Ontological approach for LOD-sensitive BIM-data management

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Abstract. The construction industry is a collaborative environment with the involvement of multiple disciplines and activities throughout the Building Lifecycle Stages. The collaboration requires the iterative and coordinated exchange of information for significant improvement of the building design, construction and management. The successful representation of these information refinements enables the identification of the required level of detail (LOD) for data sharing parameters between the multiple disciplines. Since the last decade, LOD is a promising approach for efficient representation of semantically rich BIM data in different levels. Despite the improvement, there is a lack of efficient implementation in building lifecycle functionalities, because of their fundamental heterogeneity, versatility and adaptability. The proposed approach enables the representation of LOD-sensitive BIM data through the formal definition of ontologies. The paper validates this approach based on the concept of competency questions and their respective SPARQL queries. With the demonstration and validation, the paper provides the conceptual proof for the practical application of the developed approach. The proposed solution can also be easily adaptable and applicable to the present BIM process since the representation of BIM data in different ontologies (BOT, ifcOWL, etc.) are within reach.

Keywords: LOD, ontologies, competency questions, SPARQL queries, BIM.

1 Introduction and Background

The Architecture, Engineering, Construction, and Operation (AECO) industry is a collaborative environment and requires the iterative and cooperated exchange of information between multiple disciplines at different stages of the building lifecycle process. The collaboration enables the efficient and economical design of the building and its management [1–3]. The collaboration is also crucial in identifying the needed information for a specific discipline and restricting the information exchange to the identified level of need [4, 5].

Building Information Modelling (BIM) is an emerging approach in the construction industry to describe and digitally represent information [6–8]. The concept like Information Delivery Manual aims to enhance the business application of the BIM process through the definition of discipline-based process maps and the information requirements for their execution [5]. Similarly, the approaches like LOD concepts are introduced in the BIM process for specifying the set of the required level of data export or import parameters between the multiple disciplines [9]. The defined LOD levels from the different national standards or publications describe the granularity and the sequential refinement of both the geometric and semantics information about an object [10]. These technical developments in the BIM process significantly improve the collaboration through effective sharing of the dedicated data to the specific domain requirements. The process and practice of representing the information in different levels of detail, depending on the purpose, increase the quality and reliability of the BIM data at various stages of the construction process. This LOD-based BIM data representation enables to define the characteristics of each BIM object at different levels of detail and allows the stakeholder to understand the usability and limitation of the information.

There are different standards of publications to represent the building object's geometry and attribute information in different LOD levels. The publications from USA UK, Italy, Netherlands, Denmark, etc. are introduced similar concepts for LOD in terms of Level of Development, Level of Detail, Level of Geometry, Level of Information, Level of Completeness, Level of Reliability, etc. It is true that no such LOD levels define a set of pre-requirements about the data within the level but provide a language to define these requirements based on the project, location and organization. However, despite the improvements, there is a lack of successful implementation and management of LOD functionalities within the existing BIM solutions [11]. It is mainly because of confusion on data requirements at certain LOD levels and the insufficient understanding of diverse frameworks for the adoption and representation of LOD levels.

Moreover, the uncertainty in the defined data requirements for each LOD level may also severely affect the collaboration in AECO projects. The versatility of data requirements needed for a specific process is also not allowed to specify a specific LOD level for a BIM model. Although different LOD systems are available for required data representation, these complexities brought a need in the AECO industry to define a solution that provides common model deliveries [12]. The research in this publication aimed to develop a common and flexible LOD framework that can accommodate different LOD systems in BIM data management. The framework allows different practitioners and organizations to work under a common platform irrespective of project, location and requirements. The framework also aimed to enable the user-based or project-based requirement specification for each LOD level.

The development of the LOD framework is majorly based on the linked data and ontology concepts, which brings flexibility, compliance and alignment capabilities through logical reasoning and knowledge inferencing. Furthermore, the structured representation of building data in ontologies (triples or graphs) enables the stakeholders to semantically interpret (update, extract or delete data using queries) data for various domain-specific operations with minimal human interventions [13]. The capabilities of linked data also ensure the linking of contextual information with the BIM data through the concept of IRI's. This ontological approach is also easily adaptable and applicable to the present BIM process since the representation of BIM data in different ontologies (BOT, ifcOWL, etc.) are within reach [14–16]. Further discussions regarding the ontology-based framework development and BIM data management are elaborated in the coming sections of the paper.

