BPMN-related Ontology for Modeling the Construction Information Delivery of Linked Building Data

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Abstract. The information delivery in BIM-based construction projects regarding predefined exchange requirements is crucial for the quality of information. Information modeling using Linked Building Data receives increasing attention as it may overcome current interoperability issues. Hence, this information needs to satisfy requirements defined in business processes in an Information Delivery Manual. This paper examines the compatibility of business process modeling and Linked Building Data. Considering recent research progresses, the Information Delivery Processes ontology is developed and evaluated in two demonstration cases for converting XML-based business processes to RDF-based ontology data and performing requirements validation for the attached data sets. These use cases show the feasibility of the application of the developed approach for modeling information deliveries for Linked Building Data.

Keywords: linked building data · information delivery process · ontology modeling · business process modeling · semantic web

1 Introduction

Linked Building Data (LBD) allows for vendor-neutral, decoupled, and software-independent information modeling using Semantic Web technologies. The modeled information is made available on the web, e.g., via Linked Data platforms or Distributed Common Data Environments (DCDE) [28], [26]. However, in the Architecture, Engineering, Construction, and Operation (AECO) industry, the information created in the life cycle of a building is always coupled with project-specific tasks for creating, exchanging, or using certain information. This delivery of information relies on the information requirements of the planning, construction, or operation business processes as defined by the Information Delivery Manual (IDM). In the industry, a well-established modeling language for business processes is the Business Process Modeling and Notation 2.0 (BPMN). This research aims to analyze, conceptualize and implement a solution for integrated information delivery of LBD using BPMN business processes. Regarding the recent research, there is currently no approach that integrates processes and product modeling with LBD and validation of requirements in a vendor-neutral environment.

The ontology developed in this research is based on a review of existing business processes and data flow ontologies from the Semantic Web concerning their usability for construction-specific information delivery processes. To do this, recent research in the area of information and requirement management related to Building Information Modeling (BIM) and ontologies is reviewed. A methodology for analysis and modeling of a new ontology is proposed, which is presented and evaluated in the last part of this paper. The conversion from XML-based BPMN and the validation of linked data sets is demonstrated in two use cases.

2 Background

Redmond et al. [20] examined in 2012 how information exchanges can be enhanced through cloud-based BIM applications. The investigation focuses on business processes and information exchange using standardized descriptions as the IDM, proposing a comprehensive web-based exchange of information on construction projects. The intensified use of cloud-based BIM applications is a milestone in the development of information exchange in AECO, and thus, through the increasing provisioning of planning data on the web, forms the foundation for the application of advanced web technologies such as Semantic Web and LBD.

2.1 Linked Building Data

In recent years, LBD is an increasingly studied topic in the field of information management in the AECO industry and is applied especially in the research of various aspects along the building life cycle [16]. LBD gets its impetus from the W3C LBD Community Group[1] from both research and industry. The concept of LBD relies on the modeling approaches provided by Semantic Web technologies, i.e., the Resource Description Framework (RDF) and Web Ontology Language (OWL). Many domain-specific application cases were defined and modeled into OWL-graph-based ontologies. One further advantage of these technologies is the identification of resources using the Unified Resource Identifier (URI) or Internationalized Resource Identifier (IRI), which foster the conceptualization and implementation of a network of data sources for AECO.

Based on the usage of distributed heterogeneous data sources in a linked network, Werbrouck et al. [28] provided a concept for the utilization of LBD to develop a DCDE. Research and industry seized the term and concept of a DCDE to develop new interoperable solutions for the AECO industry, especially for collaboration. This was further examined by Poinet et al. [17] who presented a novel workflow and version control utilizing DCDE. Furthermore, Valra et al. [26] presented a DCDE based on LBD to support the efficient renovation of buildings by managing the life cycle data of it and provide it queryable and interoperable.

