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Enhancement of BIM Data Representation in Product-Process Modelling for Building Renovation

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Abstract. Building Information Modelling (BIM) has the potential to become a technology which will help to use a holistic information repository to generate and represent relevant information in different building life-cycle stages (BLCS) to dedicated groups of stakeholders. However, the scope of model components of BIM data (e.g., IFC meta-data) is limited and some parts of it are not modelled in a manner that supports the diversity of engineering use cases. This paper aims to address this deficit by identifying the capability to formulate inference rules as one of the major benefits in the ontology-based information modelling approach. However, before one can formulate inferencing rules a detailed and in-depth understanding is required on how stakeholder information needs are defined in different BLCS and on how available, open-BIM meta-data models support these information requirements. Therefore, the research progressed initially on existing definitions for Level of Detail (**LOD)** and selected process-modelling standards (**BLCS**). In the subsequent part, different renovation **Activities** and the **Stakeholder** involvements are analysed. **Use cases** are defined and used as a grouping mechanism for selected scenarios. Based on these grouping mechanisms, a methodology of how components of a **BIM-model** could be classified to support automated inferencing in the future. The outcome of this research is an established 6-dimensional intercommunication framework (LOD, BLS, Scenarios, Stakeholders, Use Cases, BIM model data) based on the Linked Building Data approach and focusing on renovation processes optimization. Based on the framework, a renovation Product-Process Modelling ontology is developed to connect existing components and to support new interoperable applications.

Keywords: BIM model, Building Life-cycle Stages, Ontology for Product-Process Modelling (OPPM), Stakeholder Scenarios, Linked Building Data, Interoperability.

1 Introduction and Background

In an ideal case, buildings are managed and renovated systematically throughout their whole life cycle. The basis is the execution of the maintenance strategy of the building

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owners, which ensures that there are always up-to-date condition surveys made by professionals with long-term planning and budgeting based on them. Unfortunately, the ideal case rarely exists and resulting to the renovation debt and the poor documentation of buildings' present conditions and maintenance history. There are many reasons behind the lack of efficient approaches and this results in the overall slow implementation of renovation in the residential building stock, for example [1]:

- lack of understanding of the long-term planning and its importance;
- the need to save in housing costs in the short run, especially in the privately-owned apartment buildings;
- the non- or semi-professional ownership of the residential buildings;
- involvement of various actors along the stages of the building life cycle and misunderstandings between them [2, 3].

The BIM4EEB-project [4] aims to tackle these challenges by presenting the fast mapping to ground the initial stage quickly and produce an enriched BIM - either the building has been ideally maintained or not. This approach creates the basis for the cost-efficient renovation planning, implementation and seamless hand over for the post-renovation phase. The further process or phase in building construction and renovation requires the integrated communication and interchange of information between the involved stakeholders and tools along the building's complete lifecycle [5]. Many kinds of research progressed on data interoperability in the AEC domain either by the use of the IFC schema or other data transfer techniques. The diversity of AEC information and the complex interpretation of it among different stakeholders makes those efforts complex and challenging [6 - 8]. Research on the application of semantic web technologies in the AEC industry represents an approach to connect diverse alternative information modelling techniques to OpenBIM (IFC) concepts and enable knowledge generation, representation and sharing [9].

This paper presents a framework supporting renovation process using a Product–Process ontology, which clearly describes the different activities, tasks, sequences, their interrelations to stakeholders involved, the required information, resources, etc. Additionally, it supports the establishment of standardized collaboration protocols between stakeholders, uninterrupted communication flows and sharing of relevant information represented in BIM models when required. An explanation of parameters for the related Product-Process ontology and the development methodology is presented in this paper as well. The result of this paper is an ontological framework for BIM data representation on different levels of detail corresponding to renovation process modelling.

