the VA's *Object Element Matrix* spreadsheet as basis. In China, the Construction Industry Council (CIC) published an LOD specification based on ISO 19650 (which uses a similar basis to the LOIN, published in ISO 17412) (Construction Industry Council 2020; ISO 2018, 2020). CIC defined an LOD-G and LOD-I for the geometric and semantic information, respectively. The refinement of building elements provided in the Chinese standard is relatively similar to the BIMForum's definitions.



















In this literature review, we collected 58 international LOD guidelines for the period 2005 - 2020 (shown in Table 1). Here, it is important to note that there could be other LOD guidelines that were not identified through our search. However, we believe that analyzing these many specifications is sufficient for drawing out a common ground of the widely followed best practices. To outline the similarities and deviations of the collected specifications, they were evaluated from multiple aspects:

















- The used concept and abbreviation
- The LOD application on building and element levels
- Overlap with design phases
- Linkage to use cases
- Linkage to 2D drawings scale








As shown in Table 1, a color-coding is provided to highlight correlations between the specifications. *Green* indicates a positive relation, *Red* a negative relation (i.e., inapplicability was identified from text or illustrations), and *Grey* when a relation was not found. Overall, the use of the term *Level of Development* and abbreviation *LOD* is outstanding, 53.4% and 60% respectively, among the others through the years. Additionally, even though 38.9% of the specifications apply the LOD concept on the building level, we observe that the majority of them agree upon applying the LOD concept on the individual elements as well. Furthermore, 37% of them have shown an overlap between the assigned LODs and design phases, while only 6.7% developed the specification for the purpose of defining requirements of use cases. Finally, 23.7% have assigned one or multiple drawing scales to the individual LODs. The differences between the various concepts included in the LOD specifications will be discussed in detail in the following sections.

TABLE 1: List of the collected and investigated LOD guidelines during the period of 2005 – 2020. Extends upon Bolpagni (2016a) and Gigante-Barrera et al. (2018).

Year Origin	Standard Document	Concept Name	Abbrev.	Building Level	Element Level	Design Phases Overlap	Use case oriented	Link to Drawings Scale
2005 	Model Progression Specification v1 (VicoSoftware 2005)	Level of Detail	LoD	No	Yes	No	No	No
2006 	Layer and Object Structures 2006 (Bips 2006)	Information levels, Level of Detail	Level 0 - Level 6	Yes	No	Yes	No	Yes
2007 	3D Working Method 2006 (Bips 2007)	Information levels, Degree of Detailing	Level 0 - Level 6	Yes	No	Yes	No	Yes
2008 	E202-2008 BIM Protocol Exhibit (AIA 2008)	Level of Development	LOD	No	Yes	No	No	No
2009 	BIM Standard v1.0 (AEC UK 2009)	Component Grade (Low-high resolution), Level of Detail	Not Available	No	Yes	No	No	Yes
2010 	The Veteran Affairs BIM Guide v1.0 (Department of Veterans Affairs 2010)	Level of Development	LoD	No	Yes	No	No	No
2010 	The VA BIM Object Element Matrix Manual Release v1.0 (attributes) (VA CFM 2010)	Level of Development	LOD	No	Yes	No	No	No
2010 	Model Progression Specification v2 (Trimble 2013)	Level of Detail	LOD	No	Yes	No	No	No
2011 	BIM Project Specification (HKIBIM 2011)	Model Data, Level of Detail	Not Available	NO	Yes	Not Available	Not Available	Not Available
2011 	Model Progression Specification v3 (Trimble 2013)	Level of Detail	LOD	No	Yes	No	No	No
2011 	State of Ohio BIM Protocol (OhioDAS 2011)	Level of Development	Not Available	No	Yes	No	No	No
2011 	BIM Execution Plan v1.1 (University of Florida 2011)	Level of Development	LOD	No	Yes	No	No	No
2012 	Singapore BIM Guide v 1.0 (Building and Construction Authority 2012)	Level of Detail	Not Available	No	Yes	Yes	No	Yes
2012 	New York City - BIM Guidelines (New York City - Department of Design + Construction 2012)	Model Level of Development, Level of Development	LOD	Yes	Yes	Yes	Yes	No
2012 	BIM Planning Guide for Facility Owners v1.0 (Computer Integrated Construction Research Program 2012)	Level of Development	LOD	Yes	Yes	Yes	No	No
2012 	AEC (CAN) BIM Protocol v1.0 (CAN 2012)	level of Development, Level of Detail, Grade	LODev, LODet, G0 – G3	Yes	Yes	No	No	Yes
2012 	E, A design division BIM standard manual (The Port Authority of NY & NJ Engineering Department 2012)	Level of Development	LOD	Yes	Yes	Yes	No	No

Year Origin	Standard Document	Concept Name	Abbrev.	Building Level	Element Level	Design Phases Overlap	Use case oriented	Link to Drawings Scale
2012 	Building Information Modeling (BIM) Guidelines v1.6 (USC 2012)	Level of Detail	LOD	Yes	No	Yes	No	No
2012 	Rijksgebouwendienst - BIM_Standard v1.0.1 EN 1.0 (Rijksgebouwendienst 2012)	Level of Detail	LOD	Yes	No	Yes	No	No
2012 	BIM Standard v2.0 (AEC UK 2012)	Grade, Level of Detail (Scale)	G0 - G3	Yes	Yes	No	No	Yes
2012 	BS 8541-3-2012: Shape and measurement - code of practice (BSI 2012a)	Level of Detail, Level of Measurement	Not Available	No	Yes	No	Yes	No
2012 	BS 8541-4-2012: Attributes for specification and assessment - code of practice (BSI 2012b)	Level of Attributing	Not Available	No	Yes	No	No	No
2012 	Common BIM Requirements 2012 Series 3 Architectural Design (Gravicon 2012)	BIM Content Levels	Level 1 - Level 3	No	Yes	Yes	No	No
2013 	Document G202™-2013, Project BIM Protocol Form (AIA 2013a)	Level of Development	LOD	No	Yes	No	No	No
2013 	BIMForum Level of Development (LOD) Specification (BIMForum 2020c)	Level of Development	LOD	No	Yes	No	No	No
2013 	Singapore BIM Guide v 2.0 (Building and Construction Authority 2013)	Level of Detail	Not Available	No	Yes	Yes	No	Yes
2013 	E203-2013 BIM and Digital Data Exhibit (AIA 2013b)	Level of Development	LOD	No	Yes	No	No	No
2013 	Guide, Instructions and Commentary to the 2013 AIA Digital Practice Documents (AIA 2013c)	Level of Development	LOD	No	Yes	No	No	No
2013 	National BIM Standards US v3_2.7 (NIBS 2013)	Level of Development	LOD	No	Yes	No	No	No
2013 	BIM Planning Guide for Facility Owners v2.0 (Computer Integrated Construction Research Program 2013)	Level of Development	LOD	Yes	Yes	Yes	No	No
2013 	The uses of BIM Classifying and selecting BIM uses v0.9 (Kreider and Messner 2013)	Level of Development	LOD	No	Yes	No	Yes	No
2013 	PAS 1192-2-2013: Specification for information management for the capital/delivery phase of construction projects using building information modelling (BSI 2013)	Level of Definition (level of model detail + level of information detail)	LOD / LOI	Yes	Yes	Yes	No	No
2013 	Best Practice Guide for Professional Indemnity Insurance When Using BIMs v1 (CIC UK 2013a)	Level of Detail	N/A	Yes	Yes	Yes	No	No
2013 	Building Information Model (BIM) Protocol v1 (CIC UK 2013b)	Level of Detail	LOD	Yes	Yes	Yes	No	No
2013 	BIM-Leitfaden für Deutschland - Information	Fertigstellunggrad	Not Available	Yes	Yes	Yes	No	Yes

