Update of the Standard-Based Ontology Network for Information Requirements in Digital Construction Projects

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Abstract
In the AECOM industry, standardized information requirements are demanded for efficient data exchange and compliance. This work updates and extends a standards-based ontology network for information requirements, taking into account the latest developments in ISO standards 7817, 23387, and 23386. The revision of the LOIN, tempO, and ISOProps ontologies creates a semantically linked structure that enables machine-readable and interoperable data processing. The changes include the harmonization of the XML schemas of the two updated standards (ISO 7817-3 & 23387-3), the restructuring of the data model, and an improved adaptation strategy in which all three standards were taken into account in order to avoid inconsistencies. A use case for calculating the Global Warming Potential (GWP) of concrete components demonstrates the practical application of the developed ontology network. The research shows that combining standardized ontologies can optimize digital information retrieval, management, and validation in linked building data models.

Keywords
Digital Construction Projects, Information Requirements, Ontology Network, Alignment, ISO 23386, ISO 23387, ISO 7817

1. Introduction

Information exchange in Building Information Modeling (BIM) is critical for effective collaboration in the architecture, engineering, construction, operation, and maintenance (AECOM) industry. Clearly defined information requirements are essential for facilitating seamless data transfer and guaranteeing the quality of project deliverables, fulfilling client expectations, and complying with requirements arising from standardization [1]. Despite the availability of standardized formats such as IFC, significant interoperability issues persist due to varying interpretations and ambiguities in the definition and implementation of information requirements [2]. Machine-readable and clearly structured information specification formats, such as those introduced by LOINxml, have the potential to reduce these challenges by providing a consistent and unambiguous reference for data exchange.

Various approaches exist to define information requirements, such as the Information Delivery Manual (IDM) and the Information Delivery Specification (IDS), both developed by the non-profit organization buildingSMART International [3, 4]. The *Level of Information Need* (LOIN) standardized in ISO 7817 standard series can be emphasized among other frameworks. ISO 7817 Part 3 is currently under development, introducing LOINxml, a machine-readable XML schema to enhance information requirement implementation. This new schema supports automated compliance checking and enhances digital workflows, thereby reducing error rates and increasing efficiency in BIM-based projects [1, 5]. Additionally, leveraging standard-based ontologies and schemas such as LOINxml not only optimizes immediate project workflows but also facilitates long-term data reuse, thus contributing significantly to

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sustainable information management practices across the lifecycle of built assets [6].

The LOINxml schema employs mechanisms from the data templates defined in ISO 23387, thereby translating the closely linked relationship between the standards into a technical context. In a previous contribution by Mellenthin Filardo et al. [7], the authors established an ontology network based on ISO standard series 7817, ISO 23386, and ISO 23387 [8, 9, 10]. Since the development of ISO 23387 and ISO 7817-3 is ongoing, the XML-based schemas developed within the standardization groups ISO/TC 59/SC 13 and CEN TC 442 have undergone changes both in naming and structure within the last year. The authors implemented these changes to keep the developed standard-based ontology network for information requirements in digital construction projects up to date, and the effects of these changes are discussed in this paper.

2. Previous work

As previously outlined in Mellenthin Filardo et al. [7], the information delivery process is described in the ISO 19650 standard series, where the LOIN is established. Standardization references show how the standards are closely connected, as analyzed by Bolpagni et al. [11].

ISO 7817-1 has already been published and defines the principles of the LOIN [10]. The LOIN standard aims to define required information for object types on all project levels, thus aiming for a more flexible approach and dissolving the previous static approach of levels of detail and levels of development. Each LOIN is structured into documentation, geometrical information, and alphanumerical information and uses a breakdown structure to identify object types within a project. Since the breakdown structure is not specified, the LOIN approach remains agnostic, allowing definitions using the IFC data model, as well as others. In part 3 of the standard, an XML-based specification is under development. In the current version of the ISO 7817-3 specification, elements from the ISO 23387 XML-based specification are used.

ISO 23387 is a standalone standard for data templates for construction objects. It is closely connected to ISO standard 12006-3, which establishes a framework for the object-oriented organization of information about construction works [9, 12]. The ISO 23386 standard defines a methodology for consistently determining, managing, and sharing properties used within BIM and other digital processes in the construction industry. It ensures interoperability and enables efficient data exchange between stakeholders and systems. The standard establishes processes and structures for the lifecycle management of properties [8]. Using these standardized properties, ISO 23387 defines a structure for reusable templates to define alphanumerical information for object types using the abovementioned properties.