2 Renovation Framework

The project's [4] research idea is to bridge the current gap between renovation planning tools and their inherent process models with BIM authoring tools and their native models. The concept of integrated Product-Process Modelling is adopted to map stakeholders' basic needs and requirements with related application strategies to achieve the re-

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search aim. We have identified the major credentials for the development of an integrated Product-Process ontology framework (see Fig. 1). It comprises of six different aspects, such as BIM-objects (product data), Building Life-Cycle Stages (time context), Activities (process data), Use Cases (processes in their context), LOD (specification of integrated Spatio-temporal context), and Stakeholders (execute processes on BIM-objects).

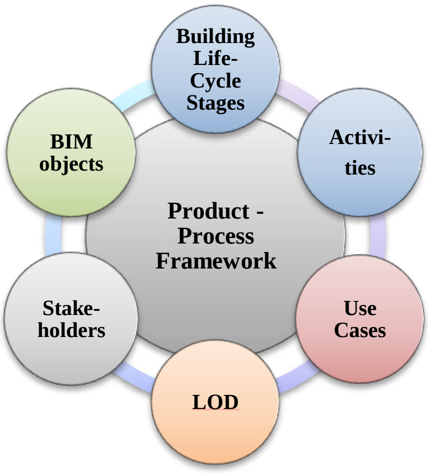

Fig. 1. Components of Product-Process Modelling

Building Information Modelling (BIM) is an advanced information technology that should be adopted by relevant Stakeholders. These stakeholders are performing their activities with the use of BIM for managing the information produced during the renovation processes throughout all BLCS. Going through the BLCS, an additional BIM-content (e.g. classes and attributes of classes) need to be populated which means the BIM-model growth. The early BIM models are broader when covering entities at the upper levels of breakdown structures and focused on constraints between those entities. This information refinement process is defined through the concept of LOD. Moreover, to simplify the understanding of the renovation process and to provide a methodology for the development of LOD-related Product-Process ontologies with general applicability. The concept of Use Cases as a dynamic combination of those activities is defined. The subsequent sections focus on the above-mentioned individual variables and enrich their internal framework with further information.

2.1 Level of Detail (LOD)

The LOD of BIM should be generally defined for key stages of projects when data sharing takes place. This would allow stakeholders to verify that project information is detailed enough to meet their requirements, enabling them to decide whether to proceed to the next project stage or not.

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Since 2004, different countries have developed dedicated LOD standards generating a complex situation at an international level. A single, unified approach for the definition of LOD is pending. The abbreviation "LOD" is used in various meanings in different countries, such as USA - BIMForum Specification [10], UK - BS 1192-1 and PAS 1192-2, 3 [11, 12], and Italy UNI 11337 part 4 [13] (see also Table 1).

Table 1. LOD system according to the different national specifications.

Country	LOD means	Sub-type	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

With the publication of ISO 19650 Parts 1 [14] and 2 [15] a consolidated structure for LOD is being proposed with the introduction of the LOIN concept (Level of Information Need). The LOIN [16] aims to replace the model of predefined scales and to switch into a gradual, incremental, milestone-free system with relevant points established beforehand. However, the LOIN concept is under development.