[1] W3C LBD CG, https://www.w3.org/community/lbd/, accessed: 11.04.2021

2.2 Information delivery in collaborative workflows

The general formalization of requirements for information delivery was examined by Cavka et al. [4], presenting a schematic representation of requirements. This work further conferred the relation to virtual and physical project products, especially for developing reusable information requirements for project delivery for owners. Bradley et al. [3] showed that the insufficient definition of information, assignment responsibilities for generation or consumption of information, and connection to business processes are crucial research gaps to improve collaboration for BIM in infrastructure and building construction.

The normative framework in ISO 29481-1 and -2 [8] provide the IDM for collaborative workflows between actors in construction projects and propose terminology, methods, and formats to formalize responsibilities, interactions, and information flow. The IDMs propose information and exchange requirements in vendor-neutral BIM projects using templates, texts, tables, and process diagrams. Several studies were conducted on the information delivery using the IDM, e.g., for controlling the information delivery process [10] or database-related approaches for formalization of information requirements [29].

An ontology for the representation of IDM and information requirements was developed by Lee et al. [12] primarily relying on an OWL Description Logic (DL) data model. It considers structures related to the Industry Foundation Classes (IFC) and the Semantic Web Rule Language for the validation of requirements using semantic reasoning. However, the authors state that IDM involves various types of requirements for data delivery that have not been evaluated for ontological modeling regarding IDM yet. Furthermore, the BIM-based information specification and delivery process for ontological data in ifcOwl [2] was specified by van Berlo et al. [27]. In their research, the validation of information requirements was developed using the IFC property set definitions, which were transferred to OWL and applied to properties in ifcOwl based datasets.

2.3 Business process modeling

Business process modeling is a method widely used in the AECO industry and required by the IDM. The BPMN [15] is a modeling framework for business processes with capabilities to model complex processes, employing data flow as well as multiple participants, and therefore is used in the development of IDMs. Several approaches address the modeling of business processes according to BPMN utilizing ontologies [14], [21].

A broader view on general process modeling ontologies and the conversion of existing modeling frameworks to ontologies was given by Annane et al. [1]. They examine business process ontologies in the concepts of process specification, including the process decomposition, workflows and conditions, process execution, and organizational and resource models. In Annane et al. [1], the BPMN ontology of Natschläger [14] is proposed as comprehensive and relevant. Nevertheless, the approach is hard to reuse because it provides neither the ontology specification nor a serialized version of the ontology. Furthermore, in contrast to ontologies based on other process modeling frameworks, the ontology presented in [14] does not allow to put participants into an organizational context.

A more intensive analysis of process-related ontologies regarding subject-oriented business process modeling was taken up and expanded by Singer [22], examining the data and process flow between participants in different swimlanes. The authors propose a BPMN ontology and validate the approach of processing XML-based diagrams into OWL-based instances of their ontology [22].

2.4 Integrated process and product modeling for Linked Building Data

The integration of processes and products using LBD is a recent research topic examined by Rasmussen et al. [19]. By taking a closer look at managing linked properties on a project level, the authors take the data exchange in AECO projects into account. They refer to the OPM ontology defined in [18] to describe the state, metadata, values, and provenance of properties utilizing established methods of describing properties. One of these established methods is using the PROV ontology to provide data on the provenance of information [11]. An approach for optimizing information delivery processes for BIM data was presented in [9], developing the Product-Process Ontology to describe process representations and interrelations to the required information. Furthermore, Torma and Zheng [25] published a comprehensive framework of ontologies to cover a large set of terminology in construction, including information, actors, and processes. Overall, these approaches provide a basis for the process-oriented description of information requirements.

3 Proposed methodology

The analysis within this paper considers the aspects and requirements from the current standardization, mainly ISO 19650 [6] and ISO 29481 [8], for the process-oriented modeling of AECO information delivery and data flow for LBD. An approach for the delivery process of solely IFC-based building models [10] has already been presented within a platform for controlling the information delivery processes. Furthermore, the BIM-based information specification and delivery process for ifcOwl data were specified by van Berlo et al. [27]. Karlapudi et al. [9] presented optimization approaches for information delivery based on a product-process integration. Nonetheless, the paper at hand presents a broader non-IFC-specific approach, considers multiple data resources and formats using LBD and containers, and employs the BPMN business standard of process modeling.