2 State-of-art-analysis

2.1 LOD systems

The LOD levels of BIM data should be generally defined for different stages of projects when data sharing takes place. This is a pragmatic approach to indicate the granularity of the BIM data and data refinements throughout the project progression over multiple stages of the building. Furthermore, this would allow stakeholders to verify that project information in detailed enough to meet their requirements, and enabling them to decide whether to proceed to the next project stages or not.

Different countries have developed dedicated LOD standards generating a complex situation at an international level (**Table 1**). The abbreviation "LOD" is used in various meanings in different countries, such as the USA - BIMForum Specification [17], UK - BS 1192-1 [18] and PAS 1192-2, 3 [19], and Italy UNI 11337 part 4 [20] (see also Table 1). In the terminology used by the U.S. legislators since 2013, LOD has assumed the meaning of Level of Development. In the USA context, there is no formal difference between geometric and non-geometric information. Nevertheless, this distinction is embedded in the two reference documents of the BIMForum Specification where Part I identifies the element geometry and Part II identifies the attribute information.

Table 1. LOD system according to the different standards of specifications.

Country	LOD means	Subtype	Scale
USA	Level of Development	LOD: As Designed	LOD 100, LOD 200, LOD 300, LOD 350, LOD 400
		LOD: As Built	LOD 500
UK	Level of Definition	LOD: Level of Detail	LOD 1, LOD 2, LOD 3, LOD 4, LOD 5, LOD 6
		LOI: Level of Information	LOI 1, LOI 2, LOI 3, LOI 4, LOI 5, LOI 6
Italy	Level of Development of Objects	LOG – Geometrical Objects	LOG A, LOG B, LOG C, LOG D, LOG E, LOG F, LOG G
		LOI – Information Objects	LOI A, LOI B, LOI C, LOI D, LOI E, LOI F, LOI G

According to the UK standards, LOD has the general meaning of Level of Definition, which includes the two distinct parts of the Level of Detail and Level of Information. The level of detail represents the description of the graphic contents at each stage, while the level of information represents the description of non-geometric contents. Simultaneously, the Italian norm UNI 11337:2017 defines the LOD as the Level of Development of the objects and is further divided into LOG, Level of development of objects – Geometric Attributes, and LOI, Level of development of the object – Informational Attributes.

2.2 Information Management

In the area of information management, the support for LODs centres around the challenge to represent (1) various LOD systems, (2) multiple versions of information about the same objects and (3) the connections of LOD-specific data to processes over the building lifecycle. A proper representation not only allows the users to access and work inside one specific LOD but enable various cross-LOD functions: to access the history of values, to utilize the links, annotations, and other enrichments of previous LOD objects with those in subsequent LODs, to check the consistency and possible deviations between objects at different LODs, and to determine what kinds of adjustments to previous LOD models would be needed. Moreover, it helps to connect LODs to other aspects of building information: to keep track of the origin of information and to maintain the rules for validating it against the requirements of subsequent activities. This analysis of LOD requirements suggests at least the following areas where ontology definitions are needed to properly support LODs. For more clear applicability and understanding a set of Competency Questions (CQ) are defined based on the requirements for each area.

1. LOD frameworks: The representation of various levels, their relations, and the links to associated definitions.
   i. CQ1 - What is the relation between the LOD sub-type to the LOD scale?
   ii. CQ2 – How do LOD levels (LOD scale) are related to each other?
   iii. CQ3 - How do LOD scales are defined based on the LOD system?
2. LOD sensitive BIM data: The representation of versioned properties of objects to capture the data at multiple different levels in an organized manner.
   i. CQ4 - What is the value for the object properties in previous levels?
3. Connection of LOD framework to processes**:** The representation of LOD-specific data by activities along with the sources.
   i. CQ5 - From which source the value of “Wall width” is extracted?
   ii. CQ6 - What level of properties are required for a specific activity?

