DEFINITION OF A CONTAINER-BASED MACHINE-READABLE IDM INTEGRATING LEVEL OF INFORMATION NEEDS

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Abstract

Information Delivery Manuals (IDM) are suited for describing construction data exchange. IDMs provide textual specifications of Exchange Information Requirements (EIR) for the exchange of the Industry Foundation Classes (IFC) data. Given the extensive amount of heterogeneous construction data beyond the scope of IFC and the inconsistency of requested and provided data, this paper proposes to define human- and machine-readable EIR for the exchange of standardized Information Containers for Linked Document Delivery (ICDD), which integrate and link heterogeneous data in a single package. To specify the required quality of the exchanged ICDD containers, an ontology is defined based on the standardized Level of Information Needs (LOIN) data schema. The developed ontology is evaluated in a use case and can be used to formulate the EIR for the interconnected packaged ICDD data within an IDM.

Introduction

The significant advantage of the Building Information Modeling (BIM) methodology is the collaborative work between participants with qualified information management in the asset life cycle (Demian and Walters, 2014). BIM-related information management is based on generating and delivering project and asset information, for which different participants are responsible regarding contracted information exchange requirements. Obtaining the right scope of information in the required quality is still a challenge for the seamless, trustworthy project execution (Tomczak et al., 2022). To simplify the information delivery for stakeholders and improve the quality of information management, human-readable Exchange Information Requirements (EIR) combined with a machine-readable data package are essential for handing over project information from the design to the operational phase.

Considering the broad implementation of BIM, this is also partly due to the development of corresponding standards for the entire asset life cycle in recent years (Bolpagni et al., 2022). For BIM information management, ISO 19650-1 (2018) provides a fundamental framework for collaboration on BIM data on a conceptual level. for structuring and formalizing the information delivery process, ISO 29481-1 (2016) provides a framework called the Information Delivery Manual (IDM) to describe the information exchange process between stakeholders and the requirements of the exchanged information. The technical implementation of the IDM is based on IFC and specified subsets of the IFC schema that are referred to as Model View Definitions (MVD). A repository of published IDMs and MVDs for various exchange scenarios is provided by the non-profit organization buildingSMART International (bSI) as the Use Case Management Service (buildingSMART International, 2017). The recent development of Information Delivery Specifications (IDS) provides a technical solution for defining human-understandable and, at the same time, machine-readable EIR based on IFC extended with various classifications or properties (buildingSMART International, 2022; van Berlo et al., 2019).

However, the IFC schema is not suitable for the information exchange with comprehensive data considering the heterogeneous information in the construction industry, e.g., schedules, cost information, or product data (Fuchs and Scherer, 2017). Combining IFC models and supplementary building data in arbitrary formats, the *Information Container for linked Document Delivery (ICDD)* is standardized in ISO 21597-1 (2020) to overcome this gap. As a standard-based framework, an ICDD information container enables the collection and exchange of information in different formats. It uses metadata to add context and interconnections to the transported information. Metadata and linking in ICDD are realized using the Semantic Web technologies of the Resource Description Framework (RDF) for asserted instance data (A-Box) and the Web Ontology Language (OWL) for terminology definitions (T-Box). The implementation and integration of ICDD in an information delivery process are addressed in current research (Hagedorn et al., 2023), while the definition of EIR combined with a container as technical implementation is still in textual form on the document level. Thus, a machine-readable definition of detailed EIR on the document and information entity level still lacks an automated checking of the delivered information regarding an EIR.

To bridge the gap between ICDD and the missing detailed EIR, in this paper, the BS EN 17412-1 (2020) standard is adapted that defines the Level of Information Need (LOIN). This standard provides a framework for describing object-oriented information requirements related to their originating documents as a subset of the EIR. For a high degree of interoperability between the ICDD and machine-readable EIR, an OWL ontology of the LOIN schema is defined to characterize the demanded container contents. The LOIN ontology conceptualization further considers the established IDM and ongoing development of IDS. The developed ontology is demonstrated on a use case from infrastructure asset management.

To conduct the proposed research, after this introduction, a brief overview of the BIM-related standards and the current research about the information exchange process is provided in the section *Related work*. The section *Methodology* explains the five steps of this research towards the LOIN ontology. The section *LOIN ontology development* presents the resulting ontology with the extensions according to IDS and ICDD. Section *Ontology evaluation* presents the detailed delivery process task of integration Loin ontology and demonstrates this with a use case. Finally, the result of this research is shown in the section *Conclusions*.