The methodology of this research follows the three-stage stepwise procedure depicted in Fig. 1, which mainly relies on the methodology for ontology engineering by Gómez-Pérez and Suárez-Figueroa [5]. The first stage is to acquire knowledge and terminology from the non-ontological resources that are IDM specifications (1), presented related research (2), and standardized process modeling approaches (3). In the second stage, ontology specification and formalization (5) is based on the acquired knowledge and the existing ontology resources

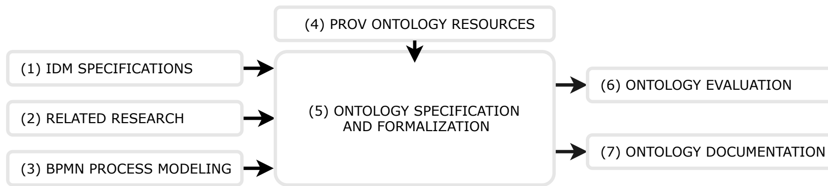

Fig. 1. Methodology for the conceptualization and implementation of the ontology

and patterns of the well-established PROV ontology [11]. Therefore, the existing concepts and domain ontologies are considered and incorporated into the outlined model. The ontology is implemented in RDF and OWL, considering the semantics between the classes derived from knowledge and terminology. In a third stage, evaluation (5) of the developed ontology is performed, transforming XML-based process diagrams into ontology-based data sets of the ontology. The documentation of the ontology will be generated and provided (6).

4 Knowledge acquisition and analysis

This section describes the relevant terms and concepts identified for the ontology modeling. Therefore, the terminology list of ISO 21948-1 defines the terms in the first column of Tab. 1. In the table, related terms and concepts from BPMN [15] and the PROV ontology are identified in the second and third column. The last column contains the terminology aggregated and used in this research.

Table 1. Terminology and concepts as the foundation for ontology conceptualization

IDM [8]	**BPMN [15]**	**PROV [11]**	**Aggregated Concept**
Information unit	Data Object	Entity	Information
Activity, transaction	Task, activity	Activity, Generation, Usage	Information delivery, Information usage
Exchange requirement	-	-	Information requirement
Information constraint	-	-	Information specification
Actor	Participant	Person	Person
Object, Project	Collaboration	Entity, Plan	Project
-	-	-	Status (ISO 19650)

According to IDM, the central aspects of information delivery are information units, actors, and activities, also modeled in generic process-related contexts in BPMN and PROV. In this research, these generic terms are specified as information, person, information delivery, and information usage. The exchange requirements and information constraints are specific concepts adapted in this research to provide a basis for attaching rules for validation of delivered information. Concerning information management in BIM workflows as defined in ISO 19650, information constantly resides in a certain status. The status and the project to which actors, activities, and information apply, finish the list of concepts and terminology. Terminology directly dependent on the *Information* has been attached with the prefix *Information*, e.g., *Information requirement*.

5 Information Delivery Processes Ontology (IDPO)

Based on the analysis, an ontology is engineered to model delivery processes as activities (see Fig. 2). In the following, the namespaces of BPMN and PROV are considered by the prefixes `bpmn2` and `prov`. The namespace of the here developed Information Delivery Processes Ontology (IDPO)[2] is abbreviated using the preferred prefix `idpo`. Other namespaces are referred to as registered in the prefix database prefix.cc.

