An explanatory use case for the implementation of Information Container for linked Document Delivery in Common Data Environments

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Abstract. The BIM process is highly focused on the enrichment and management of domain data and its interoperability between fields. Many developments were proposed for data integration and sharing in terms of common data environments (CDE), multi-model approach, and open data standards (IFC, IDM), etc. However, often the information in BIM models is still managed in other proprietary formats. In April 2020 ISO 21597 (Information Container for Linked Document Delivery - ICDD) was introduced to enhance the semantic connection of heterogeneous data and document structures in the Architecture, Engineering, Construction and Operation domain (AECO) where the usage of different data formats is still of great diversity. Within this paper, we analyse ICDD capabilities, propose a standardised workflow for ICDD deployment and present a use case demonstrating these abilities of ICDD. Finally, an evaluation of the developed workflow is carried out based on Competency Questions and related SPARQL query profiles.

1. Introduction

The AECO industry is a collaborative environment with the involvement of multiple disciplines throughout the building lifecycle process. This collaboration requires an iterative and cooperated exchange of information, and improves the building design over multiple lifecycle stages (Abualdenien and Borrmann, 2018; Cahill et al., 2012). The management of the project's lifecycle information also ensures the reduction of error-prone operations, data communication problems, and provides significant efficiency benefits, time-saving, etc. (Di Biccari et al., 2018; Karlapudi and Shetty, 2019; Manzoor et al., 2012).

Since the last decade, Building Information Modelling (BIM) is an emerging approach and an enhanced business process in the AECO Industry (Allan and Menzel, 2009; Li et al., 2017). This technical advancement aimed to improve the collaboration and data sharing between the stakeholders involved in construction projects (Keller et al., 2008; Zadeh et al., 2017). Apart from data sharing, it is also a question of managing the continuous growth of the amount of data provided in different formats (Ahmed et al., 2009; Scherer and Katranuschkov, 2019).

IFC (ISO 16739-1, 2018; Karlapudi and Menzel, 2020) and linked data approaches (Karlapudi et al., 2020; Pauwels et al., 2017) support logically consistent data modelling for BIM data sharing. Alternatively, significant developments were introduced for file-based data integration and sharing through so-called level 2 CDE. Such level 2 CDE developments are successfully implemented for the storage and exchange of BIM-documents. However, often BIM and non-BIM data is still managed in proprietary formats (context models). The information heterogeneity between these context models highly affects the project efficiency, co-ordination and causes communication barriers (Beck et al., 2020). A study on industrial reports reveals an average time of 5.5h per week is spent by each professional to extract the related project data from heterogeneous context models (Senthilvel et al., 2020). The appearance of these different context models is usual in different AECO contexts, e.g.: construction management, fire safety, energy-efficient design (Manzoor and Menzel, 2011; Menzel et al., 2008), digital-twins, facility management (Yin et al., 2011), etc.

Thus, research on efficient linking of different data domains (context models) or document structures is carried on for the efficient exchange of context-based information between stakeholders. This research led to the development of three different approaches, the Multi-Model (MM) approach (Scherer and Schapke, 2011), the COINS approach (van Nederveen et al., 2010) and the Linked Building Data (LBD) approach (Beetz et al., 2009; Pauwels et al., 2017). Based on these approaches a new ISO standard – Information Container for Linked Document Delivery (ISO 21597-1, 2020; ISO 21597-2, 2020) was developed by combing the MM approach and LBD approach (Scherer and Katranuschkov, 2019). This new development uses the concept of linked data and ontologies to represent the meta-data of the documents and to produce link-sets between the documents, which further provide information concerning the association of different data structures. The framework developed for the ICDD container is highly enriched with semantic information to better specify heterogeneous data structures in the domain of the AECO sectors. Within this paper, an overview of the development of semantics in the ICDD structure and its usage in CDE platforms is discussed.