Year Origin	Standard Document	Concept Name	Abbrev.	Building Level	Element Level	Design Phases Overlap	Use case oriented	Link to Drawings Scale
	und Ratgeber (BIM-Leitfaden für Deutschland) (BMVBS 2013)							
2013 	Project Progression Planning with MPS 3.0 (Trimble 2013)	Level of Detail	LOD	No	Yes	No	No	No
2013 	BIM and LOD - Building Information Modeling and Level of Development (NATSPEC 2013)	Level of Development	LOD	No	Yes	No	No	No
2014 	BIM/MAQUETTE NUMÉRIQUE CONTENU ET NIVEAUX DE DÉVELOPPEMENT (Le Moniteur 2014)	Niveau de Développement	ND	Yes	No	Yes	No	Yes
2014 	NATSPEC National BIM Guide (NATSPEC 2014)	Level of Development	LOD	No	Yes	No	No	No
2014 	BIMForum Level of Development (LOD) Specification (BIMForum 2020c)	Level of Development	LOD	No	Yes	No	No	No
2014 	Minimum Model Element Matrix M3 v1.3 (attributes) (USACE 2014)	Level of Development (accuracy), Grade	LOD	No	Yes	No	No	No
2014 	Guía de Usuarios BIM (Building SMART Spanish Chapter 2014)	de los niveles de desarrollo	LOD	Yes	Yes	No	No	No
2015 	BIMForum Level of Development (LOD) Specification (BIMForum 2020c)	Level of Development	LOD	No	Yes	No	No	No
2015 	Building Information Modelling – Belgian Guide for the construction Industry (ADEB-VB 2015)	Level of Development	LOD	Yes	Yes	Yes	No	No
2015 	Grundzüge einer open BIM Methodik für die Schweiz - Version 1.0 (Claus Maier 2015)	Level of Development	LoD	No	Yes	No	No	No
2016 	BIM-Leitfaden für die Planerpraxis (VBI 2016)	Modelldetaillierungsgrad	MDG (010 - 600)	Yes	Yes	Yes	No	No
2016 	BIMForum Level of Development (LOD) Specification (BIMForum 2020c)	Level of Development	LOD	No	Yes	No	No	Yes
2017 	Canadian Practice Manual for BIM (Dickinson and Iordanova 2017)	level of Development	LOD	No	Yes	No	No	No
2017 	National BIM Guide for Owners (NIBS 2017)	Level of Development	LOD	No	Yes	No	No	No
2017 	UNI 11337-4: Evoluzione e sviluppo informativo di modelli, elaborati e oggetti (PROGETTIAMOBIM 2018)	Level of Development (LOG/LOI)	LOD A - LOD G	No	Yes	No	No	No
2017 	BIMForum Level of Development (LOD) Specification (BIMForum 2020c)	Level of Development	LOD	No	Yes	No	No	Yes

Year Origin	Standard Document	Concept Name	Abbrev.	Building Level	Element Level	Design Phases Overlap	Use case oriented	Link to Drawings Scale
2018 	GSA - Level of Detail (U.S General Services Administration 2018)	Level of Design/ Detail/ Development	LOD	Yes	Yes	No	Yes	No
2018 	Building Information Model (BIM) Protocol v2 (Construction Industry Council 2018)	Level of Definition (Level of information + Level of Model Detail)	Not Available	Yes	Yes	Yes	No	No
2018 	BIMForum Level of Development (LOD) Specification (BIMForum 2020c)	Level of Development	LOD	No	Yes	No	No	Yes
2018 	MMI-Modell Modenhets Indeks (H. W., Skeie, G., Uppstad, B., Markussen, B. and Sunesen 2018)	Model Maturity Index	MMI	Yes	Yes	Yes	No	No
2019 	BIMForum Level of Development (LOD) Specification (BIMForum 2020c)	Level of Development	LOD	No	Yes	No	No	Yes
2020 	Architecture and structural engineering - LOD specification (Construction Industry Council 2020)	Level of Graphics, Level of Information and Level of Documentation	LOD, LOD-G, LOD-I, DOC	Yes	Yes	Yes	No	No
2020 	BIMForum Level of Development (LOD) Specification (BIMForum 2020c)	Level of Development	LOD	No	Yes	No	No	Yes

3.2 Level of Development vs. Level of Detail

The term Level of Development (LOD) is interchangeably used with the Level of Detail (LoD). However, there is an essential difference between both terms. Both terms follow the same scale of detailing from 100 - 500. The LoD describes the amount of detailing included in the model element regardless of its reliability. However, the LOD represents the amount of reliable information (i.e., fixed and thought through by the project participants). Accordingly, an element might be at a fabrication level of detailing (e.g., LoD 400) and at the same time at a low LOD (e.g., LOD 200), which means that a substantial part of this information is still uncertain and would probably change when progressing with the design. Practically, this is helpful during the design process, where designers explore the possible design options by detailing multiple variations of the same element to evaluate its suitability and performance.

Figure 4 illustrates the difference between both terms on an example of an inverted T-Beam. The first illustration from the right looks detailed, where sloping surfaces and MEP penetrations are modeled. Accordingly, it is detailed up to LoD 350. However, if this detailing is not thought through and fixed, then the element is at a low LOD, in this case, LOD 100. The rest of the illustrations represent how the fixed information is increasing with the LOD.

By contrast, the LoD concept is well established in the context of city models, where it is part of the exchange standard CityGML since 2005 (Kutzner et al. 2020). In this regard, as CityGML aims to represent the status of existing districts, including buildings and infrastructure assets, the LoD reflects the degree of detailing of the existing assets and provides the ability to reduce the geometrical complexity by providing coarser representations. Using the LoD concept for CityGML models is more appropriate than the LOD since they are typically used for archiving, visualization, navigation, and performing different kinds of analysis rather than representing the developing information maturity during the design process.

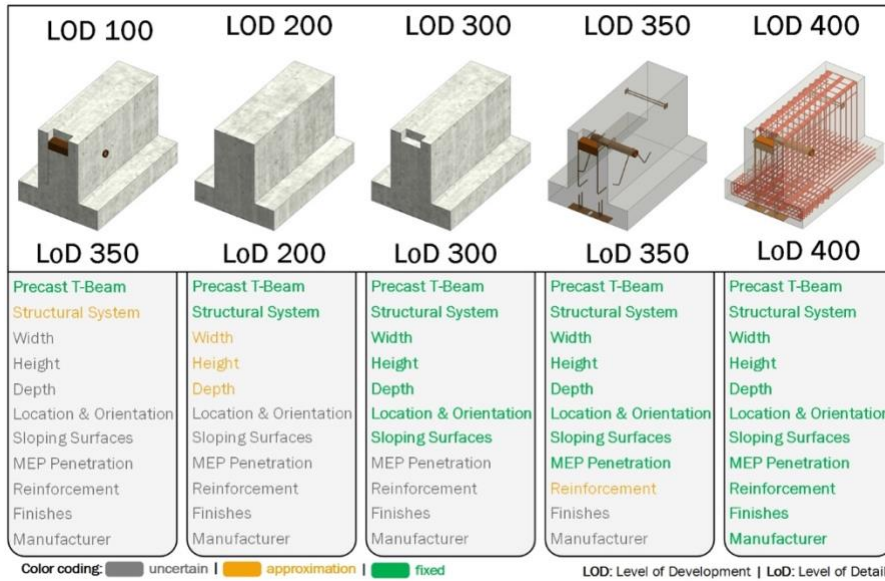


FIG. 4: Illustrating the difference between both terms, LOD and LoD, by means of an example of an inverted T-Beam.

3.3 Level of Geometry (LOG) and Level of Information (LOI)

When specifying the LOD, a fundamental distinction is made between the specification of the geometric detailing (Level of Geometry, LOG) and the specification of the alphanumeric information to be provided (Level of Information, LOI). An LOD is usually understood as a combination of both specifications.

Geometric levels of development are usually described textually, but are also underpinned with visualizations of the various levels of development for individual element types. Often, an extensive catalog of illustrations is created, which provides a good reference point for model creators (see Figure 5). Recent studies highlighted the advantage of these visual descriptions during the modeling process (Abualdenien and Borrmann 2022). The specification of the semantic information is usually done via a tabular representation in which it is specified for individual element types which attributes are required. For example, the BIMForum’s specification describes the most essential semantic information along with the geometric descriptions and then provides an extended tabular representation for specifying the individual properties and their data types (BIMForum 2020c). Similarly, the NATSPEC’s Element Matrix Manual (VA CFM 2010) provides a list of the required properties from every discipline at each LOD.