Related work

BIM-based information delivery process

The Information Delivery Manual (IDM) defined in the international standard ISO 29481-1 (2016) provides a framework for defining information delivery processes combined with EIR for data drops. Related research shows the IDM adoption from the beginning of BIM development to the most recent research especially considering the integration with IFC and MVD (Aram et al., 2010; Lee et al., 2013; Pinheiro et al., 2018; Klusmann et al., 2020). Early approaches focus on detailing the IDM Framework (Aram et al., 2010). More recent approaches realize IDM in a comprehensive technical solution combined with an EIR database (Klusmann et al., 2020) or specific IDMs for the construction domain (Lee et al., 2013; Pinheiro et al., 2018). IDM definition and technical support with IFC and MVD for information delivery are well-established in the construction industry (Klusmann et al., 2020). bSI published comprehensive IDMs for different use cases (buildingSMART International, 2017).

For a machine-interpretable and detailed EIR definition describing a single unique delivery purpose, IDS is developed by van Berlo et al. (2019) and buildingSMART International (2022). IDS is related to the IFC data schema and thus can, for instance, specify the required properties of certain object types. Therefore, it enables referring to other data dictionaries for property or building product definitions, e.g., the buildingSMART Data Dictionary (bSDD). Furthermore, the definition of IDS is restricted to data exchange for a single purpose (buildingSMART International, 2022). The dynamic adaptation of different facets for IDS simplifies the generation of the EIR and the reuse of predefined property sets. It provides a technical concept for software development implementing the machine-interpretable EIR and, with this, a possibility to automatically check requirements for delivered BIM data. Still, IDS is firmly based on the IFC data model, in which linking documents as the required information is missing. Moreover, the requirement for qualifying geometric representations is missing. The European standard EN 17412 *Level Of Information Need (LOIN)* provides a feasible basis for implementing object-oriented EIR related to documents.

Information container for BIM data exchange

The use of information containers to exchange building data is proposed in ISO 19650-1 (2018) but does not substantiate a schema for standardized information containers. However, an exchange specification for information containers is defined in ISO 21597-1 (2020) as ICDD containers. The ICDD standard provides a framework for delivering interrelated documents supplemented with metadata. Research shows the implementation of ICDD in web environments (Senthilvel et al., 2021) and the utilization of ICDD for information collection and exchange (Hagedorn et al., 2023; Göbels and Beetz, 2022) in use cases. The integration of ICDD containers and external data sources, for instance, relational databases with historical data, is essential for the operation of buildings and structures and is provided by Liu et al. (2022).

Even though the use of information containers is addressed in recent research, the characterization of the container and its content in machine-readable form considering the demand of the construction domain is a research gap (Hagedorn and König, 2021). Therefore, the purpose of the container contents can be misunderstood by humans and is not assessable by machines. Thus, the requirements checking is inefficient and error-prone using the textual-based EIR decoupled from the container contents. For a machine-interpretable IDM specifying requirements for information containers, the process map definition can refer to an ICDD container throughout the delivery process as reported in previous work by Hagedorn and König (2021).

Semantic Web for EIR

Semantic Web technologies offer benefits for interoperability and usability between different kinds of construction data (Pauwels et al., 2017). The definition and use of internationally agreed ontologies, for instance, the Building Topology Ontology (BOT) and the OWL serialization of IFC as ifcOWL, fosters the uniform usage of construction data (Pauwels et al., 2022). Ontologies can be reused and aligned with each other to easily extended the context information to build a network of usable schemas.

For data exchange, Venugopal et al. (2015) showed a framework to define a clear structure of the IFC data model using an ontology proposed for creating MVDs, which provides more semantic robustness. Another ontological approach for defining data exchange requirements based on MVD is presented by Lee et al. (2016). Furthermore, an ontology for property definition considering ISO 23386 is developed by Zentgraf et al. (2022). It provides a basis for defining the standard-based alphanumeric information, which can be utilized for requirements checking. The review paper by Tomczak et al. (2022) highlights different approaches for defining formalized EIR. In their review, related concepts and their applicability are analyzed. Linked Data and Semantic web technology, such as Shapes Constraint Language (SHACL) to check EIR defined in Linked Data, is examined by Tomczak et al. (2022). The definition of EIR for a container-based machine-readable IDM using Semantic Web technology is the main goal of this paper. It can be embedded into a requirement-checking procedure using SHACL.