2. Related Research and Background

2.1 CDE: Common Data Environment

A CDE is "an agreed source of information for any given project or asset, for collecting, managing and disseminating each information container through a managed process"(ISO 19650-1:2018, 2018). CDE is a solution for structuring, combining, distributing, managing and archiving digital information related to any domain (Preidel et al., 2018). In digital sharing environments (e.g. CDE) it is possible to carry out integrated management of different context models, federated models and documents relating to a project over time (Daniotti et al., 2020). A BIM information repository must not necessarily be kept in one place due to widely dispersed teams. Consequently, CDE workflows can be developed and used across different platforms based on the constraints of collaborative work practice using information containers. These types of workflows are increasingly used in the AECO industries to support collaboration over the whole project life cycle.

As early as in 2013 a distinction between different BIM-Levels was introduced (BSI, 2013). Whereas BIM-Level 2 is defined as "federated file systems" BIM Level 3 is defined as an "integrated, interoperable BIM repository". Numerous commercial collaboration platforms claim to support BIM-Level 3, e.g. BIMCollab, BIMcloud, A360, etc. (Valluru et al., 2021). However, these commercial tools lack of effective integration and interlinking of various data structures or formats. To achieve fully integrated building information models, new workflow specifications should be established concerning AECO-work practice. Such workflows can be strengthened by using the concept of ICDD which specifies the linking of heterogeneous data structures along with its meta-data descriptions.

2.2 ICDD: Information Container

The main objective of the ICDD specifications is to enable the semantic linking of heterogeneous documents and data which contribute significantly to the value of information delivery. It describes file structures and meta-data related to documents. ICDD specifications are defined using RDF, RDFS and OWL semantic web standards and fulfil the linked data principles. Representing the information in widely used semantic web concepts along with ontology descriptions facilitates the interlinking of models and also enables the connection of data with external sources. The defined resource ontologies, Container.rdf, Linkset.rdf and

ExtendedLinkset.rdf in (ISO 21597-1, 2020; ISO 21597-2, 2020) are the core elements to describe the meta-data about the context models and the interrelations between them. The container ontology provides references to linked data sets, including meta-data related to contributors, version management, documents or models, descriptions, etc. Similarly, the Linkset ontology provides the syntax for the link data sets and manages the different links between the documents or with the identifiers inside the document.

Links are defined as a cluster of two or more *ls*[1]*:LinkElements* and can be further explored in the connection process as shown in Figure 1. Links are further categorized into *ls:BinaryLink* which allows only the link between exactly two *ls:LinkElements*. But the class *ls:DirectedLink* can describe the links between many *ls:LinkElements* and the direction of the links is differentiated with the help of *ls:hasFromLinkElement* and *ls:hasToLinkElement* object properties. *ls:Directed1toNLink* is the subclass of *ls:DirectedLink* and which is specialized in restricting the incoming links to only one and as usual outward links are from one to many. Further evolution of both, the *ls:DirectedLink* and *ls:BinaryLink* are the *ls:DirectedBinaryLink* provides exact one and the only link between two *ls:LinkElements*. The *ls:LinkElement* can be related to exactly one *ct:Document* described in the Container ontology using *ls:hasDocuments* object property. Similarly, the *ls:hasIdentifier* object property enables the linkage of the specific entity (string or identifiers) within the document. Basically, for explicit entity identification, these Identifiers are further categorized into various types, in particular, query-based, string-based and URI-based identifiers. In addition to these generic links, ISO 21597-2:2020 describes specializations to these links based on the categories comparative, ordering and dependency. All these specializations of the links and their structure are illustrated comprehensively in Figure 1 with the help of UML.