3 Ontology-based LOD representation

3.1 LOD framework

The development of an ontology framework for LOD representation is progressed towards providing all the answers for the above-identified requirements. From the general analysis of different LOD systems, a methodological ontology schema is developed and illustrated in **Fig. 1**. Since different construction projects can adopt different LOD systems, the developed ontological structure for the LOD framework can accommodate the different standards of representations detailed in **Table 1**. The methodological idea is to represent LOD systems and their levels as classes, which can then be instantiated on a project-to-project basis. The class dicl[1]:LODFramework can be instantiated with the frameworks called USA BIMForum, UK LOD, Italian LOD, etc. (refer to **Table 1**). Similarly, the levels in different frameworks are added as instances to the class dicl:LODLevel. Later on, the link between the framework and its respective levels are generated using the object property dicl:hasLevel and its inverse property dicl:isLevelOf.

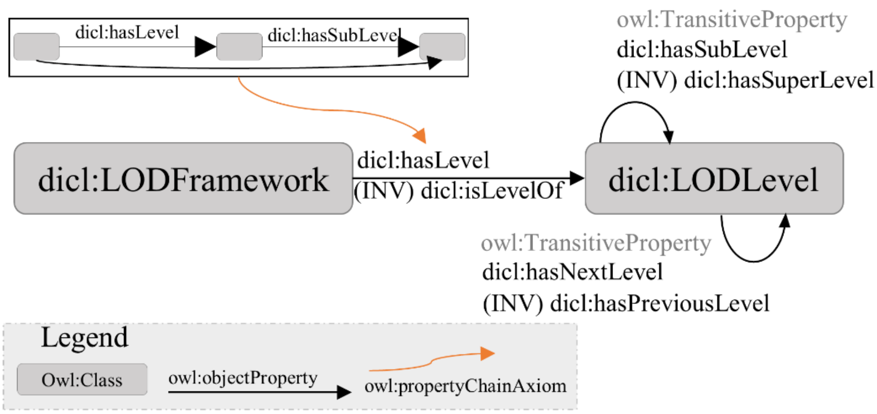

Fig. 1. Ontology-based LOD framework

Furthermore, relationships between the levels of a framework are indicated using the transitive object properties dicl:hasNextLevel, dicl:hasSubLevel and their inverse properties dicl:hasPreviousLevel, dicl:hasSuperLevel respectively. A sub-property chain axiom is assigned to the object properties dicl:hasLevel to define semantic interpretation between the LOD levels and LOD subtypes. An exemplary demonstration is presented in the below subsection to elaborate on the functionalities of the developed ontology framework.

3.2 Exemplary demonstration

For the demonstration, the BIMForum LOD framework (see in **Table 1**) is considered and align to the developed ontological schema. As represented in **Fig. 2**, the instances inst:AsDesigned and inst:AsBuilt are assigned as levels for the instance inst:USA_BIMForum using dicl:hasLevel object property. Since this object property's (dicl:hasLevel) domain and range are fixed to the classes dicl:LODFramework and dicl:LODLevel respectively, the inferencing engine automatically inference the new knowledge by saying the instance inst:USA_BIMForum belongs to the class dicl:LODFramework and the other instances are belonging to the class dicl:LODLevel. This inferenced knowledge is illustrated in **Fig. 2** and **Fig. 3** using the grey dashed lines and the defined relationships are represented with solid black lines.

[1] Prefix dicl: <https://w3id.org/digitalconstruction/0.5/Lifecycle#>

Similarly, the same representational concepts can also be used for the remaining LOD systems mentioned in **Table 1**.