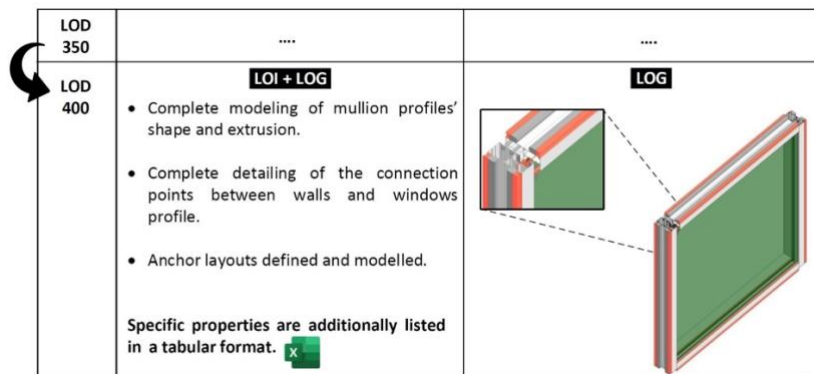


FIG. 5: An example of the LOD specification of an exterior window on LOD 400 (inspired from the BIMForum’s specification (BIMForum 2020c), the NATSPEC’s Element Matrix Manual (VA CFM 2010), and Trimble’s Project Progression Planning (Trimble 2013)). The information available on an LOD also comprises the information from the previous LODs.

Best practice has shown that geometric specifications are generally applicable, while semantic specifications are largely defined on a customer- or project-specific basis. For this reason, it has recently been increasingly questioned whether the concept of *levels* is adequate for capturing the semantic information.

3.4 Level of Information Need (LOIN)

Recently, a European standard was introduced, called the Level of Information Need (LOIN), which specifies the information required (type of elements including their geometric details and information) at a particular design phase to perform a specific task by a specific actor (ISO 2020). The standard was introduced with the goal to overcome the limitations of existing LOD definitions. A LOIN is defined for specific exchange scenarios - accordingly it needs to have a purpose, actors, and project milestone assigned as metadata. In its core it specifies a set of semantic and geometric information requirements, and extends by the possibility to define requirements for additional documents. At this point, the authors of the LOIN standard refrain from using the term *level*, as they believe that the geometric and semantic requirements are too diverse to be captured by a limited set of levels. At the same time, for the geometry specification, a set of more fine-grained sub-elements is introduced, including Detail, Dimensionality, Location, Appearance and Parametric Behavior. However, the standard remains vague when it comes to the exact usage of these elements in terms of choosable values etc.

Compared to the LOD concept, the LOIN neither describes the reliability of the provided information nor defines the maturity of the design. LOIN is focused on communicating which information is required to perform a specific task (use-case centered, such as visualization and quantity take-off). In contrast, the LOD is concerned with the refinement/development of building elements information during the design process (elements-maturity centered, independent from any use case), which can then be evaluated and used for fulfilling the needs of one or multiple use cases. For example, visualization typically requires highly detailed elements (LOD 400), whereas calculating heating and cooling demand could be performed with elements at LOD 300 (Abualdenien and Borrmann 2019).

Figure 6 highlights the main differences between the structures of both concepts. The LOD focuses on the definition of the geometric and semantic information of one object type (e.g., a door). Additionally, the defined information at one level builds over the definitions specified at the previous level (incremental). Whereas creating a LOIN instance requires more information, such as the purpose and actor. Furthermore, a LOIN comprises multiple building elements, including their geometric and semantic requirements, and does not have a connection to any previously created LOIN instances.

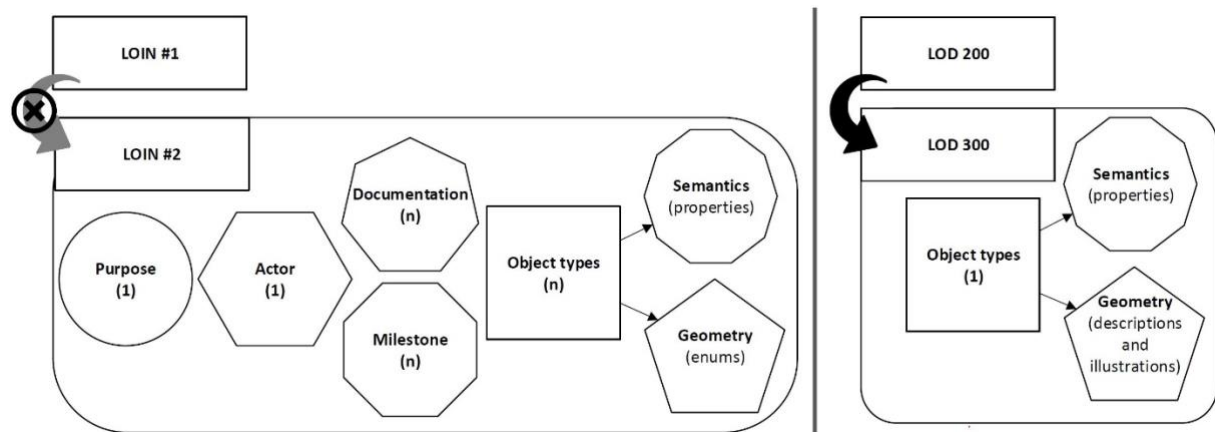


FIG. 6: Comparison between the structure of the LOIN and LOD concepts. Besides the different set of required information, the LOIN comprises requirements of multiple object types (for achieving a specific use case), while the LOD defines the required information only for one object type. Additionally, the required information at every LOD build over the requirements from the previous levels

3.5 Deviations among the LOD standards

Most of the published standards in the U.S. are based on the AIA and BIMForum's specifications. While multiple standards do not have a known basis in Europe, the U.K.'s standards are based on the PAS 1192-2 Specification

(BSI 2012a), and the available standards in the Netherlands, Italy, Switzerland, and Belgium are using the AIA and BIMForum’s specification as a basis.

As discussed in the previous section, there are numerous LOD specifications published worldwide. In a recent study, Gigante-Barrera et al. (2018) identified 24 standards in the U.S and another 16 in Europe. A common ground among the developed standards is the concept of the maturity and refinement of a digital model from one level to another. Additionally, all specifications agree that each level has a description of both semantic and geometric information, where the information becomes more reliable when the level increases. A common convention among the specifications is the separation of geometric and semantic information, where the majority of the specifications make use of the terms, level of information (LOI), and level of geometry (LOG) when describing refinement at each level (Hausknecht and Liebich 2017).

On the other hand, there are four crucial differences between the investigated specifications:

- The used term and abbreviation: the terms Level of Detail, Level of Development, Level of Definition, and Level of Design are interchangeably used for the same purpose. Similarly, the abbreviation LOD vs. LoD. However, there are multiple fundamental differences between their official specifications (as discussed previously).
- Assigning the LOD to the entire model (for example, LOD 400 building model) vs. the individual building elements: this is practically misleading because when following the typical design process, foundation, exterior walls, or structural elements will be on a relatively high LOD compared to interior walls, HVAC system, or plumbing. Figure 7 illustrates the difference between both conceptions.