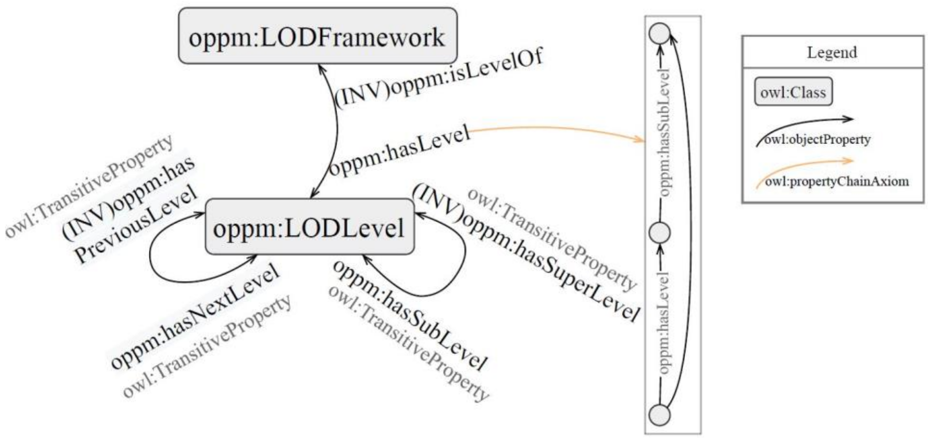

Fig. 2. Ontological representation of LOD Framework

Based on the above analysis of different LOD frameworks, an ontology schema has been developed as illustrated in Fig. 2. Since different renovation projects can adopt different LOD systems, the developed ontological representation of the proposed LOD framework can accommodate the different representations summarized in Table 1.

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The methodological idea is to represent LOD frameworks and its levels as classes, which can then be instantiated on a project-to-project basis. The class oppm[1]:LOD-Framework can be instantiated with the frameworks called USA BIMForum, UK LOD, Italian LOD (refer Table 1). Similarly, the levels in different frameworks are added as instances to the class oppm:LODLevel. Later on, the link between framework and its respective levels are generated using the object property oppm:hasLevel and its inverse property oppm:isLevelOf. As represented in Fig. 2 these two relationships are inversed to each other to provide bi-lateral compatibility for the relationship or the link.

Furthermore, relationships between the levels of a framework are indicated using the object properties oppm:hasNextLevel, oppm:hasSubLevel and their inverse properties oppm:hasPreviousLevel, oppm:hasSuperLevel respectively. A property characteristic called owl:TransitiveProperty is defined for these properties in-order to represent aggregation relationship between levels. For example, an individual inst[2]:LOD100 has next level inst:LOD200, and inst:LOD200 has next level inst:LOD300, then the ontology can infer that inst:LOD100 has also its next level inst:LOD300. Another way of defining semantic interpretation of the levels is with the use of axioms. In the LOD Framework (represented in Fig. 2), a subproperty of chain axiom (oppm:hasLevel o oppm:hasSubLevel subPropertyOf: oppm:hasLevel) is assigned to oppm:hasLevel object property. This axiom infers that all the sublevels (inst:LOD100, inst:LOD200, etc.) defined within the main levels (inst:AsDesigned or inst:AsBuilt) are also been the levels of specific LOD framework.

2.2 Building Life-cycle Stage

An intense analysis is carried on the BLCS framework according to the different standards of specifications for categorization of the building renovation process. The specification of BLC stages is necessary for each construction project to manage and assess engineering services. However, the standard stages in the project differ from country to country and may also be subjected to differences in legislation. Some of those specified standards and the publications are listed below:

- BS EN 16310:2013 – Engineering services terminology to describe engineering services for buildings, infrastructure and industrial facilities [17],
- HOAI – Official Scale of Fees for Services by Architects and Engineers [18],
- RIBA – RIBA (Royal Institute of British Architects) Plan of Work 2013 [19],
- ISO 22263:2008 – Organization of information about construction work – Framework for management of project information [20].

The developed ontological structure of the LOD framework can accommodate different standards for BLCS representation. A process of mapping between those standards was carried out and comprehensibly detailed in Table 2. This mapping process intends to

[1] The word 'oppm' called prefix for Product-Process Ontology, which generally represents the IRI of the ontology. PREFIX oppm < https://w3id.org/digitalconstruction/oppm#>

[2] The prefix 'inst' is used to represent some example individuals in the explanation.

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distinguish the difference between the standards in terms of their life-cycle stage information and vocabulary notation. The application or the usage of these standards in building construction and management projects is based on the locality, requirements and legislation regulations, etc. Thus, a newly proposed ontological schema for a BLCS framework should be capable to represent all these standards more comprehensively. Similar to the LOD framework, an ontological BLCS framework is proposed to denote different life-cycle stages as shown in Fig. 3.

Table 2. BLCS in different standards and publications.