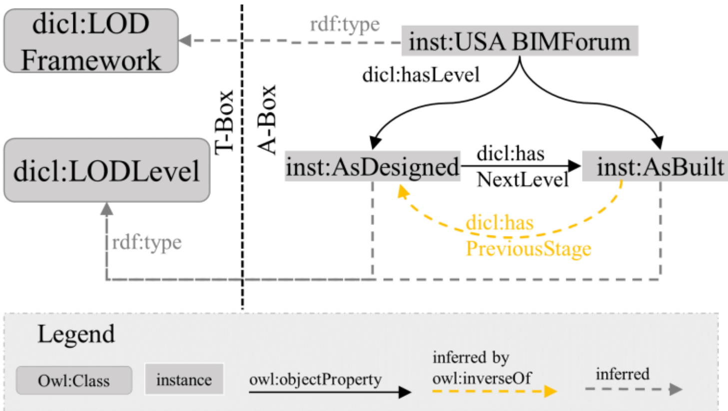

Fig. 2. Relationship between the LOD Sub-types

Moreover, the relationship between the instances inst:AsDesigned and inst:AsBuilt is assigned using dicl:hasNextLevel transitive object property. As defined in the ontology framework, the dicl:hasNextLevel object property has assigned an inverse relationship with dicl:hasPreviousLevel. Which substantially generates the new knowledge between these instances concerning the previous stage relationship. The inferenced knowledge from the inverse relationships is represented by using yellow dashed lines in **Fig. 2** and **Fig. 3**.

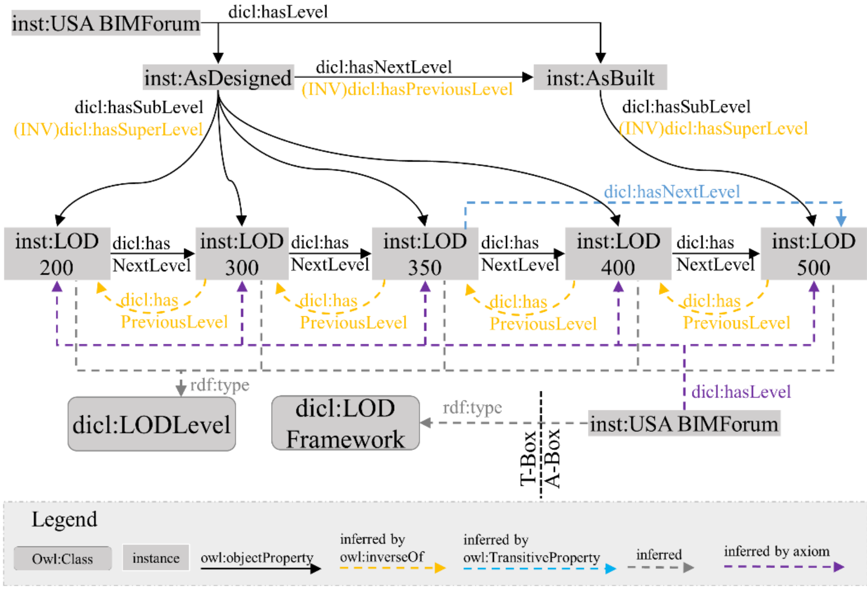

Fig. 3. Relationship between the LOD scales

Furthermore, the LOD scale information (LOD levels) regarding each LOD sub-type is defined by using dicl:hasSubLevel transverse object property and its inverse property dicl:hasSuperLevel. Because of the transverse property nature of these object properties, any further sub-levels of a LOD scale is also considered as a LOD level. Similarly, due to the defined axiom to dicl:hasLevel property, all these LOD scales are inferred as Levels to the dicl:LODFramework (inst:USA_BIMForum). Also, the relationship between the LOD levels is developed by using dicl:hasNextLevel object property. Along with this defined information, a new relationships are generated between LOD levels, for example, between inst:LOD350 and inst:LOD500, which is clearly represented with blue dashed lines in Fig. 3. These generated relationships are because of the transitive property characteristic of the object properties dicl:hasNextstage and dicl:hasPreviousStage.

4 BIM data management

4.1 LOD sensitive BIM data

The representation of BIM data in a LOD-sensitive manner is based on the ideology that (1) Identifiers of objects are not LOD sensitive, but (2) All properties of objects can be LOD sensitive. That means, objects are not associated with a specific LOD level but their property values can be. It is not possible to ask which LOD an object belongs to because the object can simultaneously have properties belonging to many different LODs.