Methodology

The five steps outlined in Fig. 1 are pursued in this paper to realize the machine-readable EIR combined with an information container in an ontology. The steps follow the established Linked Open Terms (LOT) methodology developed by Poveda-Villalón et al. (2022). LOT proposes four top-level steps to specify ontology requirements, implement an ontology, publish it, and maintain it afterward. The five steps of the methodology in this paper are related to their respective counterparts in the LOT methodology, while the ontology publication and maintenance according to LOT are not in the scope of this paper.

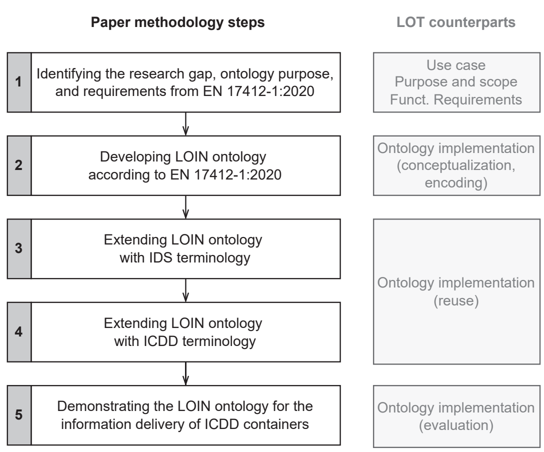

Figure 1: Methodology for developing the LOIN ontology

The ontology requirements step from LOT contains the definition of a use case, purpose and scope, and functional requirements. In the first step of the methodology in this paper, the research gap in the digitalized information delivery process is identified through a review of BIM-related standards about information delivery and various research in the related work leading to the purpose and requirements of the conceptualized ontology. The standards provide a basis for vendor-neutral information delivery solutions with common understanding and acceptance. The scope and requirements of the ontology are thus clearly defined through the utilized standards.

Implementing an ontology for machine-readable information requirements using LOIN and its combination with information containers are executed in the four subsequent steps (Fig. 1, steps 2-5). In the second step, the functional requirements and key terminology from BS EN 17412-1 (2020) are considered to identify classes and relations to be included in the ontology. The ontology concept is the first deliverable of this task. In the third step, the LOIN ontology is extended with vocabulary considering the terminology and data structure from the IDS. Supplemental terminology is provided to the LOIN ontology for linking to and describing container content in the fourth step. Therefore the ICDD ontologies are reused. In the last step, a detailed workflow of the creation of EIR for an information container is provided, and the ontology is evaluated. The evaluation is the last part of the ontology implementation top-level task from the LOT.

LOIN ontology development

Research gap, ontology purpose and requirements

The LOIN ontology aims to provide machine-readable information requirements based on the LOIN standard and combine it with existing vocabulary for ICDD containers and IDS specifications. This ontology development addresses the research gap between the combined application of IDM, IDS, and ICDD. Functional requirements for the ontology arise from the BS EN 17412-1 (2020) LOIN schema. Terminology for modeling the ontology is identified in BS EN 17412-1 (2020) and the IDS specification buildingSMART International (2022). Container ontologies provided by ISO 21597-1 (2020) are reused to extend the ontology.

Ontology development according to EN 17412-1

The LOIN (BS EN 17412-1, 2020) has introduced the contextual aspects and the content of information needs delivering a standardized structure. The principal terms introduced by the standard are defined as terminologies in the proposed ontology. The proposed ontology is identified with the prefix `loin`. The LOIN ontology covers four contextual aspects as prerequisites for the information delivery process describing the required information about *what* (object) should be exchanged *why* (purpose) and *when* (milestones) by *whom* (actors). These contextual aspects are defined as the classes `loin:Purpose`, `loin:InformationDeliveryMilestone`, `loin:Actor` and `loin:Object` as reported in Fig. 2. Three requirement types are introduced to specify the information needs for objects, which are defined as `loin:Geometry`, `loin:Information` and `loin:Documentation` considering the LOIN standard terms *geometrical information*, *alphanumerical information*, and *documentation*. For each of these requirements, further detailed terms are defined, e.g., `loin:GeometrySpecification` and its subclasses or `loin:InformationContent` and its subclasses. Instances of respective ontology classes, e.g., `loin:detailed` and `loin:simplified` instanti-