Stages	Standards				
	BS EN 16310:2013		HOAI	RIBA	ISO 22263
1	Initiative	Market study	Establish the base of the project	Strategic Definition	Inception
		Business case			
2	Initiation	Project initiation		Preparation and Brief	Brief
		Feasibility study			
		Project definition			
3	Design (D.)	Conceptual D.	Preliminary Design	Concept Design	Design
		Preliminary D.			
		Developed D.	Final Design	Developed D.	
		Technical D.	Bldg. Execution Drawing	Technical Design	
		Detailed D.	Prepare contract award		
4			Bldg. permission applic.		
5	Procurement	Procurement	Assist award proc.		
		C. Contracting			
6	Construction (C.)	Pre-construction	Project Supervision (C. Supervision)	Construction	Production
		Construction (C.)			
		Commissioning	Project control & documentation	Handover and Close Out	
		Hand Over			
		Regulatory Approval			
7	Use	Operation		In Use	
		Maintenance			
8	End of Life	Revamping			Demolition
		Dismantling			

The proposed ontology framework is more generic and capable to represent the BLCS framework according to different standards, publications, user-defined or project-based specifications. The adopted methodology is similar to the LOD framework ontology in terms of assigning the stages as a class (oppm:BLCStage). It provides the relationship between the stages using the object properties called oppm:hasSubstage, oppm:hasNextStage and their respective inverse properties oppm:hasSuperStage, oppm:hasPreviousStage. Similarly, the transitive character of the properties is enabled by assigning owl:TransitiveProperty to each object property which further enables the aggregated relationships between the stages.

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In addition to the property characteristics, some axioms are defined to achieve the complete semantic meaning of BLCS stages into an ontological framework. These defined axioms are clearly illustrated in Fig. 3. In an example scenario of BS EN 16310 framework, each stage is comprised of many sub-stages and technically these sub-stages are also stages to that framework. This semantic meaning is inferred in ontology with the help of the subProperty chain axiom (oppm:hasStage o oppm:hasSubStage subPropertyOf: oppm:hasStage) defined to the object property oppm:hasStage. Similarly, in the same scenario, the main stage inst:Design (refer Table 2) have a next stage relation with the substage called inst:Maintenance (refer Table 2) or vice versa. These complex relations are modelled in the ontology by using axioms oppm:hasNextStage o oppm:hasSubStage subPropertyOf: oppm:hasNextStage, oppm:hasPreviousStage o oppm:hasSubStage subPropertyOf: oppm:hasPreviousStage assigned to properties oppm:hasNextStage, oppm:hasPreviousStage respectively.

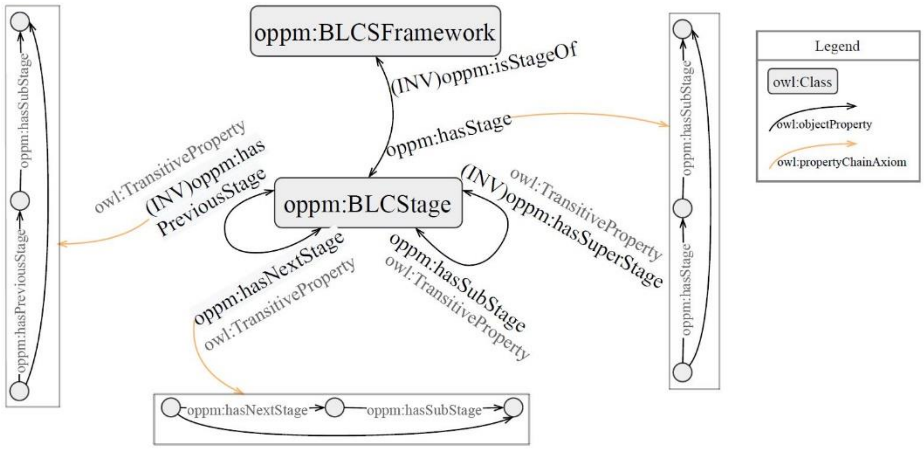

Fig. 3. Ontological representation of BLCS Framework

2.3 Activity and Stakeholder

The term Activity indicates the task to be carried out in the process of building renovation. In general, these activities are performed by the different stakeholders involved in the project at different BLCS based on the available information. When a renovation process takes place, different stakeholders are responsible for several activities. For mapping a renovation process, considering the experience of the main author and through a literature review [1, 19, 21 and 22], the list of involved stakeholders has been produced in the BIM4EEB project [4].