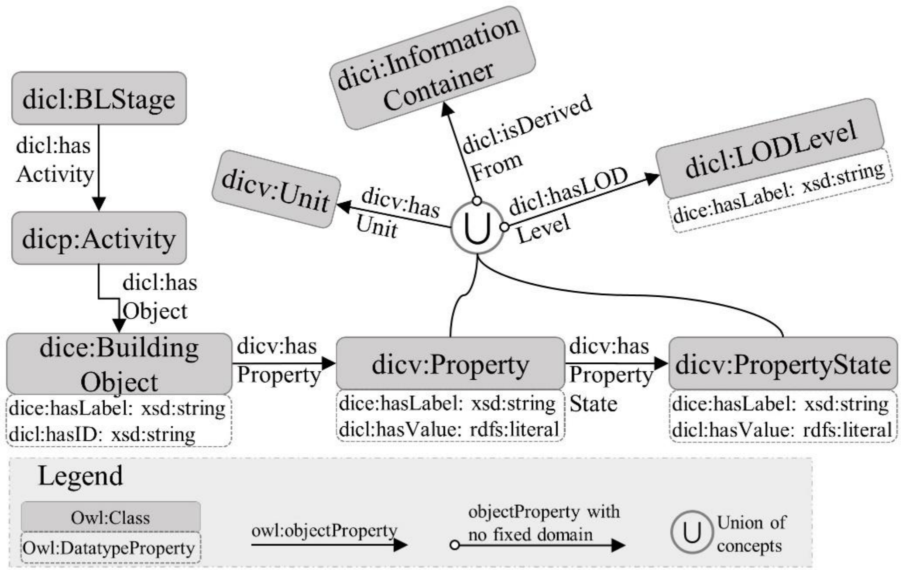

Fig. 4. LOD-sensitive BIM data representation

The developed ontological schema in **Fig. 4** express the same ideology and establish relationships between BIM object data and its respective LOD levels. In the developed ontology framework, a class dice[2]:BuildingObject represents the building elements. Similarly, the class dicv[3]:Property in the ontology framework make it possible to add an ultimate number of properties to building objects using the object property dicv:hasProperty. Also, the class dicv:PropertyState is defined to indicate the growth of these properties accuracy throughout the project life-cycle. The framework also supports defining meta-data attributes for each object (e.g. label and ID), property (e.g. label, value, unit, and source) and property state (e.g. label, source, timestamp, value, etc.). The class dicl:LODlevel is connected to dicv:PropertyState to indicate its level of growth by representing a specific LOD level. The object property dicl:hasLODLevel is used to develop this relationship between dicv:ProperyState and dicl:LODLevel. A sample BIM data representation is illustrated in **Fig. 5** according to the developed ontology framework.

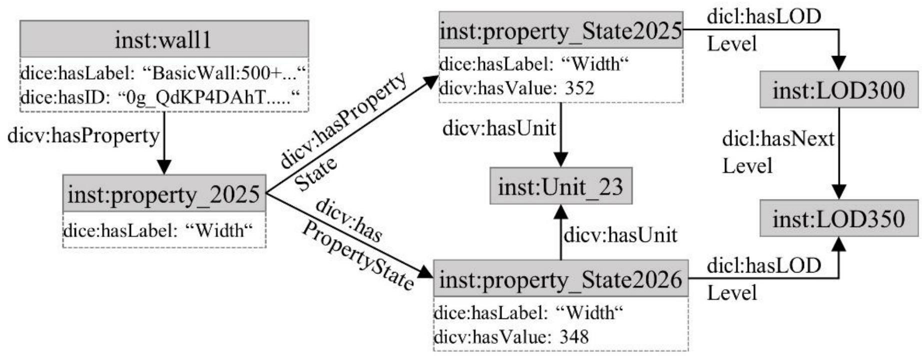

Fig. 5. Example BIM data representation at different LOD levels

4.2 LOD framework to processes

LOD data by activities. The connections of LODs to processes happen through the information objects created in activities and/or their requirement to execute activities. Different activities require different object properties at a specific level of detail. In this ontological framework, an explicit mapping methodology is specified to represent these requirements. The framework enumerates the information interms of (1) Object type (e.g. wall, slab, etc.), (2) Property name (e.g. a single property or grouping of properties), (3) Nature of data needed (e.g. a LOD level or other specification) for each activity. Based on the adopted methodology, the class dice:BuildingObject is further interrelated to the Activities (dicp[4]:Activity) in the project using the object property dicl:hasObject. As illustrated in **Fig. 4**, the adopted ontology framework is