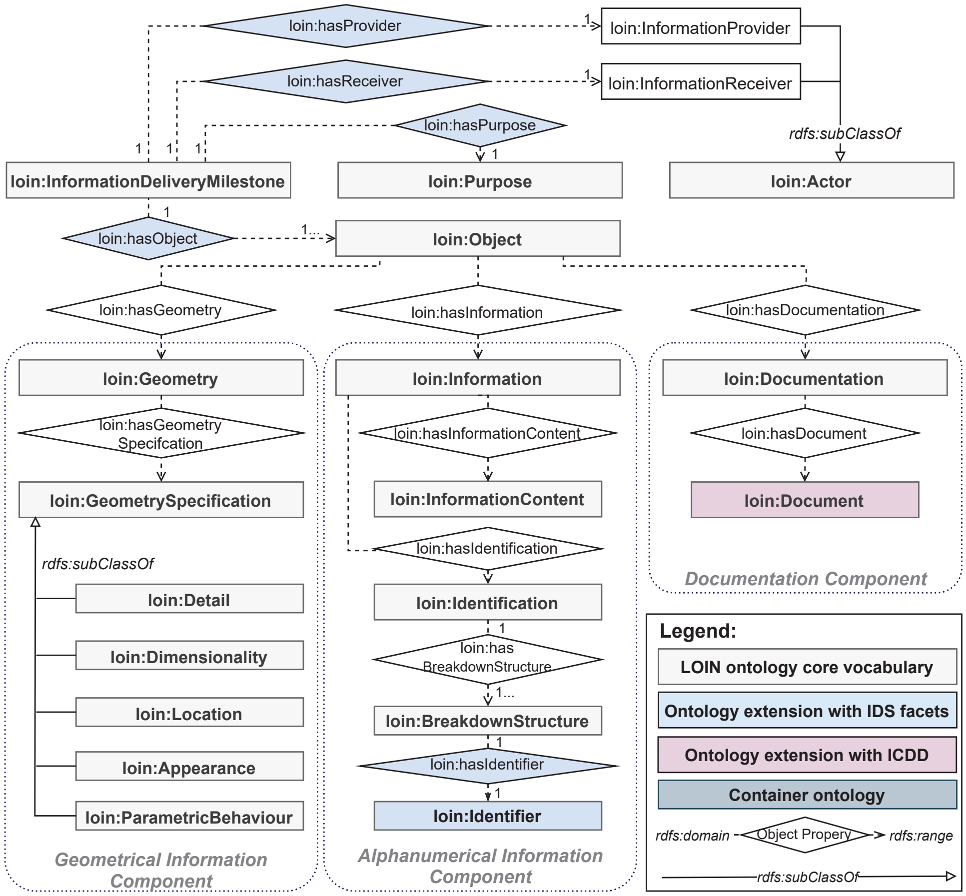

Figure 2: Overview of the core LOIN ontology and interfaces to the IDS and ICDD extensions

ated from `loin:Detail`, are defined to simplify the usage whenever examples or descriptions are available from the standard itself. The relationships between the object to be exchanged, the three requirement types of the LOIN, and the associated detailed terms are defined as OWL object properties of type `owl:ObjectProperty`, e.g., `loin:hasGeometrySpecification`.

The LOIN standard describes an open relationship and a flexible restriction of the contextual information, e.g., *"The same level of information need can be required by different actors at the same milestone to fulfill different purposes."* (BS EN 17412-1, 2020). Therefore, strict relationships and restrictions for contextual classes are defined considering the intention of IDS development to refine an EIR definition for a distinct exchange.

Relationships of contextual aspects are restricted starting with `loin:InformationDeliveryMilestone`, which is related to exactly one purpose through the `loin:hasPurpose` object property. The stakeholders of an `loin:InformationDeliveryMilestone` are defined as an information provider and an information receiver by ISO 19650-1 (2018) and are attached through the object properties `loin:hasProvider` and `loin:hasReceiver`. The exchanged objects are related to the `loin:InformationDeliveryMilestone` through the `loin:hasObject` object property.

Extending LOIN ontology with IDS facets

Specifying machine-readable EIR for IFC data, the IDS approach is developed, enabling the automated building model checking against the defined requirements (buildingSMART International, 2022). It contains information specifications as requirements for specific IFC entities. Three parts must be included in a specification: a description for human interpretation, the scope of the IFC classes the requirements apply to, and the requirements for specifying what information is demanded. To facilitate the definition of the scope and requirements, a facet pattern is employed using fixed facet parameters as introduced by IDS. The LOIN ontology can define the precise information content of an EIR with the adoption of IDS extending the specification of the alphanumerical component as reported in Fig. 2.