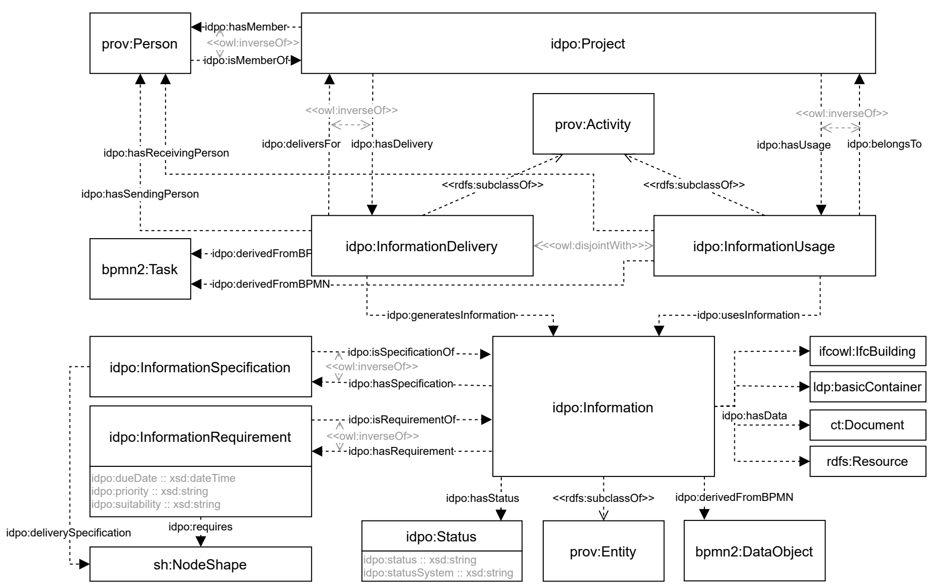

Fig. 2. Overview of the Information Delivery Process Ontology (IDPO)

The class `idpo:Project` is defined to host actors as `prov:Person` instances which can be associated with each other using the `idpo:hasMember` or inverse `idpo:isMemberOf` object property. The actors in a project are referred to from `idpo:InformationDelivery` and `idpo:InformationUsage`. These classes are

[2] IDPO namespace: https://w3id.org/idpo#

subclasses of the prov:Activity and are disjoint with each other as the same information is regularly not delivered and used in the same activity. The inheritance from prov:Activity enables to associate additional metadata on the specific subclasses. Moreover, each of the two subclasses has an association to an actor either using the object properties idpo:hasSendingPerson for delivery or idpo:hasReceivingPerson for usage activities. The classes for delivery and usage of information are associated with bpmn2:Task instances if they have converted from a BPMN diagram using the idpo:derivedFromBPMN object property. A demonstration of BPMN conversion in the context of IDPO is presented in the use case in section 6.1.

Information that is delivered or used is modeled utilizing the idpo:Information class. This is a subclass of the prov:Entity and is connected to deliveries or usages with the idpo:generatesInformation or idpo:usesInformation object properties, respectively. Information can only be generated once while it can be used several times. Information instances are linked to bpmn2:DataObject instances with the idpo:derivedFromBPMN object property. Delivery and usage activities can have multiple instances of idpo:Information. Each instance of idpo:Information has a status which itself is an instance of the class idpo:Status containing datatype properties for status description and status system reference. A status is, for instance, "Work in Progress" or "Published" while the status system reference is a string literal node, accordingly "ISO 19650", or a literal node that conforms with xsd:anyUri.

The idpo:Information is the domain of the idpo:hasData object property which establishes a relation between the information and the actual data. The range of the idpo:hasData property includes the general rdfs:Resource class, which links all types of RDF-based resources to information. Furthermore, providing specific formats for delivering AECO construction information, instances of ifcowl:IfcBuilding, which represent delivered building models, or instances of ct:Document from the Information Container for Linked Document Delivery (ICDD) [7] can be attached. A more generic type to utilize is the ldp:basicContainer from the Linked Data Platform [23] specification.

In the ontology definition, each instance of the information class refers to at least one idpo:InformationRequirement providing a minimal set of metadata for the information, such as the due date, priority, or suitability of the information and its delivery. Furthermore, the information requirement class implements a set of rules for the delivered information employing the idpo:requires object property. Using the Shapes and Constraint Language (SHACL), these rules are defined by the sh:NodeShape type and usually allow for validation of instances in range of the idpo:hasData property. This, for example, can be a rule validating the existence in general, the type of delivered information, or metadata of the delivery. A demonstration of validation in the context of IDPO is presented in section 6.2. Moreover, validations of the quality of delivered information are attached to the instances of idpo:InformationSpecification using the idpo:deliverySpecification property. The delivery specifications employ either a set of sh:NodeShapes or delivery specifications like presented in [27].