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[2] Prefix dice: <https://w3id.org/digitalconstruction/0.5/Entities#>
[3] Prefix dicv: <https://w3id.org/digitalconstruction/0.5/Variables#>
[4] Prefix dicp: <https://w3id.org/digitalconstruction/0.5/Processes#>

completely fulfilling these connection requirements between LOD levels and the activities within the project.

Sources of LOD data. The possible sources of LOD data are different kinds of information objects. These are primarily BIM models but can also include drawings, documents, messages and events/notifications. In some cases also the information contained in various information management systems can be relevant. Each information object – explicitly or implicitly – provides information at certain LOD levels, and therefore the data should primarily be converted in a LOD sensitive manner. According to the developed framework, the sources of information can represent by using the class dici[5]:InformationContainer. The connection of each property in the LOD sensitive representation to the source of data can be attained with an object property dicl:isDerivedFrom (**Fig. 4**).

5 Framework validation

The validation of the developed framework is performed by running the SPARQL queries based on the competency questions listed and used for the framework development. As represented in **Fig. 2** and **Fig. 3**, the information related to instances and relations (solid black lines) is developed to the main default framework ontology. Similarly, an example BIM data (in **Fig. 5**) is populated to the developed framework to verify the BIM data management process using LOD's. After the population of instances, a reasoner called Pellet has used to inference the new knowledge and to check the consistency, correctness of the developed ontology. Thereafter performed several queries to extract the generated information to check the consistency and quality by comparing it with the original information from the standards (see **Table 1**). Some of the developed query profiles and their results are presented in **Table 2**.

Table 2. Queries and their results for listed competency questions

SPARQL Query	**Query Results**		
Query1:- What are the LOD scale for USA Level of Development (LOD) system?			
SELECT ?System ?Sub_type ?Scale Where{ ? System dicl:hasLevel ?Sub_type. ?Sub_type dicl:hasSubLevel ?Scale . **FILTER**(?System =:USA_BIMForum).}	**System**	**Sub_type**	**Scale**
	USA_BIMForum	AsDesigned	LOD200
	USA_BIMForum	AsDesigned	LOD300
	USA_BIMForum	AsDesigned	LOD350
	USA_BIMForum	AsDesigned	LOD400
	USA_BIMForum	AsBuilt	LOD500
Query 2:- What is the relationship between LOD200 and LOD500?			
SELECT ?Level1 ?relation ?Level2 Where{?Level1 ?relation ?Level2 . **FILTER**(?Level1=:LOD200 && ?Level2=:LOD500)}	**Level1**	**relation**	**Level2**
	LOD200	dicl:hasNextLevel	LOD500

5 Prefix dici: <https://w3id.org/digitalconstruction/0.5/Information#>

<table>
<tr><th>SPARQL Query</th><th colspan="3">Query Results</th></tr>
<tr><td colspan="4">Query 3:- What is the relationship between the USA LOD system and LOD Scale?</td></tr>
<tr><td rowspan="6">SELECT ?System ?realtionship ?Scale
Where{
?System dicl:hasLevel ?Sub_type.
?Sub_type dicl:hasSubLevel ?Scale .
?System ?realtionship ?Scale .
FILTER(?System=:USA_BIMForum)}</td><th>System</th><th>relationship</th><th>Scale</th></tr>
<tr><td>USA_BIMForum</td><td>dicl:hasLevel</td><td>LOD200</td></tr>
<tr><td>USA_BIMForum</td><td>dicl:hasLevel</td><td>LOD300</td></tr>
<tr><td>USA_BIMForum</td><td>dicl:hasLevel</td><td>LOD350</td></tr>
<tr><td>USA_BIMForum</td><td>dicl:hasLevel</td><td>LOD400</td></tr>
<tr><td>USA_BIMForum</td><td>dicl:hasLevel</td><td>LOD500</td></tr>
<tr><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="4">Query 4:- What is the value of “Wall width” in different LOD levels?</td></tr>
<tr><td rowspan="3">SELECT ?Wall ?Width ?Level
Where{ ?Object dice:hasLabel ?Wall.
?Object
dicv:hasProperty/dicv:hasPropertyState
?PS.
?PS dicv:hasValue ?Width .
?PS dicl:hasLODLevel ?Level .}</td><th>Wall</th><th>Width</th><th>Level</th></tr>
<tr><td>BasicWall:500+..</td><td>352</td><td>LOD300</td></tr>
<tr><td>BasicWall:500+..</td><td>348</td><td>LOD350</td></tr>
</table>