An overview of the IDS extension for the LOIN ontology is shown in Fig. 3. The IDS information specification for an object can be defined using `loin:IDSDataDefinition`. The class `loin:IDSFacetDefinition` determines the applicability and requirements. This class contains several subclasses for expressing the facets intro-

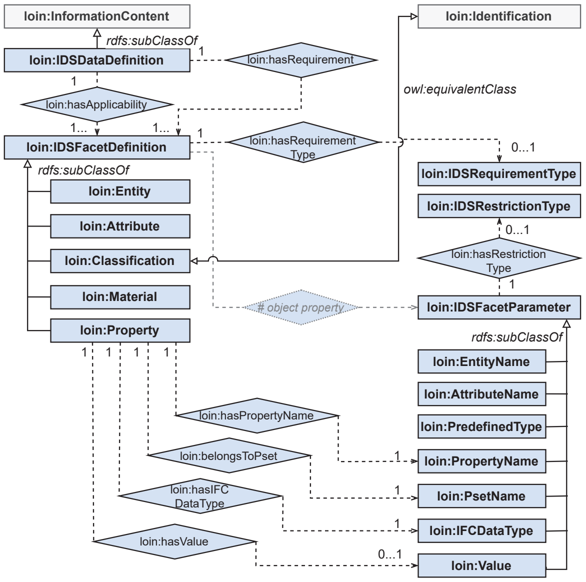

Figure 3: LOIN extension for employing IDS facets

duced by IDS. The datatype property `loin:description` is used for a human-interpreted description. Using the object properties `loin:hasApplicability` and `loin:hasRequirement`, the defined facet information can be specified as applicability or requirements. The detailed information of a facet can be defined via the subclasses of `loin:IDSFacetParameter`, which provides the fixed parameters for each facet. The relationship between a facet (subclass of `loin:IDSFacet-Definition`) and its related facet parameters (subclass of `loin:IDSFacetParameter`) can be defined using the respective object properties. For example, the facet definition of IFC properties needs four fixed parameters: the property name (`loin:PropertyName`), the property set name (`loin:PsetName`), the IFC datatype (`loin:IFC-DataType`) and the possible value (`loin:Value`), which are related with each other using the four object properties shown in Fig. 3.

Furthermore, using the classification facet, the IDS feature of referencing classification systems, e.g., "OmniClass", can be realized. The classification facet contains the same information as the breakdown structure (`loin:BreakdownStructure` shown in Fig. 5) and its identifier. For representing the object in different classification systems, the identification can be related with detailed information of `loin:Identifier`, `loin:BreakdownStructure`. Therefore, the classification facet is an equivalent class to the breakdown structure. Furthermore, for defining the restriction of parameter expressions and labeling whether a specification is required or optional, the classes `loin:IDSRestrictionType` and `loin:IDSRequirementType` are defined.

Extending LOIN ontology with ICDD vocabulary

Considering the required comprehensive data for the construction and operation phase accompanying the BIM data from the design phase, the concept of the ICDD information container is more feasible for data exchange beyond just only the IFC model.

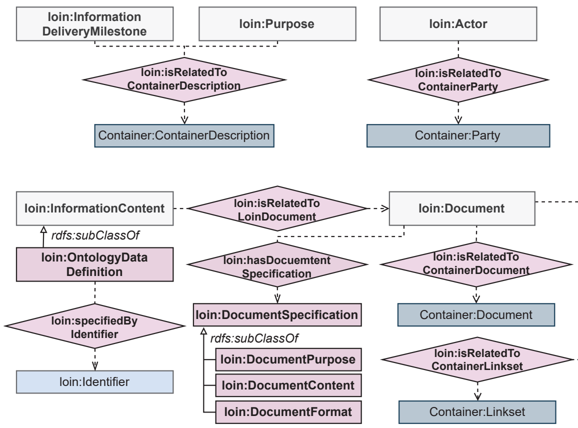

Figure 4: LOIN extension for referring to ICDD containers

In order to define the EIR and use it for the specification of the ICDD container content, the contextual information, alphanumerical information, and documentation components of LOIN ontology are extended by reusing the container ontology as reported in Fig. 4.