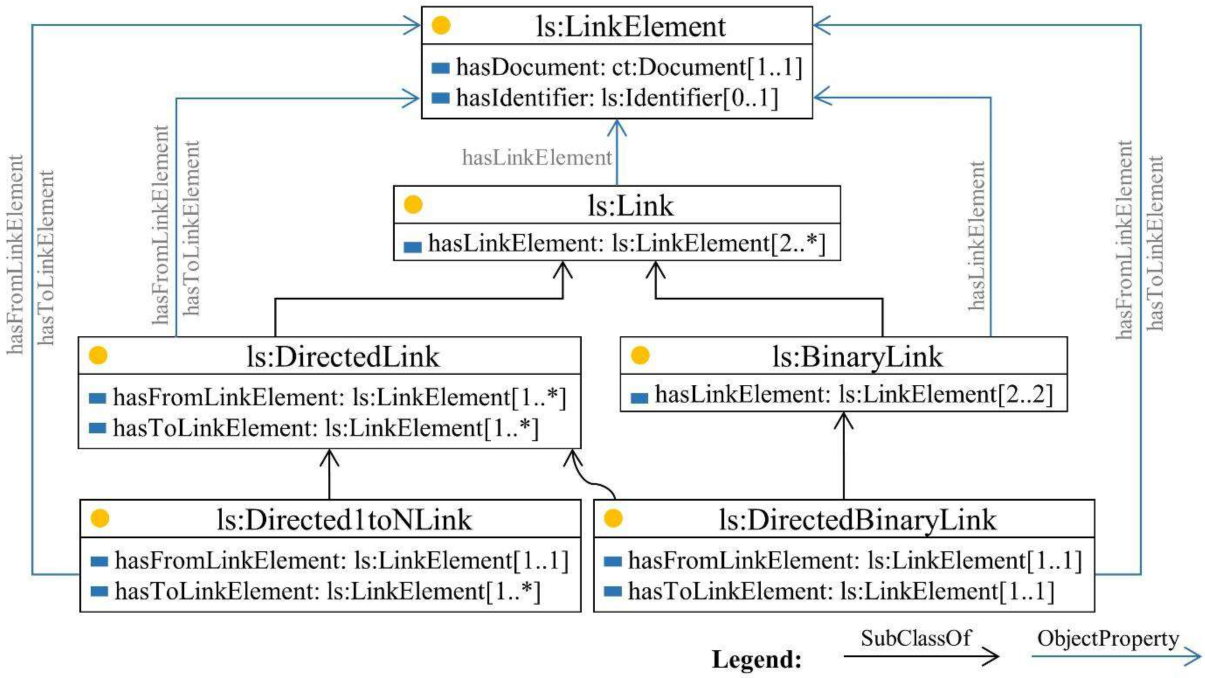

Figure 1: Diagrammatic representations of Link structure (as per ISO 21597-1:2020, 4.2)

[1] https://standards.iso.org/iso/21597/-1/ed-1/en/Linkset.rdf

3. Methodological Workflow

The information generated within a construction project can be categorized into either structured and unstructured data, federated information models, or object-based server models (ISO 19650-1:2018, 2018). To make these information models accessible among project partners, the information models need to be organized, integrated, or linked. The proposed methodology aims to enhance the capabilities of CDE through the implementation of ICDD specifications within CDE workflows. As part of the methodology, an information layer is described in Figure 2 in conjunction with the ICDD concept and CDE workflows. The information layer indicates the information and its source from where the different data structure or formats are generated within a construction project. The generated information can either be a part of a CDE or can be externally located in other data storage systems.