6 Conclusion and Future work

The paper explains the developed ontological framework for the effective representation of various LOD systems and their corresponding levels through the demonstration example. The development process is carried out based on the analysed requirements (CQ), which should be fulfilled by a LOD framework. With the defined and inherited knowledge capabilities of the developed ontology framework represents its applicability and functionalities in terms of representing the BIM data in different LOD levels. The ontological representation of the LOD systems brings flexibility, compliance and alignment capabilities through logical reasoning and knowledge inferencing. The paper also explains the framework capabilities corresponding to the BIM data management in terms of LOD sensitive data representation and its connection to processes. The developed ontological framework is also easily adaptable and applicable to the present BIM process since the representation of BIM data in different ontologies (BOT, ifcOWL, etc.) are within reach. Finally, the validation and evaluation of the developed LOD framework are performed based on the SPARQL queries, which represents the framework requirements.

As represented in the paper, the developed methodological framework is only addressing the attribute information about the object but not the geometrical information. The further possible extension of the methodology is corresponding to the representation and management of building object’s geometrical data. The research in this paper is limited to the representation of LOD-sensitive BIM data. The future focus of this research is on the validation of existing BIM data in the context of different LOD levels using SHACL constraints.

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8 References

1. Abualdenien, J., Borrmann, A.: Multi-LOD model for describing uncertainty and checking requirements in different design stages. In: Karlshøj, J., Scherer, R. (eds.) eWork and eBusiness in Architecture, Engineering and Construction, pp. 187–195. CRC Press. London (2018). DOI: https://doi.org/10.1201/9780429506215-24.
2. Abualdenien, J., Borrmann, A.: A meta-model approach for formal specification and consistent management of multi-LOD building models. Advanced Engineering Informatics 40(4), pp. 135–153 (2019). DOI: https://doi.org/10.1016/j.aei.2019.04.003.
3. Karlapudi, J., Menzel, K., Törmä, S., Hryshchenko, A., Valluru, P.: Enhancement of BIM Data Representation in Product-Process Modelling for Building Renovation. In: Nyffenegger, F., Rivest, L., Ríos, J., Bouras, A. (eds.) Product lifecycle management enabling smart X. PLM 2020, Rapperswil, Switzerland, vol. 594, pp. 738–752. Springer. Cham (2020). DOI: https://doi.org/10.1007/978-3-030-62807-9_58.
4. Mangialardi, G., Di Biccari, C., Pascarelli, C., Lazoi, M., Corallo, A.: BIM and PLM Associations in Current Literature. In: Ríos, J., Bernard, A., Bouras, A., Foufou, S. (eds.) Product lifecycle management and industry of the future. PLM 2017, Seville, Spain, vol. 517, pp. 345–357. Springer. Cham (2017). DOI: https://doi.org/10.1007/978-3-319-72905-3_31.
5. Xu, Z., Abualdenien, J., Liu, H., Kang, R.: An IDM-Based Approach for Information Requirement in Prefabricated Construction. Advances in Civil Engineering 2020, pp. 1–21 (2020). DOI: https://doi.org/10.1155/2020/8946530.
6. Keller, M., O'Donnel, J., Menzel, K., Keane, M.: Integrating the Specification, Acquisition and Processing of Building Performance Information. Tsinghua Science and Technology 13(1), pp. 1–6 (2008).
7. Zadeh, P. A., Wang, G., Cavka, H. B., Staub-French, S., Pottinger, R.: Information Quality Assessment for Facility Management. Advanced Engineering Informatics 33, pp. 181–205 (2017). DOI: https://doi.org/10.1016/j.aei.2017.06.003.
8. Karlapudi, J., Shetty, S.: A methodology to determine and classify data sharing requirements between OpenBIM models and energy simulation models. In: Sternal, M., Ungureanu, L.-C., Böger, L., Bindal-Gutsche, C. (eds.) 31. Forum Bauinformatik, pp. 331–338. Universitätsverlag der TU Berlin. Berlin (2019). https://nbn-resolving.org/urn:nbn:de:bsz:14-qucosa2-735487.
9. Treldal, N., Vestergaard, F., Karlshoj, J.: Pragmatic Use of LOD – a Modular Approach. In: Christodoulou, S., Scherer, R. (eds.) EWork and eBusiness in Architecture, Engineering and Construction. ECPPM 2016, Limassol, Cyprus, vol. 2016, pp. 129–136. CRC Press. London (2016). https://backend.orbit.dtu.dk/ws/files/127947941/ecppm2016_paper_54.pdf.