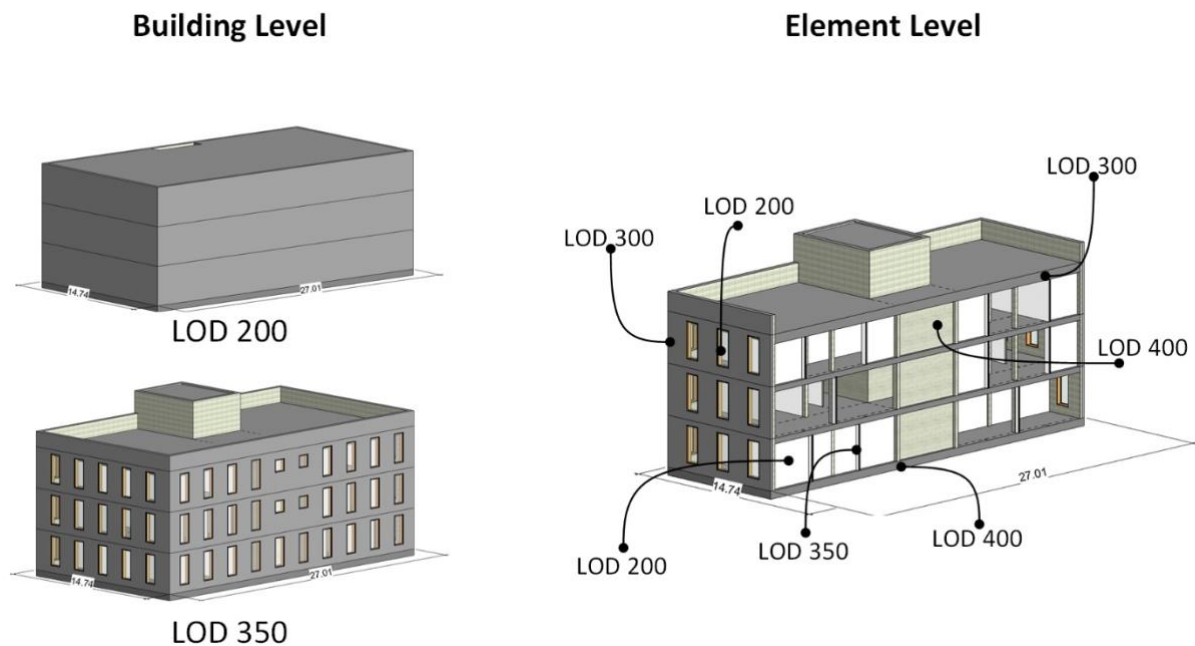


FIG. 7: Illustration of the difference of assigning the LOD to the entire model (left side) or to the individual building elements (right side).

In this regard, the authors of the BIMForum specification have confined their LOD definitions to describe the maturity of the elements inside the building model; in their words:

“There is no such thing as an ‘LOD ### model.’ As previously noted, project models at any stage of delivery will invariably contain elements and assemblies at various levels of development.” (BIMForum 2020c)

This is crucial for the collaboration among the domain experts involved in the project as well as for the contractual agreements. When a designer agrees to deliver a LOD 400 model, it means that all the elements contained within the delivered model must be at LOD 400. Otherwise, the designer would breach a signed contract.

- Correlating and mapping the LODs to the design phases: some practitioners conclude that all elements reach a particular LOD (e.g., LOD 300) when a project reaches a specific design phase (e.g., the design development phase). There is indeed an overlap between the development of some building elements (such as the building foundation) and the design phase since their refinement is progressing from the beginning of the project. However, it is not the case for other elements (like windows, doors..etc.). The argument here is similar to the LOD of the entire model; the LOD of elements varies within each design phase. Therefore, it is more practical to define the requirements of completing each design phase using the LOD of elements (e.g., external walls at LOD 250, interior walls at LOD 150, and structural columns at LOD 300).
- Comparing LODs to the requirements necessary to perform a particular use-case (like structural analysis or cost estimation (Kreider and Messner 2013)) rather than defining the refinement of building elements along the design phases. Use cases could require less information than what the model currently includes, which means they can be already performed. Sometimes, use cases need more information, which means performing them should be postponed until the design is more elaborate. Accordingly, use cases rely on the LOD but they are not analogous.

Those deviations form the basis of the research questions formalized in this study (described in Section 2), where a systematic literature review is conducted to assess the researchers' interpretation and application of the LOD concept. More details are presented in Section 4.

3.6 Industrial Examples on the Application of LODs

The adoption of BIM worldwide is rapidly increasing (Dodge Data & Analytics 2017). The majority of users see a positive value of using BIM, where it improves their processes and project outcomes mostly by reducing errors and providing cost predictability.

In Germany, BIM adoption has increased especially after the announcement of the Ministry of Transport for making the use of BIM mandatory for all federal infrastructure projects (BMVI 2015). Accordingly, multiple leading clients, including Deutsche Bahn (DB), Deutsche Einheit Fernstraßenplanungs- und -bau (DEGES), and many others, have developed their own detailed LOD specification which the different architectural and engineering planners are required to fulfill (DEGES 2020; Deutsche Bahn 2020). In this regard, DB describes the geometric detailing using the LoD term and the maturity of the semantic information using the LOI term. Similar to the concept of MDG, the DB has mapped their specification to the national design phases definitions (HOAI 2013). On the other hand, DEGES used the LOD term that comprises both LOG and LOI scaling from 100 – 500 (DEGES 2020). Additionally, since digital drawings are still a required deliverable in practice, building models should be capable of producing drawings with different scales. In this regard, DEGES maps the LODs to the different drawing scales. For example, LOD 100 is mapped to M 1:5000 and M 1:1000 (conceptual design and pre-planning, respectively). Finally, DEGES also recommends specifying the LODs according to the design phases' definitions.

To provide a foundation for the mandatory use of BIM in infrastructure, the German Ministry of Transport funded the project BIM4INFRA2020, which established a set of guidelines and recommendations (BIM4INFRA 2019). An essential part of these guidelines was an LOD specification describing infrastructure elements. BIM4INFRA2020 has adopted the term LOD that comprises both LOG and LOI for describing the maturity of the geometrical detailing and semantics. Following the other LOD specifications in Germany, BIM4INFRA2020 mapped the LODs to the national design phases' definitions.

Other companies across Europe, for example Modelical (modelical 2016), REBIM (REBIM 2020), Interscale (Interscale 2020), Ergodomus (Ergodomus 2020), Integrated BIM (Integrated BIM 2020), and many others, follow diverse LOD specifications, like the UK's *Level of Definition* (BSI 2012a), LOIN (ISO 2020), or sometimes a mix between them and the BIMForum's LOD specification. The U.K.'s National Building Specification (NBS) has developed a popular guideline (Kell and Mordue 2015), where the *Level of Definition* is described by the *Level of Detail* for the geometric representations and *Level of Information* for the semantics. In the U.S., numerous companies published guidelines describing how they perceive the LOD, such as (Autodesk 2019; Lanmar Services 2014; lodplanner 2018; United BIM 2020). The majority of them are compliant with the AIA and BIMForum's specifications. Similar to multiple international companies, the BIMForum's definitions are prevalent (A2Kstore 2021; Invicara 2019; Tekla 2021).

The need for the LOD concept is evident in the different projects and countries. The different companies invest effort in managing their workflows based on the LOD as a communication language among the domain experts and as a contractually binding agreement. However, as discussed, several LOD specifications are published, and practitioners adopt the specification that best fits their understanding and established workflows, ideally as simple as possible and also flexible enough to precisely capture their information needs. For example, since the national design phase definitions are essential for cost and effort estimation, some practitioners favor mapping the LODs to the design phases. Typically, the design handover to the client happens at the end of the respective design phase. Hence, the content to be delivered is defined per phase, both in conventional and also in BIM-based projects. When multiple disciplines are involved, the current best practice is to define both discipline- and phase-specific LOD specifications instead of a generic one especially that the development velocities vary across the different disciplines.

3.7 Application of LODs in the Design Process

As the LODs provide means for specifying and communicating which information is expected to be present at a specific milestone, they were used by numerous practitioners and researchers for defining the required information throughout the design phases (Abualdenien and Borrmann 2019; Gigante-Barrera et al. 2018; Schneider-Marín and Abualdenien 2019; Vilgertshofer and Borrmann 2017). Abualdenien and Borrmann (2019) developed a meta-model approach for specifying the design requirements of individual families using the LODs, incorporating the information uncertainty. In the same context, Gigante-Barrera et al. (2018) included the LODs as an indicator for the necessary information within Information Delivery Manuals (IDMs). Abou-Ibrahim and Hamzeh (2016) developed a framework for applying lean design principles based on LODs. Additionally, Grytting et al. (2017) introduced a conceptual model of a LOD decision plan, based on a set of interviews and use-cases, to support design decisions. Furthermore, Karlapudi et al. (2021) introduced representing LOD-related BIM data using ontologies, which facilitates their linkage and retrieval during the projects' life cycle.

To support the decision-making process from the early design phases, Abualdenien et al. (2020) used the LODs to integrate the design process with energy simulations and structural analysis. Additionally, Exner et al. (2019) proposed an LOD-based framework for comparing the different design variants and their detailing. To exchange design requests and issues between projects participants, Zahedi et al. (2019) proposed a communication protocol that leverages the LODs to describe design requirements, and M.Q. Huang et al. (2022) introduced a workflow for enhancing the interoperability of multi-LOD BIM models. Abualdenien and Borrmann (2020) developed multiple visualization techniques to depict the information uncertainty associated with the LODs throughout the design phases. Finally Abualdenien and Borrmann (2022) explored machine learning approaches for checking the LOG of building elements.