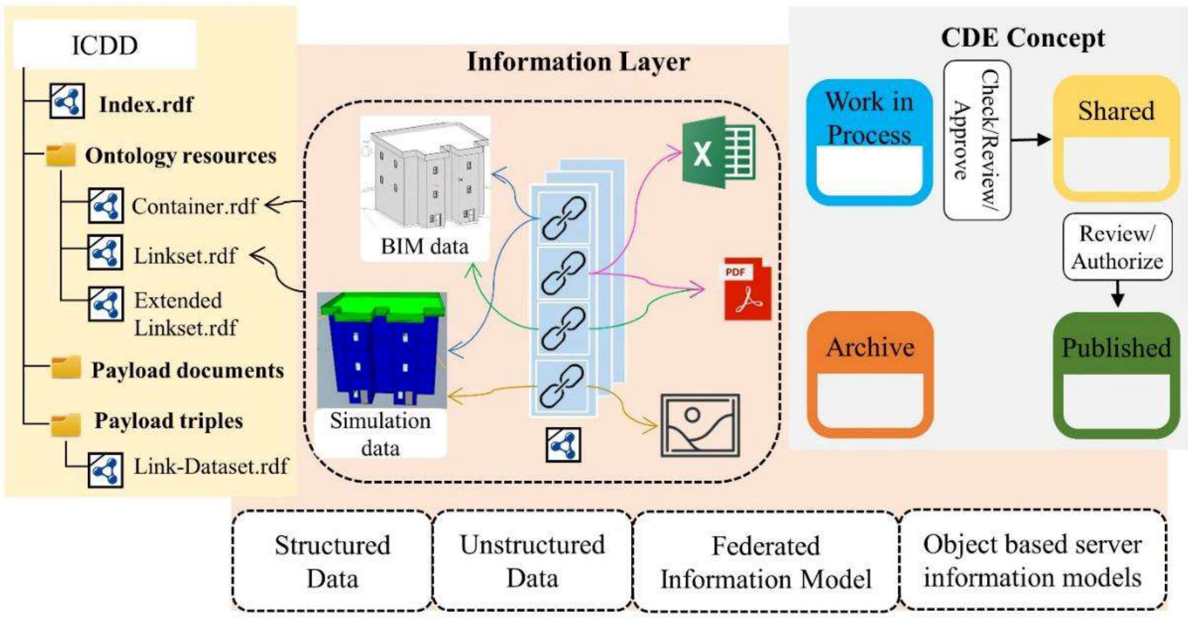

Figure 2: Methodological framework for the Linksets in CDE

To enable this information management and stakeholder collaboration, the ISO standard introduces a common workflow for CDEs (see Figure 10 in (ISO 19650-1:2018, 2018)). This CDE workflow describes the states of each information container (Work in Progress, Shared, Published and Archive) and meta-data assignments to the documents but is in lack of describing the interrelations among the information within the data structures. To enhance these interlinking capabilities, the ICDD container encompasses resource ontologies to specify the meta-data about the data structures and their linking with internal or external data formats. The specifications related to these resource ontologies are adopted to CDE workflows to enhance these link capabilities within the CDE file management systems. These generated link files are incorporated within the CDE environment and provide access to project partners according to their requirements.

As represented in Figure 2, a use case is selected in the domain of building renovation to explain these features additionally adopted to the CDE environment. The set of resource ontologies from ICDD specification is used to generate the relationships between the different data structures categorized in the information layer. A clear demonstration of this process is comprehensively presented in the subsequent section.

4. Demonstration

Based on the comprehensive analysis and understandings of the ICDD framework, this paper progresses with a demonstration exploring the application of ICDD concepts in the process of linking heterogeneous data. For the demonstration, we consider a use-case from the building renovation domain with an emphasis on data management of wall objects in a specific building information model. The use case focuses on the semantic interlinking of data from different sources available both in the CDE environment and outside of the CDE. Data sources considered in this example are:

1. **BuildingMaterial.rdf** is an ontology file that contains the material information and construction details of a specific building.
2. **Building_Model.ifc** is an IFC-based BIM model which represents the geometry and the placement of building objects extracted by surveying services.
3. **Wall10025.jpg** represents the present condition of the wall object (inside and outside).
4. The document **CIB_Plan.pdf** denotes the present renovation plan or retrofitting activities for building objects.
5. **PrecastPanelLibraries.html** is describing the information stored within the company storage profiles. It is represented with a Web link (URL).