10. Hooper, M.: Automated model progression scheduling using level of development. Construction Innovation 15(4), pp. 428–448 (2015). DOI: https://doi.org/10.1108/CI-09-2014-0048.
11. Papadonikolaki, E., Leon, M., Mahamadu, A. M.: BIM solutions for construction lifecycle: A myth or a tangible future? In: Karlshøj, J., Scherer, R. (eds.) eWork and eBusiness in Architecture, Engineering and Construction, pp. 321–328. CRC Press. London (2018). DOI: https://doi.org/10.1201/9780429506215-40.
12. van Berlo, L. A. H. M., Bomhof, F.: Creating the Dutch National BIM Levels of Development. In: Issa, R. I., Flood, I. (eds.) Computing in Civil and Building Engineering (2014), pp. 129–136. American Society of Civil Engineers (2014). DOI: https://doi.org/10.1061/9780784413616.017.
13. Karlapudi, J., Menzel, K.: Analysis on automatic generation of BEPS models from BIM model. In: Monsberger, M., Hopfe, C. J., Krüger, M., Passer, A. (eds.) BauSIM 2020 - 8th Conference of IBPSA Germany and Austria, pp. 535–542. Verlag der Technischen Universität Graz. Austria (2020). https://nbn-resolving.org/urn:nbn:de:bsz:14-qucosa2-735477.
14. Beetz, J., van Leeuwen, J., Vries, B. de: IfcOWL: A case of transforming EXPRESS schemas into ontologies. Artificial Intelligence for Engineering Design, Analysis and Manufacturing 23(1), pp. 89–101 (2009). DOI: https://doi.org/10.1017/S0890060409000122.
15. Pauwels, P., Zhang, S., Lee, Y.-C.: Semantic web technologies in AEC industry: A literature overview. Automation in Construction 73, pp. 145–165 (2017). DOI: https://doi.org/10.1016/j.autcon.2016.10.003.
16. Chen, W., Chen, K., Cheng, J. C. P.: Towards an Ontology-based Approach for Information Interoperability Between BIM and Facility Management. In: Smith, I. F. C., Domer, B. (eds.) Advanced computing strategies for engineering. 25th EG-ICE International Workshop 2018, Lausanne, Switzerland, vol. 10864, pp. 447–469. Springer. Cham, Switzerland (2018). DOI: https://doi.org/10.1007/978-3-319-91638-5_25.
17. BIMFORUM: Level of Development (LOD) Specification Part I & Commentary - For Building Information Models and Data (2020). BIMFORUM.
18. PAS 1192-2: Specification for information management for the capital/delivery phase of construction pro-jects using building information modelling (2013). BSI Standards Limited.
19. PAS 1192-3: Specification for information management for the operational phase of assets using building information modelling (2014). BSI Standards Limited.
20. UNI 11337-4: Building and civil engineering works – Digital management of building information process – Part 4: Evolution and development of information within models documents and objects (2017). UNI.