Overall, the majority of existing literature highlights the importance of the LOD concept for managing design requirements, assisting the collaboration among the different disciplines, and supporting design decisions, starting from the early phases. Further analysis of the different use cases is presented in Section 4.2.3.

4. BIBLIOGRAPHY ANALYSIS

To get an overview of the prominent sources in publishing relevant literature, Scopus¹ was used for searching peer-reviewed journal papers using both keywords *Building Information Modeling* and *LOD*, yielding into 1,580 publications. The results were then analyzed in terms of number of publications and citations between the different journals using VOSViewer¹, a well-known bibliography analysis and visualization tool. As Figure 8 shows, there are four main clusters conducting research in this area, providing an insight into the researched topics (from architecture to civil-engineering, geoinformatics, environmental-engineering, and more). The nodes' size is proportional to the total number of publications and the edges represent the citations.

¹ <https://scopus.com/> | <https://www.vosviewer.com/> |

The initial search resulted in a total of 741 potential publications. Each of the publications was then analyzed for applicability to our study by reviewing the individual papers' title, abstract, keywords, and in some cases, introduction and conclusion. The exclusion criteria followed for filtering publication includes:

- Studies investigating a different domain. Although the keywords were specific, multiple publications belong to computer graphics, biology, sociology etc.
- Studies investigating city and urban representations. Those publications were excluded since the LoD corresponds to the cityGML's Level of Detail, which addresses a different purpose than the scope of this study.

As a result, 299 publications out of 741 were selected as applicable for our study. Then each of the selected papers was analyzed with respect to answering the research questions defined in Section 2. Accordingly, first, the LOD standard was identified, where its definition and references were evaluated. Then, the parts that apply and use the LOD within each study were carefully evaluated to understand the authors' interpretation. Finally, multiple statistical calculations were performed to develop an overview of the current state of the art and identify trends over time.

4.2 Analysis Results

4.2.1 Publications per year and journal

This section presents the analysis results of the selected 299 publications. The first results provide an overview of the publications over the period 2000 – 2020. Figure 9 shows the number of publications per year and per the LOD standard name (Level of Development, Detail, Definition, and not available). The category named not available represents papers that specify an abbreviation (e.g., LOD 200 or LoD 200) but do not provide any name or citation reference.

Although the specifications of VicoSoftware (VicoSoftware 2005) and AIA (AIA 2008) have been published since 2005 and 2008, respectively, only a few publications incorporating the LOD concept were published by 2011 in the investigated scholar databases. However, afterward, the LOD concept started gaining a continuous increase in popularity, reflecting the increasing demand for standardizing the progression of building information across the design phases. Figure 9 highlights the continuous co-existence of both naming conventions, the Level of Development and Detail. Some of the publications' background sections acknowledged the Level of Definition and Level of Information Need. The Level of Definition was used in two publications, and the Level of Information Need in none. The main reason for not using the LOIN in publications yet could be that it is still relatively recent in comparison to others.

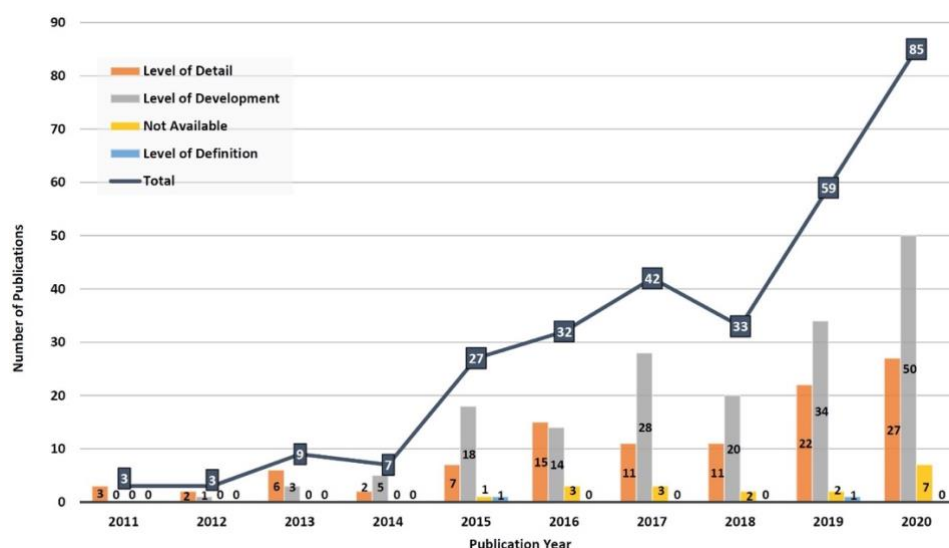


FIG. 9: An overview of publications over the study period, 2000 – 2020. No relevant publications were found before the year 2011. The blue line shows the total publications per year and the bars at each year represent the total count of the selected LOD term.

To get an insight into the domains that are interested in investigating the LOD concept, the publications were grouped according to their source. Figure 10 depicts a sorted list of the identified journals with their corresponding percentage of publications. In total, 43 different journals were identified, which conveys the applicability of the LOD concept on the different domains and scales. In comparison to other journals, the contributions of the *Journal of Automation in Construction (AutCon)* are outstanding (represents 30% of all publications), which is approximately 3.6-fold the publications of the subsequent journal.

The results presented in Figure 9 answer part of RQ1 as they show the current trend of increasing the adoption of the LOD concept and highlight which standards are more popular than others over time. Additionally, Figure 10 shows an overview of the LODs' relevant research domains.