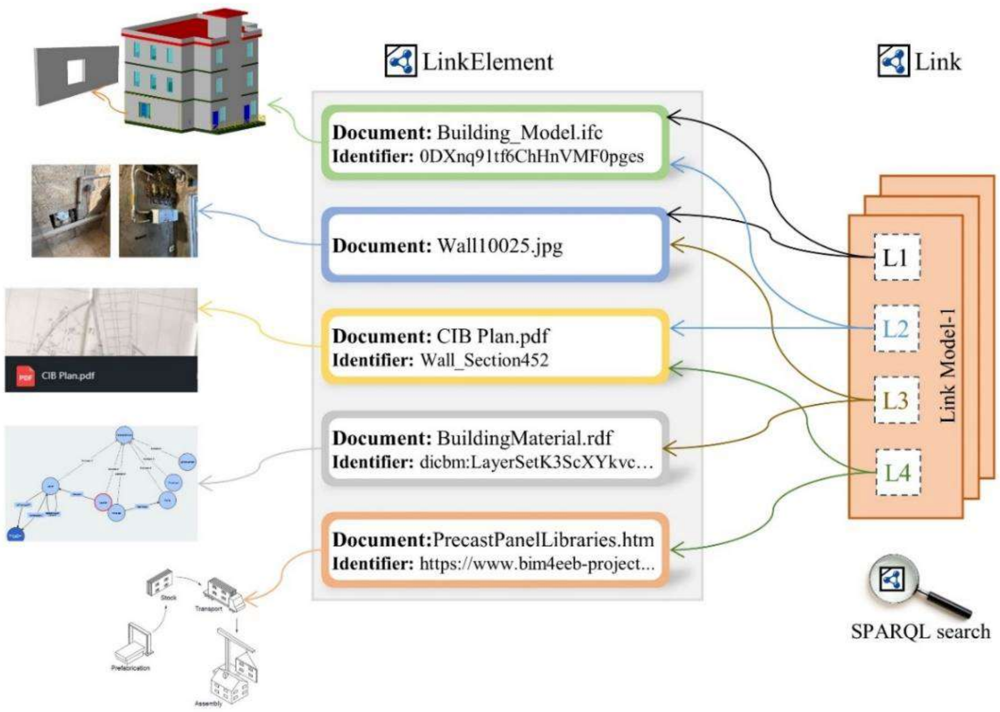

Figure 3: Demonstration example to represent the usage of ICDD ontologies

The different data sources and their linking according to the ICDD framework is represented in Figure 3. The process of documents reading, and link model generation is carried out according to the resource ontologies Container.rdf and Linkset.rdf with the help of a java algorithm. This algorithm can be used to develop minor APIs within a CDE environment to support a user-centric link generation process. Since the paper is restricted to workflow explanations, the present demonstration focuses more on link generation and validation.

Within the example demonstration, several link-scenarios are considered to display or showcase the maximum capabilities of ICDD link specifications. In the linking process, the link elements were considered in such a fashion, some contain a string-based identifier, URI-based identifiers and others with no identifiers, to enable to demonstrate these link-scenarios.

For example, the digital representation of the wall element is considered from an IFC file called "Building_Model.ifc". This originates from "field surveying services" and subsequent "object identification". The GUID of this wall object is a string-based identifier. It is also linked with the image file Wall10025.jpg representing the current condition of the wall. The basic information of these Link elements are represented with the set of data properties such are creator, description, filetype, filename, format, and name, etc. Additionally, this digital wall representation is linked to the specific wall identifier (Wall_section452) used in the renovation plan represented in PDF file format ("CIB Plan.pdf").

Furthermore, current construction and material details of the wall object are saved in an ontology file ("BuildingMaterial.rdf"). The specific details of the layers-system of a wall object are saved as an instance called "dicm[2]:LayerSetK3ScXYk" and is linked to the image file representing the current wall condition. In addition to the representation of the present condition of the wall, a link is generated between the CIB Plan.pdf document and an online Html documentation file PrecastPanelLibraries.html. This documentation provides the relevant information regarding the preparation and installation of the panels to the wall object and as well as the available pre-cast element libraries. Figure 3 illustrates the list of all these link elements (models or documents) and the generated links.