6 Demonstration

The ontology defined in the previous section is evaluated in two use cases. The first one includes the automated creation of IDPO instances from the BPMN diagrams in XML format. The second use case focuses on the linking of IDPO instances to distributed data and the validation of this data in the context of an information delivery or usage.

6.1 Case 1: Derivation of information delivery from BPMN diagram

For the demonstration of the ontology, a minimal business process for creating, exchanging, using, and verifying the model regarding requirements and specifications is defined as depicted in Fig. 3. The process diagram contains two processes, one data object with annotated requirements and specifications and two users.

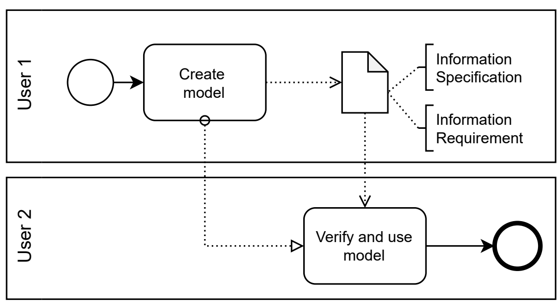

Fig. 3. Minimum BPMN diagram input for the demonstration case

To generate and derive information delivery instances from a BPMN, the XML file of the diagram needs to be converted to RDF. Therefore, the converters `ontmalizer`[3] and `redefer-xsd2owl`[4] are used to transform XML schema (XSD) files into OWL ontologies first and in a second step converting XML instance data to RDF data using the mapping from the XSD to OWL. Nevertheless, both tools have limitations in generating the semantic relations between element node contents that are regularly used in the BPMN XSDs and have an insufficient automated mapping process for these XML nodes. To overcome these limitations and to fully exploit the potential of semantic linking between BPMN elements, a converter with a BPMN-specific mapping from XML to RDF was implemented in a prototype for this paper. The converter[5] bases on SPARQL-Generate introduced by Lefrançois et al. [13]. It provides a JAX-RS webservice with routes for converting BPMN-XML data either into BPMN instances or into IDPO instances.

[3] https://github.com/srdc/ontmalizer, accessed: 06.07.2021
[4] https://github.com/rhizomik/redefer-xsd2owl, accessed: 06.07.2021
[5] https://github.com/RUB-Informatik-im-Bauwesen/idpo-gen, accessed: 06.07.2021

The mapping between the XML schema of BPMN and the ontologies is provided in a set of query files in media type `application/vnd.sparql-generate` with the extension `.rqg`. The generated triples from each query are merged into a common RDF graph using Apache Jena. An implementation of the converter is also presented within the ontology documentation. Results of the conversion to the BPMN ontology are shown in Fig. 4. The figure shows converted instances of a task, a data object, and the related data association to link the data object as an output of the task (see also original BPMN in Fig. 3).

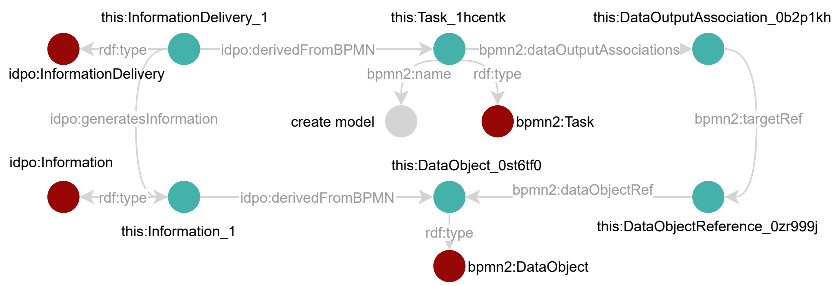

Fig. 4. BPMN to IDPO conversion output

For further transferring from BPMN to IDPO, the converter creates an instance of `idpo:Information` for each `bpmn:DataObject` and either an instance of `idpo:InformationDelivery` for each `bpmn:Task` with outgoing data object relations or an `idpo:InformationUsage` for each `bpmn:Task` with incoming data object relations. All of these individuals are linked to their originating BPMN elements (see Fig. 4). Further information on participants, projects, statuses, requirements, and specifications are generated but not depicted in Fig. 4 for brevity. This demonstration proves, that it is possible to create RDF instances in compliance with IDPO on the basis of the processes, data objects and associations from BPMN.