To overcome possible inefficiencies due to the incorrect or redundant data exchange among stakeholders, it is necessary to rationalize the information flow. This can be reached by adequate management of information during the different renovation process stages (BLCS) and by the appropriate connection of various stakeholders involved (e.g. inhabitants/end-users, clients/owners, designers, surveyors, etc.) [23].

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2.4 BIM Object (Product Information)

BIM is a process of managing the physical and functional characteristics of building objects. The BIM process results in the digital representation of a different aspect of the project and supports decision making through the project life-cycle. Several international and national standards [11, 12, 14, 15 and 24] were published to support the data management and data transfer capabilities within the AEC domain and between the domains. The standard ISO 16739 (2018) [24] proposes a vendor-neutral meta-data model called Industry Foundation Classes (IFC) to manage the information of all physical, functional and process objects involved within the project. In this research, the IFC entities are considered to represent the buildings physical and functional characteristics within the ontology and are related to other variables (BLCS, LOD, Stakeholder, Use Case).

Product, System and Control elements
Among building core-and-shell elements, it is necessary to describe services, processes, and control elements (for services and/or processes) within enriched BIM models. These developed BIM data entities are listed below as used in the development of the product-process ontology for building renovation.

- Building core-and-shell elements (e.g. wall, slab, window, door, shading, beam etc.);
- Distribution and flow elements (in terms of control processing, e.g. actuator, alarm, sensor, flow control device, flow fitting device, etc);
- Spatial and feature elements (i.e. building, storey, site, space, opening);
- Element and Furnishing components (e.g. furniture, fasteners, tendon, etc.).

Properties and Quantities
The definition of related properties and quantities for each component or element in the building is necessary to enrich the BIM model and make it more informative. There are different attributes related to associated building systems within the IFC schema. All of this complex information is incorporated into the building objects by using property sets and quantity sets parameters. Additionally, the IFC schema allowed us to attach the user-defined property sets to building elements. The developed ontology schema is considering these capabilities and incorporating a specific adaptive mechanism.

2.5 Use Cases

Within the development of the product-process ontology for renovation, the aspect of Use Cases is considered as an additional feature to represent grouped activities involved in renovation process modelling. The list of pre-defined activities was taken from the D2.1 [1] of the BIM4EEB project. All of them were clearly defined and distinguished according to the life cycle phases of the built asset. Based on the above factors (see credentials in Fig. 1), we have outlined the three main Use Cases as a dynamic combination of selected activities performed by related stakeholders during the renovation processes. The purpose of these Use Case definitions is to narrow down the scope of

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the work concerning the development of the product-process ontology. The specified three Use Cases in the project are as following:

- Use Case 1 (UC1): Data acquisition for HVAC Design, Operation and Efficiency Management;
- Use Case 2 (UC2): HVAC Design, Operation and Efficiency Management;
- Use Case 3 (UC3): Fast Track Renovation Operation.

3 Product-Process Ontology

The development goal of an integrated renovation Product-Process ontology is to clearly describe the different activities, tasks, and sequences, their interrelations to stakeholders involved, the required information, other resources, etc. Fig. 4 represents the methodological approach adopted for ontology development. The developed methodological schema results in the 6-dimensional intercommunication framework including Activity, Stakeholder, BLCS, LOD, BIM data and Use case (see Fig. 1). The clear understanding of these aspects is presented in the Renovation Framework section of this document. The represented methodology in Fig. 4 also expresses the relationship between these six aspects of the building renovation process.