To specify the purpose and the information delivery parties of the ICDD container for a certain data drop, the respective classes of the LOIN ontology are linked to container ontology classes, e.g., the `loin:InformationDeliveryMilestone` is linked to a `container:ContainerDescription` as contextual information using the `loin:isRelatedToContainer-Description` object property. Due to ICDD's capability for handling RDF-based information, required information can be defined and collected using ontologies inside a container. For defining these requirements, `loin:OntologyDataDefinition` is created as a subclass of `loin:InformationContent`.

To exchange various documents in an ICDD container, the class `loin:Document` is used to define the demanded documents, which must be registered in the information container prior to exchange. For a detailed document description, `loin:DocumentSpecification` is defined with subclasses for specifying the content, the purpose, and the format. For example, a technical specification (defined as an instance of `loin:DocumentContent`) is provided for information (instance of `loin:DocumentPurpose`) in the PDF format (instance of `loin:DocumentFormat`). The object property `loin:isRelatedToLoinDocument` is defined for identifying the relationship between every requirement of the alphanumerical information and the document in the ICDD container. Combined with the information defined by `loin:DocumentSpecification`, the document can be specified either as a prerequisite provided by the information receiver or as a result delivered by the information provider.

The object properties `loin:isRelatedToContainer-Document` and `loin:isRelatedToContainerLinkset` are defined for linking the actual documents in the container with the specified document definition by `loin:Document`. In summary, there are two approaches to link the actual information content in the form of documents and the defined document in the LOIN ontology on the instance level:

- Using the ICDD links provided by the Linkset ontology to connect the document as registered container content with a demanded document defined with `loin:Document`.
- Using the extended object properties, e.g., `loin:isRelatedToContainerDocument` to link the existing document within the container.

Ontology evaluation

After the specification and encoding of the LOIN ontology, the EIR can be defined digitally. The defined document information within the EIR can appoint the ICDD container content. For the evaluation of the developed ontology, a use case for creating an ICDD container with EIR is demonstrated in this section. As the first step, the internal process of the definition and creation of an EIR for an ICDD container by the information receiver is introduced in Fig. 5. The task "EIR preparation" can be detailed with three steps for using ICDD integrated with LOIN.

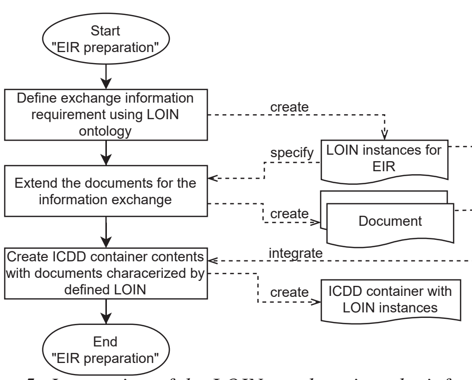

Figure 5: Integration of the LOIN ontology into the information delivery process

The first step is to describe the exchange requirements using the LOIN ontology. The EIR definition is conducted to determine the contextual aspects, define the objects to be exchanged, and specify the required information and document for the object. The documents demanded in the EIR definition are then created considering the specifications in the second step. At last, the documents are added to the ICDD container. The defined EIR is also put into the container as RDF-based data for supplementing the container content through linking with the documents. As a result of the "EIR preparation" task, the ICDD container is then prepared for delivery to the information provider.

After defining the process of creating EIR using the LOIN ontology, a use case for "road inspection" introduces how to provide information requirements within an information container. As described in the first step, the contextual information of the EIR is defined as instances of LOIN classes listed in Table 1. The focused objects are a road section of 1000 m with homogeneous inspection sections of 100 m. Two as-built IFC models of the road section and the inspection layers for the sections to be inspected are provided.

Table 1: Contextual information defined as instances of the LOIN ontology

LOIN class	LOIN instance
loin:Information-DeliveryMilestone	uc:Inspection
loin:Purpose	uc:Condition-Assessment
loin:InformationReceiver	uc:AssetManager
loin:InformationProvider	uc:EngineeringOffice

Four properties representing the pavement condition for each section, e.g., crack width defined with the name "CrackWidth", must be delivered with measured data by the information provider. The required properties are defined with classes of the IDS extension of the LOIN ontology (see Fig. 6). The LOIN instances and the actual documents are uploaded to the information container and links between both are established in a linkset. After creating the container for the road inspection, the parties can retrieve the container content and metadata with details using the SPARQL Protocol and RDF Query Language (SPARQL). As an example, Fig. 7 shows a SPARQL query and the related result of the EIR specification of the payload documents. This information can help the information provider to get an overview of the delivered documents concerning their purpose, content, and format.