5. Validation

Apart from the link generation, it is also necessary to verify the generated links to specify the efficiency of the interlinking process. It also helps to rectify the mismatches or inconsistencies in linking. The quality and correctness of these generated links are investigated based on appropriate ontology evaluation techniques.

Here, in the validation process, a set of Competency Questions (CQ) are introduced. In general, CQs are natural language questions used to verify the knowledge representation in ontologies. In other terms, these questions assist to specify the information requirements and scope of ontologies. In our case, CQs are developed to identify the different links between the documents or the documents involved in the linking mechanism retrospectively. In a subsequent step, the natural language CQs are translated in SPARQL queries which are further used to extract the knowledge or information from the link ontology.

Table 1: CQ-1: Extracting the basic links between the documents

SPARQL Query	Query Results	
SELECT Distinct ?Doc1 ?Doc2 WHERE { ?link ls:hasLinkElement ?l1. ?link ls:hasLinkElement ?l2. filter(?l1!=?l2)	**Doc1**	**Doc2**
	BuildingMaterial.rdf	Wall10025.jpg
	Wall10025.jpg	BuildingMaterial.rdf
	Precast panel Libraries.html	CIB Plan.pdf
	CIB Plan.pdf	Precast panel Libraries.html

[2] https://w3id.org/digitalconstruction/0.5/Materials

<table>
<tr><td rowspan="4">?l1 ls:hasDocument [ct:filename ?Doc1].
?l2 ls:hasDocument [ct:filename ?Doc2].
}</td><td>Wall10025.jpg</td><td>Building_Model.ifc</td></tr>
<tr><td>Building_Model.ifc</td><td>Wall10025.jpg</td></tr>
<tr><td>CIB Plan.pdf</td><td>Building_Model.ifc</td></tr>
<tr><td>Building_Model.ifc</td><td>CIB Plan.pdf</td></tr>
</table>

The SPARQL query described in Table 1 is to identify the list of the documents involved in the linking process along with the representation of their interrelationship. The Query results shown in Table 1 illustrate the eight relationships between Doc1 and Doc2, but in the demonstration, there were only four links between the documents. The table also indicates the duplication of links by interchanging the position of documents between Doc1 and Doc2 columns. This is because of the lack of directional representation of links, i.e. the definition of the link from which element to which element.

Table 2: CQ-2: Extracting the directional relationship between the documents

<table>
<tr><th>SPARQL Query</th><th colspan="2">Query Results</th></tr>
<tr><td rowspan="5">SELECT Distinct ?Doc1 ?Doc2
WHERE {
?link ls:hasFromLinkElement ?l1.
?link ls:hasToLinkElement ?l2.
filter(?l1!=?l2)
?l1 ls:hasDocument [ct:filename ?Doc1].
?l2 ls:hasDocument [ct:filename ?Doc2].}</td><td>Doc1</td><td>Doc2</td></tr>
<tr><td>Building_Model.ifc</td><td>Wall10025.jpg</td></tr>
<tr><td>CIB Plan.pdf</td><td>Precast panel Libraries.html</td></tr>
<tr><td>CIB Plan.pdf</td><td>Building_Model.ifc</td></tr>
<tr><td>BuildingMaterial.rdf</td><td>Wall10025.jpg</td></tr>
</table>

In the next case, the links were furthermore explicitly defined by using the class ls:DirectedBinaryLink and object properties is:hasFromLinkElement, ls:hasToLinkElement. The CQ-2 and SPARQL query is developed to validate this requirement and the extracted results in Table 2 confirm the achievements by reducing the duplicated links. Apart from the direction specification to links, the typed links can also be generated between the documents according to the ExtendedLinkset ontology defined in (ISO 21597-2, 2020).