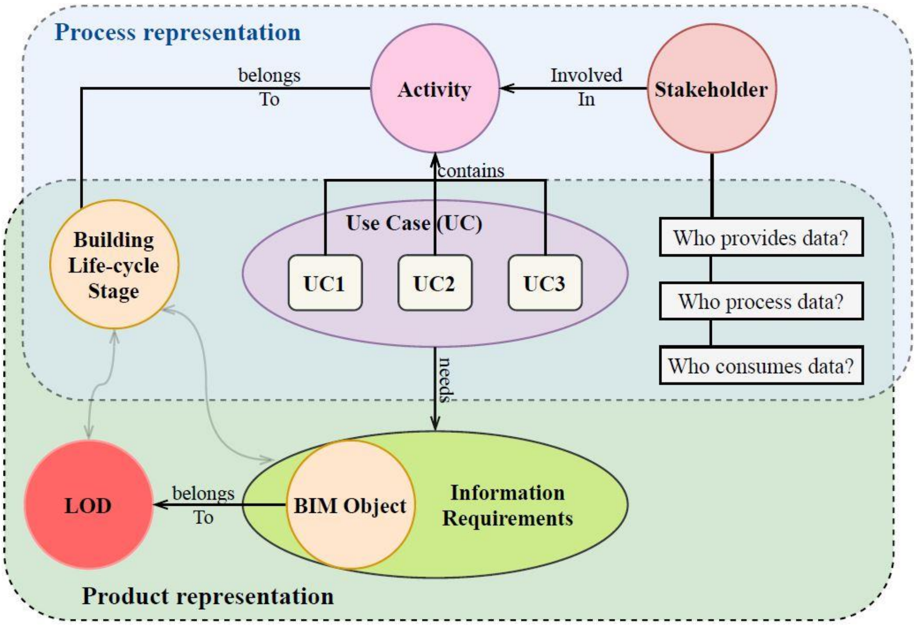

Fig. 4. Product-Process ontology framework

A major step towards the development of an ontology is the development of a precise understanding of the scope, the content and the relations between the constituent elements of the ontology. The complete methodology is represented in two stems called

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Product representation and Process representation. The Product representation indicates the relation between BIM objects and their level of detail needed in building life-cycle stages through the involved activities in it. The ontological representation of these interrelations between activities, BIM data and its level of detail is comprehensively elaborated in Fig. 5.

Similarly, the Process representation describes the role of different stakeholders involved in the renovation interventions or activities. According to the framework definition, represented in Fig. 4, the stakeholder roles are categorized dependent on data development, process and consumption activities. As described in the above sections, all the activities are grouped into different use cases needed for the specific tools or domain tasks involved in the renovation process. Based on the developed framework, the ontology for the renovation process is explained in the subsequent sections.

3.1 Activity – BIM data – LOD

The developed ontological schema in Fig. 5 aims to establish relationships between Activities, BIM object data and its LOD for a specific activity in the project. A difficult representational challenge in RDF is how to represent the values of the same properties of objects at multiple different levels. The most typical approaches are to use objectified properties or named graphs of RDF datasets. In the following, the former approach objectified properties is adopted. Existing work on Ontology for Property Management (OPM) [25], Building Topology Ontology (BOT) [26] in the Linked Building Data (LBD) community and ifcOWL ontology [27] is used. In the OPPM ontology, a class oppm:BuildingObject is produced to hold the information of the objects and is aligned to classes of existing ontologies (bot[3]:Element, bot:Space and ifcowl[4]:IfcObject) using rdf:subClassOf property. This oppm:BuildingObject is further interrelated to the Activities (oppm:Activity) in the project using the object property oppm:requires and its inverse property oppm:wasNeededFor.