LOIN class	LOIN instance	Container document
loin:Object	uc:InspectionSection	
loin:hasInformation		
loin:Information	uc:InspectionLayer	
loin:hasInformationContent		
loin:IDSDataDefinition	uc:ConditionProperty [1]	
loin:hasApplicability		
loin:Entity	uc:IfcElementProxy [1]	
loin:hasRequirement		
loin:Property	uc:Friction [1]	
loin:Property	uc:Evenness [1]	
loin:Property	uc:RutDepth [1]	
loin:Property	uc:CrackWidth [1]	
loin:hasDocumentation		
loin:Documentation	uc:InspectionDoc	
loin:hasDocument		
loin:document	uc:As_built_Model [2]	As_builtRoadModel.ifc
loin:document	uc:InspectionLayer [2]	RoadInspectionSection.ifc

1. Requirement definition for alphanumerical information considering IDS
2. specification andlinking of container documents

Figure 6: EIR definition and linking documents with container

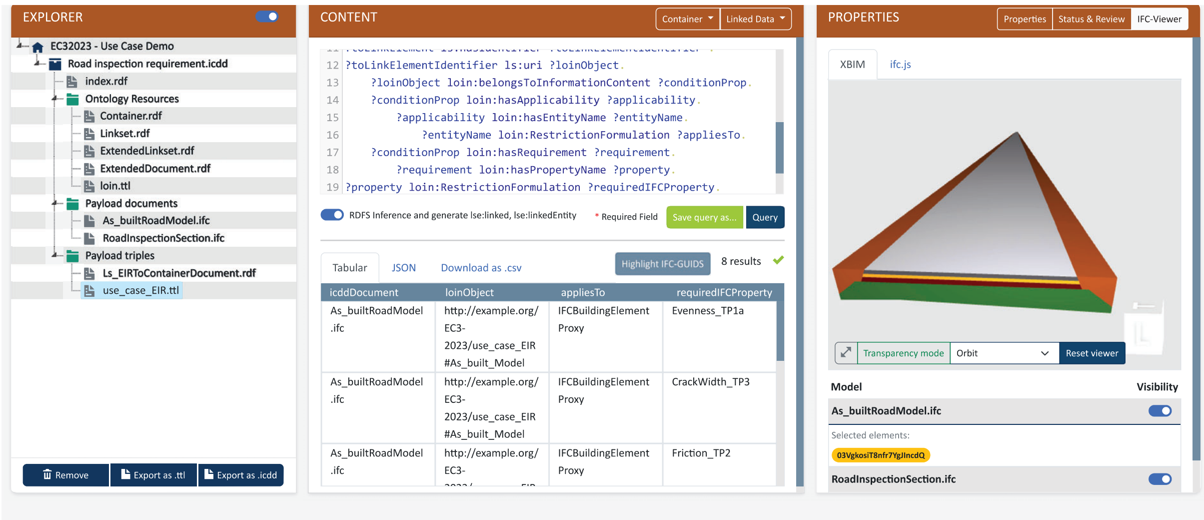

Figure 7: SPARQL query and results for container document specifications defined with LOIN ontology using the ICDD platform developed by Hagedorn et al. (2023)

Conclusions

This paper presented the development of a LOIN-compatible ontology for defining machine-readable information requirements considering IDS and ICDD standards. A task description for the delivery process to create the EIR is introduced, which integrates the EIR based on the LOIN ontology and characterizes the content of the information container. Within the ontology evaluation, an information container is created considering the EIR. By utilizing SPARQL queries, EIR-related specifications of the container content can be retrieved. This paper focuses on the early steps of the information delivery process with EIR definition and providing an information container for the information provider. Altogether, this work can be the foundation for a systematical implementation of ICDD for the quality-assured information exchange in the construction industry and the automatic validation of ICDD containers using SHACL. These approaches facilitate the application of Semantic Web technologies for the construction industry.

However, there are still two major challenges facing the information delivery process with information containers to be addressed in future work: (1) generating EIR automatically from textual descriptions and IDS specifications using the LOIN ontology, linking EIR automatically to ICDD documents, and referring LOIN instances back to a human-readable text; (2) checking the delivered information against the requirements within the container automated to reduce manual effort and errors.

Data availability

The ontology developed in this paper and the data generated for the evaluation are provided at `https://w3id.org/loin`

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