Table 3: CQ-3: Extraction of links between the identifiers with in the documents

<table>
<tr><td>SPARQL Query</td><td colspan="4">SELECT Distinct ?Doc1 ?Identifier1 ?Doc2 ?Identifier2
WHERE {
?link ls:hasFromLinkElement ?l1.
?link ls:hasToLinkElement ?l2.
filter(?l1!=?l2)
?l1 ls:hasDocument [ct:filename ?Doc1].
?l2 ls:hasDocument [ct:filename ?Doc2].
{{?l1 ls:hasIdentifier [ls:identifier ?Identifier1].}
UNION
{?l1 ls:hasIdentifier [ls:url ?Identifier1].}}
{{?l2 ls:hasIdentifier [ls:identifier ?Identifier2].}
UNION
{?l2 ls:hasIdentifier [ls:url ?Identifier2].}}}</td></tr>
<tr><td rowspan="3">Query results</td><td>Doc1</td><td>Identifier1</td><td>Doc2</td><td>Identifier2</td></tr>
<tr><td>CIB Plan.pdf</td><td>Wall_Section452</td><td>Building_Model.ifc</td><td>0DXnq91tf6ChHnVMF0pges</td></tr>
<tr><td>CIB Plan.pdf</td><td>Wall_Section452</td><td>Precast panel Libraries.html</td><td>https://www.bim4eeb-project.eu/</td></tr>
</table>

CQ-3, CQ-4 and the respective SPARQL queries are developed to extract the information related to links between identifiers as well between the identifier and the document. The results in Table 3 from the CQ-3 clearly represent the interrelationship between the identifiers within the documents. The results in Table 4 illustrate the connection of an identifier within a document to other documents. Thus, one can conclude that different link-scenarios can easily be retrieved and shared among users. Retrieved link information can be further used to explore information related to specific objects saved in a CDE environment. This further enhances collaboration and information sharing between project partners.

Table 4: CQ-4: Extraction of links between the identifier in a document to the other document

<table>
<tr><td>SPARQL Query</td><td colspan="3">SELECT Distinct ?Doc1 ?Identifier1 ?Doc2
WHERE {
?link ls:hasFromLinkElement ?l1.
?link ls:hasToLinkElement ?l2.
filter(?l1!=?l2)
?l1 ls:hasDocument [ct:filename ?Doc1].
?l2 ls:hasDocument [ct:filename ?Doc2].
{{?l1 ls:hasIdentifier [ls:identifier ?Identifier1].}
UNION
{?l1 ls:hasIdentifier [ls:url ?Identifier1].}}
FILTER (NOT EXISTS
{{?l2 ls:hasIdentifier [ls:identifier ?Identifier2].}
UNION
{?l2 ls:hasIdentifier [ls:url ?Identifier2].}})}</td></tr>
<tr><td rowspan="3">Query results</td><td>Doc1</td><td>Identifier1</td><td>Doc2</td></tr>
<tr><td>Building_Model.ifc</td><td>0DXnq91tf6ChHnVMF0pges</td><td>Wall10025.jpg</td></tr>
<tr><td>BuildingMaterial.rdf</td><td>https://w3id.org/digitalconstruction/BuildingMaterials#
LayerSetK3ScXYkvck2p36CZNM</td><td>Wall10025.jpg</td></tr>
</table>

6. Summary and Future work

The research in this paper presents an analysis of ICDD specifications regarding their semantic representation and interlinking techniques for heterogeneous data structures. Upon the analysis, it demonstrates how these ICDD specifications can enhance the capabilities of CDE platforms concerning efficient management of documents and their interrelation with other data formats. Finally, this paper also validates the enhanced capabilities of CDE workflow using the set of competency questions and SPARQL query profiles. By implementing the ICDD structural framework within a CDE, the abilities of the CDE is enhanced in terms of interlinking the available documents and even enable the links based on sublevels (identifiers) of documents. This implementation also allows the linking of CDE documents with external documents, for example, data on the web. The technical enhancement to CDE progressively increases the efficient structuring of information along with the stakeholder coordination and information access.

The integration of the ICDD concepts into a CDE environment is considered as Future development. The identification of integration requirements and integration process is an ongoing research work in the BIM4EEB Project. Furthermore, the research is extended to the identification of implementation challenges and possible application or API developments.

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