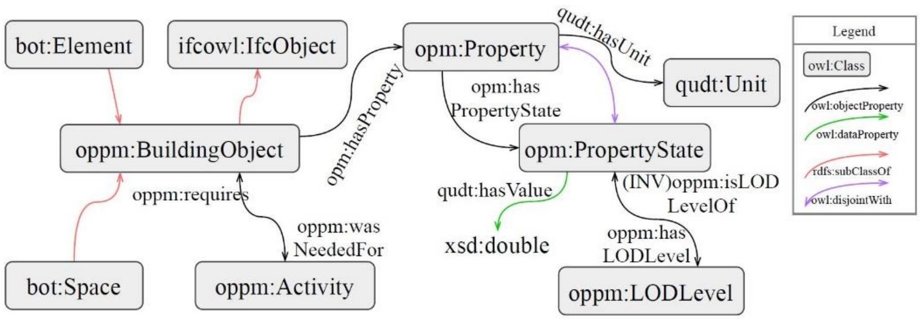

Fig. 5. An ontology representing the relation between Activity, BIM data and LOD

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[3] PREFIX bot: <https://w3id.org/bot#>

[4] PREFIX ifcowl: < https://standards.buildingsmart.org/IFC/DEV/IFC4/ADD2_TC1/OWL#>

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The classes opm[5]:Property and opm:PropertyState in OPM ontology make it possible to add an ultimate number of properties to building objects and their growth of accuracy throughout the project life-cycle. Additionally, it supports for defining meta-data attributes for each property (e.g. role or quantity kind) and each property state (e.g. source, timestamp, etc.). Fig. 5 indicates these capabilities for instances of OPM classes. The developed ontology also supports the modelling of relationships between LOD and BIM attributes by using the object property oppm:hadLODLevel and its respective inverse property oppm:isLODLevelOf.

3.2 BLCS – Activity – Stakeholder

The next phase of the ontology development is to enable modelling of the data flow between Agents (either Stakeholder or Actor in a project) according to their requirements and involvement in the activities specified by the BLCS. In the ontology for Product-Process-Modelling the class oppm:Agent specifies all actors/stakeholders involved in the building renovation process. As represented in Fig. 6, the list of identified actors/stakeholders are instances of the class oppm:Agent. A role is assigned to them based on their involvement in the specific activity (oppm:Activity). A class oppm:Role accommodates different roles (oppm:InformationConsumer, oppm: InformationProcessor, oppm: InformationProvider) as its subclasses and is assigned to the agent through the object property dice[6]:hasRole and its inverse property dice:isRoleOF.

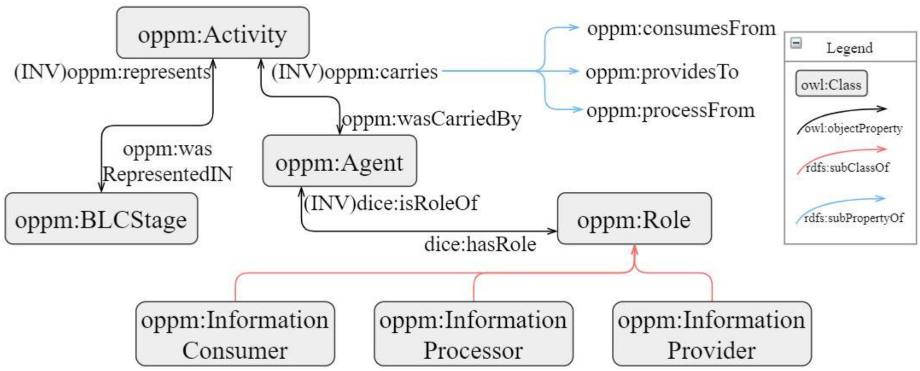

Fig. 6. An ontology representing the relation between BLCS, Activity and Stakeholder

A simple relationship is defined between activity and the agent in terms of agent oppm:carries activity and vice-verse activity oppm:wasCarriedBy agent. Furthermore, the object property oppm:carries is categorized into three sub-properties oppm:consumesFrom, oppm:providesTo and oppm:processFrom, which are used based on the role of the agent. In common practice, the activities are listed according to the BLCS of the project and the same is represented in the ontology using the object property

[5] PREFIX opm: < https://w3id.org/opm#>
[6] PREFIX dice: < https://w3id.org/digitalconstruction/Entities#> [28]

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called oppm:wasRepresentedIn and its inverse property oppm:represents. The class oppm:Activity is also directly related to the BIM object data (see Fig. 5).