6.2 Case 2: Validation of requirements using SHACL

The second use case focuses on the validation of requirements and delivered information. As defined in section 5, information requirements and information specifications define validation rules. These are rules defined as `sh:NodeShapes` according to the SHACL. The shapes have target nodes of the `idpo:Information` type, which are linked via the `idpo:InformationRequirement` or `idpo:InformationUsage` (see Fig. 5). Using this linking, the node shape validate paths along the `idpo:hasData` predicate. For information requirements, for example, these paths can access the class type of the attached data or any relation of this node shape.

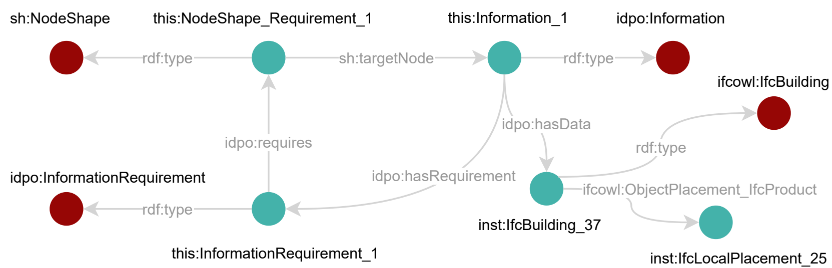

Fig. 5. Applying `sh:NodeShape` requirements targeting `idpo:Information` instances

Exemplarily, the node shapes are applied to an attached ifcOwl-based building model, for which a set of requirement rules and specifications has been defined. Each node shape employs a set of `sh:PropertyShape`s that cover the path to the actual data and define conditions like the type value of the focused node, in this case of the `inst:IfcBuilding_37`. Moreover, further properties of the focus node can be validated, such as the placement of the building. Example RDF-instance data and SHACL shapes are available and documented[6]. Comprehensive research on the application of SHACL for the validation of ifcOwl data can be found in [24]. These shapes can also be shared within the whole project or across multiple projects and referenced in several information requirements and specifications. This enables, for instance, to reuse company knowledge resources on the web and also to integrate knowledge generated in projects back to the company's knowledge base, thus creating added business value for the project delivery.

7 Conclusion

This research examines the interrelation between business processes, information delivery, exchange requirements, and LBD. The ontology IDPO based on terms of BPMN, PROV, and IDM has been developed and presented. The demonstration cases show the feasibility of this approach and the application of IDPO for modeling information deliveries based on state-of-the-art modeling of business processes using BPMN. Nevertheless, the use cases demonstrate only an excerpt from the possible applications. With further developing representations of IFC-related property specifications and the approach of the building SMART Data Dictionary under development, a completely integrated information delivery is possible. Overall, this approach shows a way to align business processes with construction-specific information delivery processes for LBD. Due to this, the delivery processes are generated from process diagrams following the BPMN standard. With its generic definition for information delivery and the relation to the PROV ontology, the developed ontology can be integrated into multi-

[6] Example instances data set, http://w3id.org/idpo/4537_instances

ple linked data platforms, thus leveraging a cloud-based structured information exchange for the construction industry.

However, further evaluations in a web platform for the Information Container for Linked Document Delivery will be carried out as part of a layered platform implementation. Possible improvements and further integration can lead to managing access to information according to previously defined delivery processes for users and roles in projects or leveraging pattern-based access to LBD and automated triggered SHACL validations based on events.

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