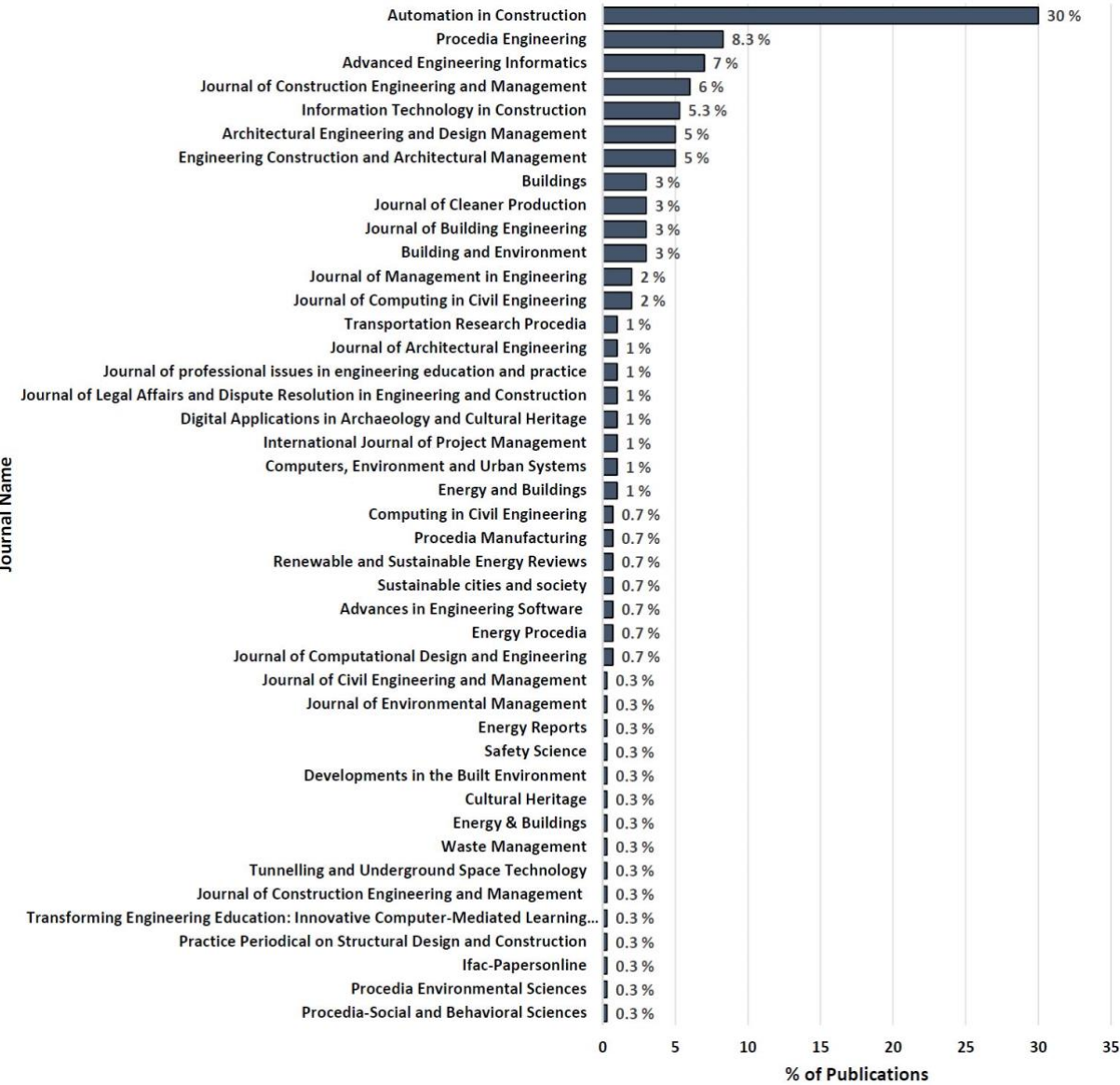


FIG. 10: An overview of publications per journal over the study period 2000 – 2020. Journals are sorted in descending order. In total, 43 journals were identified.



4.2.2 Analysis of the references to LODs

Afterwards, the selected publications were reviewed in detail. The first investigation was to identify which LOD concept is more popular. To identify this information, three main aspects were evaluated: (1) the concept's name, (2) its abbreviation, and (3) its scientific reference (citation).

Figure 11 shows the LOD names and their corresponding percentages that were found during the literature review. The *Level of Development* was the most widespread naming convention, where it was used in 58% of the publications, followed by the *Level of Detail* with 35%. Additionally, 1% of the publications used the *Level of Definition* in their work. From those who used *Level of Development*, the decomposition of information to both *Level of Geometry* (LOG) and *Level of Information* (LOI) was frequently observed. Finally, 6% of publications did not mention the full concept name or a specific reference, represented as *Not Available*. Those publications considered mentioning the abbreviations *LOD* and *LoD* is clear enough for describing the geometric detailing (such as mentioning the extraction of exterior walls surfaces at LoD 200), presence of material layers (for example, the need for at least LOD 300 for energy calculations), and the required information from the different disciplines during the design process.

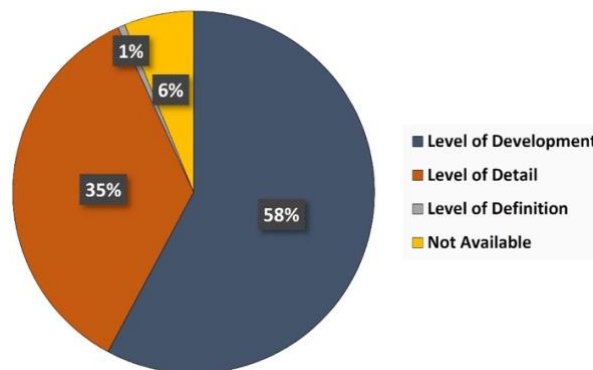


FIG. 11: An overview of the used LOD standard names, “Level of Development”, “Level of Detail”, “Level of Definition”, and “Not Available”.

It is worth mentioning that the authors' hesitation in using a specific term was clear in multiple publications; for example, when writing *Levels of Development (or detail)*, *Levels of Development/detail*, or vice versa. In the same context, numerous synonyms were also used across the different publications when describing the meaning of what an LOD is meant to represent, such as *Level of Design*, *Level of Representation*, *Level of Knowledge*, *Level of Granularity*, and *Level of Abstraction*.

Figure 11 showed multiple LOD naming conventions, where 6% were *Not Available*. When checked the used abbreviations, 99% of publications included an abbreviation, and the most prevalent abbreviation was the *LOD* with 85% (see Figure 12). For example, the AIA and BIMForum's specifications use the abbreviation *LOD* while some others use *LoD* (BSI 2012a; Build Informed 2020; Deutsche Bahn 2020). Additionally, a noticeable assignment of the *LoD* to the *Level of Detail* was observed, where 69% of publications that used *LoD* were referring to the *Level of Detail*.

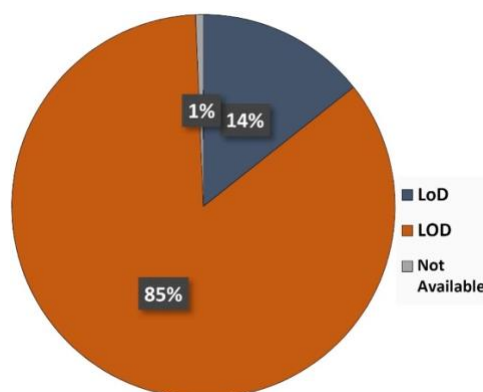


FIG. 12: An overview of the used LOD abbreviations, “LOD”, “LoD”, and “Not Available”.

Next, the referenced specifications or guidelines were checked in the individual publications. The results, presented in Figure 13, emphasize the lack of scientific publications referencing the guidelines, where 54% of the publications were satisfied with stating the LOD abbreviation or name and presumed that it is adequate to provide a clear and understandable meaning for readers. The explanation of this result can be related to the current state of practice, where domain experts use the LOD language to define their information requirements (e.g., requirements of LOD 300) without explicitly referring to a particular specification (van Berlo and Bomhof 2014). However, based on surveys, every practitioner has an own idea of what requirements a specific LOD should include (van Berlo and Bomhof 2014).

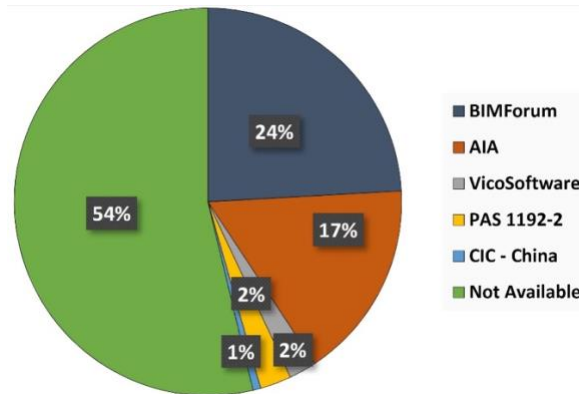


FIG. 13: An overview of the referenced LOD specifications, “BIMForum”, “AIA”, “VicoSoftware”, “PAS 1192-2”, “CIC – China”, and “Not Available”.

From the publications that included a reference to a specific guideline, the *BIMForum* and *AIA* were the most referenced with 24% and 17%, respectively. Those were followed with few references to the UK’s *PAS 1192-2* and China’s *LOD CIC - China*.

Overall, from the results presented in this section, we observe the authors’ preference of using the *Level of Development* term with *LOD* as an abbreviation. Additionally, the *BIMForum* and *AIA* specifications were referenced in 41% of the publications (these observations answer RQ2 for reporting about the popularity of the different standards and naming conventions).

4.2.3 Analysis of the application of LODs

The previous section focused on evaluating the referenced LOD standards in the different publications. This section presents the results of carrying a detailed investigation on the use of the LOD standards in those publications. Accordingly, the areas where the application of the LOD concept was described were analyzed in detail.

The first aspect investigates whether the LOD was applied to the individual elements or the overall models, such as a multilayered wall or an overall building model. Figure 14 shows the percentages of applying the LOD, where 48% of the publications referred to applying it on the overall building model, in comparison to 37% on the element level, and 15% did not provide sufficient information on how the LOD was applied. This result has multiple perspectives; as described in Section 3.5, the *AIA* and *BIMForum* have explicitly confined the use of their guidelines on the element level and stated that there is no correlation between the LOD and the progression during the design phases.