The use case (UC1, UC2, and UC3) variable defined in the methodological framework in Fig. 4 represents the grouping of the activities. In general, these are mostly application-oriented and can be defined by the user and relates to the ontology.

4 Validation

This research is still not at the stage to enable a proper validation with models populated with significant amounts of data or with data gathered over the construction lifecycle. Validation work is, however, ongoing in the BIM4EEB project, first focusing on LODs and limited scopes of data and initially concerning particular renovation measures. The validation method is to formulate competency questions for the OPPM-ontology complemented by SPARQL queries. Some examples are provided below.

 # CQ1. What contexts precede this context?

```
SELECT ?context ?predecessor
WHERE
{ ?context oppm:hasSuperLevel*/oppm:hasPreviousLevel+/oppm:has-
SubLevel*  ?predecessor }
```

 # CQ2. What are the attributes of an entity in a given context?

```
SELECT ?context ?subject ?property ?value
WHERE
{ ?subject opm:hasProperty ?property .
  ?property opm:hasPropertyState ?propertyState .
  ?propertyState oppm:hasLODLevel ?context .
  ?propertyState oppm:hasValue ?value }
```

 # CQ3. How has the data properties of an entity changed from one context to another?

```
PREFIX dicv: <https://w3id.org/digitalconstruction/Variables#>
SELECT ?context ?subject ?value ?previousContext ?previousValue
WHERE
{ ?subject opm:hasProperty ?property .
  ?property opm:hasPropertyState ?propertyState .
  ?propertyState oppm:hasLODLevel ?context .
  ?propertyState oppm:hasValue ?value .
  ?property dicv:limitedBy ?previousPropertyState .
  ?previousPropertyState dicv:applicableIn ?previousContext .
  ?preivousPropertyState dicv:hasValue ?previousValue }
```

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5 Conclusion

The presented research results in a modelling approach based on a six-dimensional intercommunication framework for process modelling to support building renovation interventions. The established integrated Product-Process Modelling ontology for building renovation is capable to describe activities and their sequences in different phases of the building life-cycle along with the involvement of stakeholders and the required information to execute these activities. From the development process of the Product-Process Modelling ontology for building renovation, it becomes clear, that one can specify the roles and responsibilities of project partners on the level of activities for specific BLCS and related LOD. The Ontology for Product-Process Modelling is an instrument which will support the flexible, automatic generation of “filters” or “queries” against a holistic BIM-repository. When available, it will simplify the work and lead to efficiency gains through time-savings. Moreover, it also supports automated quality checking of BIM-files, since it provides information on attribute level about the information content to be shared.

6 Future work

The underlying ontologies – OPPM, ifcOWL, BOT – are still going through refinements, especially related to harmonization with existing ontologies and ease of understanding for human readers. The greatest significance of future work is to progress on the enhancement of either inclusion of already used vocabulary in the BIM4EEB ontologies or the range of the emerging ontology standards by ISO, CEN, or W3C. Harmonization is a principal mechanism to promote wide-spread usage and applicability of ontologies by building connections to the expanding linked data and ontology ecosystem. This process needs to be carried out using alignment and evaluation techniques for ontologies.

Moreover, refinements in the technical capabilities of the ontologies to support efficient information management may also become possible through alternative approaches, especially concerning the way how to capture multi-context data, e.g. by utilizing the mechanism of named graphs for RDF databases. Furthermore, a demonstration use case is planned to provide a clear understanding and to prove the practical applicability of the OPPM Ontology presented in this paper. A basic example of extracting data concerning the activity, level of information needs and so on is organized based on the implementation of different SPARQL queries.

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