However, 27.3% of those who referenced the *AIA* or *BIMForum* have applied it on the overall building model. A reason for this kind of confusion could be as the influence of other well-established specifications, such as the *LoD* in *cityGML* (it describes the geometric representation of the overall building and city models), as some of them are established for more than a decade (Kutzner et al. 2020). Additionally, there is a clear need to have an LOD standard that is capable of representing the overall building model across the design phases. For example, *Abualdenien and Borrmann (2019)* proposed a concept, *Building Development Level (BDL)*, which acts as a container describing the overall building model’s requirements at a particular milestone (using the *LOD* language for specifying the requirements of the individual elements).

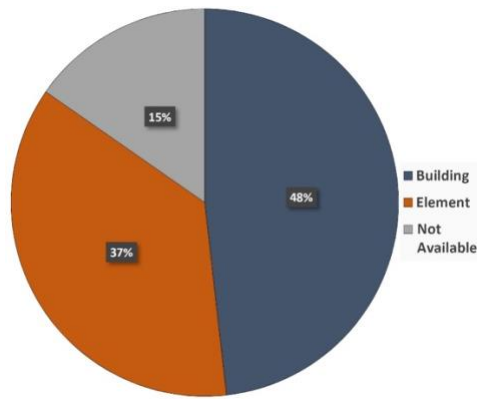


FIG. 14: An overview of the applying the LOD concept in the investigated publications. 60% applied the LOD on the overall building and infrastructure models while 37% applied specifically on elements, while 11% did not include sufficient information to identify how the LOD was applied.

The next step was to categorize the individual publications according to their purpose. The aim is to identify which use cases the LOD was mainly involved in. The results are depicted in Figure 15, where 16 use cases were identified, including visualization, quantity take-off, model checking etc. Figure 15 shows the corresponding percentage of each use case. Here the use of LODs for supporting decisions, such as enhancing the collaboration and integration of the different disciplines starting from the early design phases, was used in more publications than others. The second highest use case was life cycle assessment and sustainability (represented as LCA), followed by requirements management and model checking.

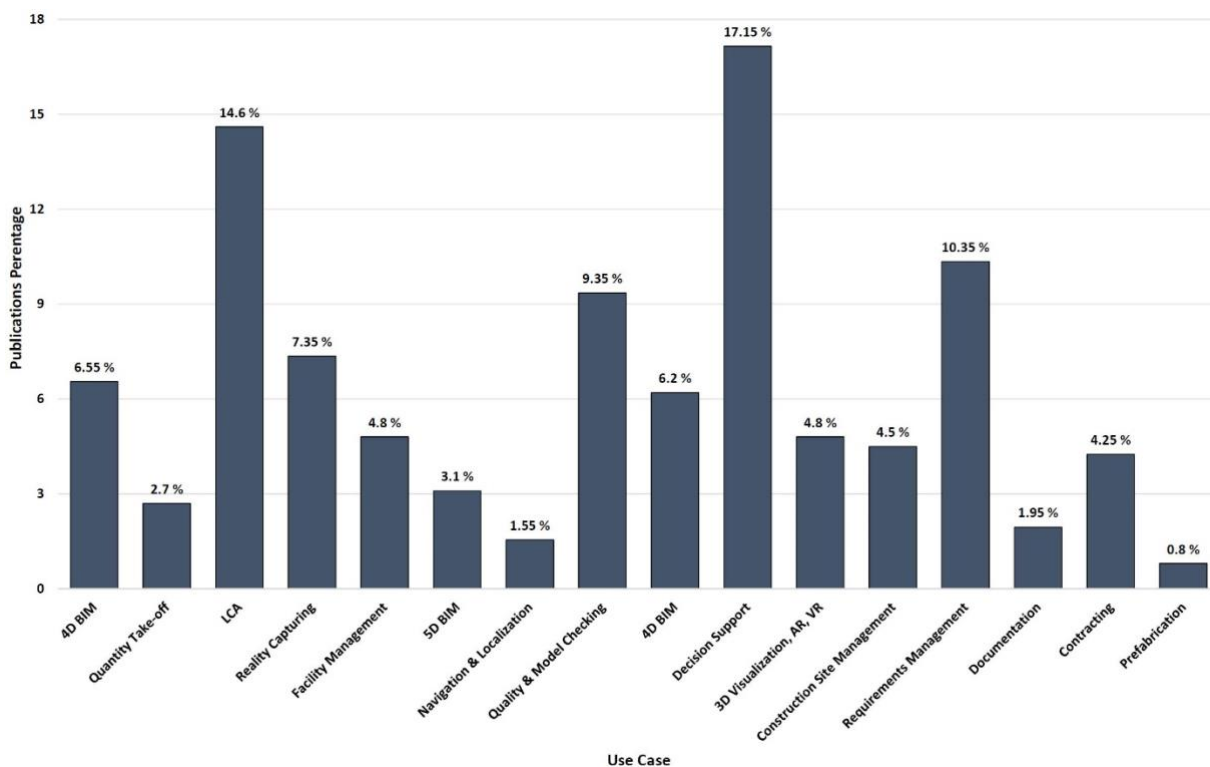


FIG. 15: A list of the identified use cases for applying the LOD.

The fifth highest use case was *Reality Capturing* (with 7.35%). This use case is essential in multiple phases of a projects' life cycle, including:

- Design: supporting architects and owners who are considering renovating an existing asset, or capturing the current site's conditions to construct a new facility.

- Construction: capturing the progress of construction to support carrying next tasks, such as capturing the anchor rod placement to confirm the interfaces of geometry and alignment of steel base plates with the anchor rods cast into the concrete (BIMForum 2020b).
- Documentation: documenting the current state of assets, including any existing health issues, such as cracks.

During the investigation of the publications it was observed that several authors (43% of the reality capturing relevant publications) used the *Level of Development* term to describe the geometric detailing of the existing assets' as-is conditions. However, based on the definitions provided by the different specifications (see Sections 3.1 and 3.2), the term *Level of Detail* is more suitable for this purpose as it describes the geometric detailing of elements rather than the state of their development (during the design process). Capturing reality is an essential use case for many applications in the AEC industry. Hence, especially with the emerging topic of Digital Twinning of the built environment, it is crucial to carefully apply standards according to their intended use. For example, when describing the accuracy of scanning and reconstructing the captured assets, it would be more suitable to combine the *Level of Detail* with specialized standards for representing the accuracy, such as the *Level of Accuracy (LOA)* (USIBD 2019) and *Level of Acceptance (LoA)* (BIMForum 2020b).

The different use cases highlight the applicability of the LOD concept for the entire life cycle of projects, from contracting to 4D/5D BIM, and finally, documentation and facility management (which provides sufficient information to answer RQ3).

5. DISCUSSION

Different domain experts base their work on models provided by experts from other disciplines during the design, construction, and operation of an asset. At this point, the exchanged geometric and semantic information must fulfill specific criteria to develop the design further, evaluate its performance or actually build the asset. Hence, there is a need for a common language that the different disciplines can follow to define and communicate their requirements and specify the expected deliverables. This is the primary motivation behind creating and publishing all of these LOD specifications internationally. As illustrated in Figure 16, the requirements of the delivered BIM models are typically specified in contracts and BIM execution plans, where the geometric and semantic information required for the individual element types from each domain expert is specified for every design phase.

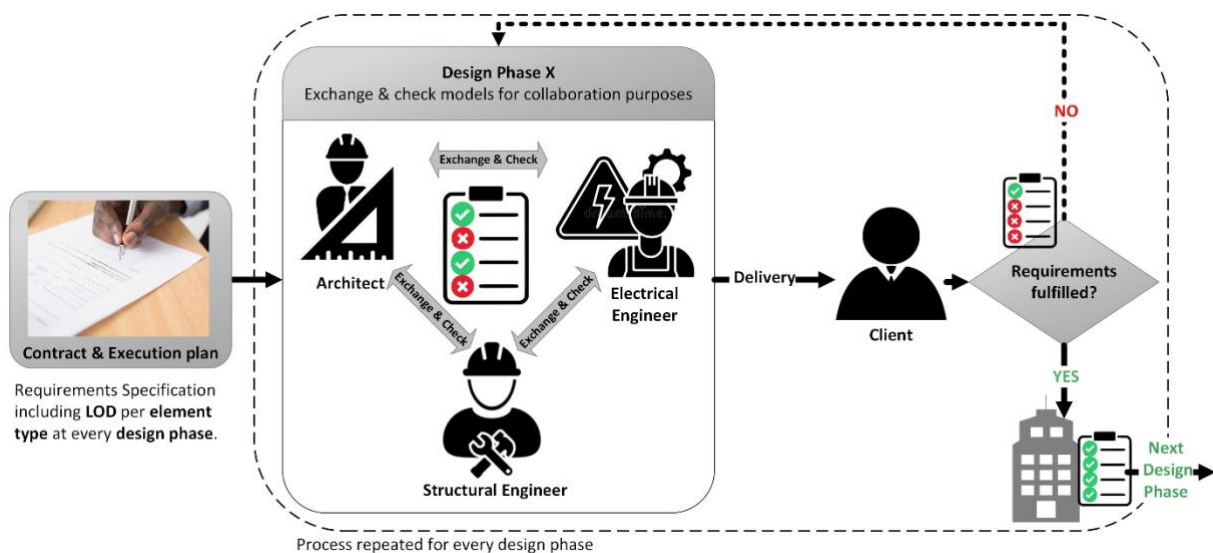


FIG. 16: Illustration of the multidisciplinary design process, highlighting the specification of a project's LOD requirements in contracts and BIM execution plans, and then validating the specified requirements during the collaboration with different disciplines as well as delivery to the client.

By reviewing the evolvement of the LOD specifications between 2005 and 2020 we witness the different countries' attempts to reflect their needs by standardizing their best practices. In multiple cases, countries have adopted different methodologies and terminologies in their subsequently published specifications. This revolutionary period of 15 years has explored the advantages and limitations of various alternatives for standardizing design requirements (Section 3.5 emphasized the differences between the different approaches). Hence, future LOD specifications will be influenced by the currently dominant specifications, as their methodology and terminology are being adopted internationally, assisting in reaching a global consensus.

On the other hand, the literature review of scholarly publications has revealed a trend towards increasingly relying on the LOD concept over time as a fundamental aspect for carrying out the different tasks across diverse domains (which answers RQ1). Similar to the LOD specifications, the term *Level of Development* and abbreviation *LOD* were the most common among other alternatives. In our analysis, we identified that the term *Level of Detail* was repeatedly connected to the geometric detailing (answering RQ2). However, although the worldwide specifications differ from various aspects, we identified that almost half of the publications did not provide a reference (citation) to the specification they are following. This highlights the ready mentality for internationally standardizing the LOD definitions among practitioners, as it is seen as a common communication language.

However, so far, the AEC industry is still lacking this kind of common language. Hence, various European and international activities are trying to fill this gap with new standards, such as the *Level of Information Need* (ISO 2020), and a simplified and computer-readable framework, like the *Information Delivery Specification* (buildingSMART International 2021). Currently, numerous industry practitioners communicate their LOD requirements using a tabular matrix (an example is shown in Table 3). In this representation, each element type and its corresponding required LOG and properties are specified. The presence of properties is identified using an *X* character, while the geometric detailing is described using the LOG levels 100 – 500. This reduces the uncertainty of which semantic information must be present at each design phase. However, an agreement of what LOG 100 – 500 means is still necessary. Hence, explicitly referring to a particular LOD specification is crucial for clearly defining projects' scope and estimating efforts. After all, 16 common use cases were identified for the application of the LOD concept, where the top five are decision support, LCA, requirements management, quality & model checking, and Reality capturing (answering RQ3).

TABLE 3: Example of an LOD specification, showing the required types of building elements and their corresponding LOG and LOI specifications.

Identification		Level of Geometry	Level of Information (LOI)								
Element Type	IFC Class	LOG	Name	Core Material	Load-bearing Function	Surface Covering (texture)	Fire Protection Characteristics	Part of Escape Route?	Sound Insulation Characteristics	Is External?	Thermal Transmittance
Windows	IfcWindow	300	x	x			x	x	x	x	x
Walls	IfcWall	350	x	x	x	x	x	x	x	x	x
Curtain Walls	IfcCurtainWall	350	x	x	x	x	x	x	x	x	x
Stairs	IfcStair	200	x	x				x		x	
Ramps	IfcRamp	200	x	x				x		x	
Doors	IfcDoor	200	x	x				x		x	
Ceiling	IfcCeiling	300	x	x	x		x				
Sanitary	IfcSanitary	100	x								
Rooms	IfcSpace	-	x					x		x	
Slabs	IfcSlab	300	x	x	x		x		x	x	
Roofs	IfcRoof	300	x	x	x		x		x		x
Beams	IfcBeam	200	x	x	x					x	
Columns	IfcColumn	200	x	x	x		x	x		x	
Structral Truss	IfcAssembly	200	x	x	x						
Foundation	IfcFooting	350	x	x	x		x				x
Framing	IfcBuildingElementProxy	300	x	x	x		x		x		

Other standards than the LOD, such as IDM and LOIN, are certainly more suitable for the specification of many aspects of the information exchange, including the process description, the semantic requirements and the

documents. However, where LOD is unrivalled so far is the specification of design maturity with a clear focus on the geometry of building elements. It lays out a common understanding of the progression of BIM elements in a grouped set of additions in terms of modelling. The industry’s rapid and wide adoption of the LOD clearly indicates that this is an essential part of specifying BIM deliverables.

Table 4 summarizes the applicability of the three concepts, LOD, LoD, and LOIN. All of them can be used as part of exchange requirements. However, as emphasized before, the LOIN is more comprehensive and suitable for defining exchange requirements, as it comprises most of the necessary information (including the specification of milestones, actor, and all the necessary element types and their requirements). On the other hand, although the LoD and LOD define the exchange requirements for the individual element types on each level, they require additional details to be aligned with the project delivery or to fulfil a particular use case, such as, which design phase and the responsible actor.

TABLE 4: Summarized comparison between the features provided by the three concepts, LOD, LoD, and LOIN.

Concept \ Feature	Maturity Indicator	Detailing Indicator	Incremental Levels	Applicable for One vs. Multiple Element Types	Use case Oriented	Part of Exchange Requirements
Level of Development (LOD)	x	x	x	One		x
Level of Detail (LoD)		x	x	One		x
Level of Information Need (LOIN)				Multiple	x	x

This highlights an essential difference between LOIN and others, where LOIN focuses on specifying the requirements of multiple object types for a particular use case. At the same time, the LOD and LoD define the requirements of developing one object type further from one level to another. Furthermore, although the LOD and LoD follow a similar approach for describing the detailing of a single element through the different levels, the LOD is the only concept that provides an indicator of thought through information (i.e., mature and fixed).

6. CONCLUSIONS & FUTURE WORK

The LOD concept is contractually binding and essential for collaboration among the different domain experts. Practitioners typically define their design requirements and the detailing of their deliverables using the LOD language. However, numerous LOD specifications were published worldwide by public organizations and commercial companies. These specifications share a common basis of information progression and refinement from one level to another. However, they have multiple fundamental deviations, such as confining the applicability of their guidelines on the element-level rather than the building-level and describing the geometric detailing vs. the reliability of the information.

Hence, this paper investigated the interpretation and application of the LOD concept in the different domains. This paper presented a systematic literature review, where 299 peer-reviewed publications were analyzed in detail. The review results show an evident trend in increasing the adoption of the LOD through the years. A further investigation highlighted that practitioners favor the use of the term *Level of Development* in comparison to others, like *Level of Detail*, *Definition*, or *Information Need*. Additionally, this investigation identified a set of common domains and use cases in which the LOD concept was applied.

At the same time, this literature review revealed multiple misconceptions and application issues, including the use of *Level of Development* for describing the geometric detailing of as-is assets. Furthermore, more than 50% of the publications who used the LOD in their work did not provide a citation reference to which specification they are referring to, which emphasizes the authors’ assumption that the meaning of *LOD 200* or *LOD 300* is a common knowledge and understandable by the community.

This study stressed the need for unifying the different LOD concepts internationally as their deviations cause multiple misinterpretations. Such issues hinder the value of the LOD as it is meant to provide a common ground and language for defining requirements and deliverables. Additionally, scholars should carefully apply the LOD concept in the research by revisiting the official LOD specifications and providing a proper citation reference. As a next step, it would be beneficial to internationally standardize the different LOD specifications (publishing

international LOD guidelines). The authors are convinced that the different specifications share the same basis and can be unified.

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