The previously developed ontology network addresses the three described ISO standards (ISO 7817-3, ISO 23386, and ISO 23387). ISO 7817-3 (version from January 2024) translates into the LOIN ontology, ISO 23387 (version from January 2024) translates into the DT ontology, and ISO 23386 (published final version) translates into the ISOProps ontology. All three ontologies are interconnected, thus creating a standard-based ontology network. The relations between the developed ontologies and their standards are depicted in Figure 1.

The previously developed LOIN ontology was based on an earlier version of the ontology developed by Liu et al. [13] and kept with the main principles of the LOIN. It established an `loin:SpecificationPerObjectType` element, to which the prerequisites (information delivery milestone, receiving and sending actors, as well as purpose) are related (cf. 2 left). The definition of the object type, also referred to as construction object in this version, was done employing the class `dt:ConstructionObject` from the DT ontology. Moreover, the `loin:SpecificationPerObjectType` is related to the elements `loin:Document`, `loin:AlphanumericalInformation` and `loin:GeometricalInformation`. The `loin:GeometricalInformation` defines the appearance, detail, dimensionality, and parametric behavior of the required geometry and is, therefore, very closely aligned with the ISO 7817-3 specification. In the previous version of the LOIN ontology, the `loin:AlphanumericalInformation` was defined, as depicted in Figure 2 using the class `dt:DataTemplate` from the DT ontology.

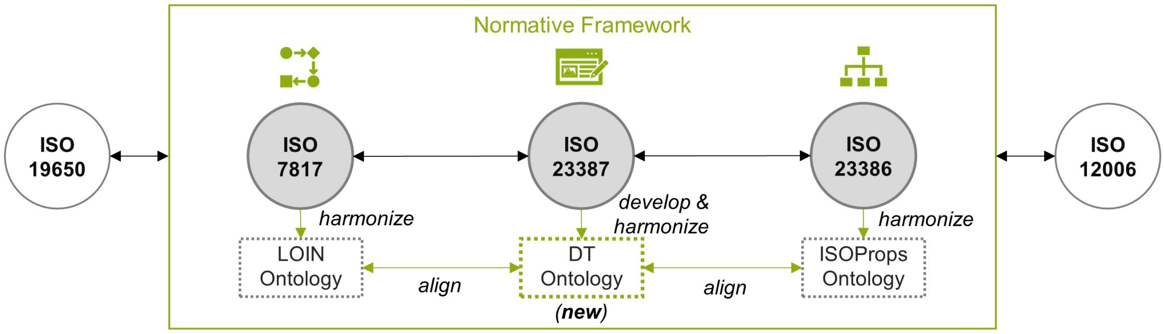

Figure 1: Established ontology network employing the DT ontology (ISO 23387) and the alignment with LOIN (ISO 7817) and ISOProps (ISO 23386) [7]

The DT ontology was developed anew to connect the existing LOIN and ISOProps ontologies. It defines the elements `dt:ConstructionObject`, `dt:DataTemplate`, `dt:SetOfProperties`, `dt:PhysicalQuantity`, `dt:ReferenceDocument`, and `dt:Unit`, all subclasses of the container element `dt:LibraryComponent` (see Figure 2 middle column). The classes `dt:PhysicalQuantity` and `dt:Unit` are set as equivalents of the QUDT classes *Unit* and *QuantityKind*, given that they are both SI-based and thus avoid inconsistencies [14]. As previously mentioned, the `dt:ConstructionObject` and `dt:DataTemplate` are referenced and used by the LOIN ontology. Furthermore, the DT ontology defines a property class that is equivalent to the ISOProps Property class, thus aligning with the framework described in the respective ISO standards. The root class `dt:LibraryComponent` also has an `isoprops:ExternalDictionaryReference`, which is also set in equivalence to the `isoprops:-ExternalDictionaryReference`, which allows all subclasses to make external references.

The previously developed ISOProps ontology was based on an earlier version of the ontology, formerly known as the Interconnected Data Dictionary Ontology (IDDO) [15]. The ontology was developed to map the information requirements contained in regulatory documents in a structured digital format. The classes relevant for the alignment are also shown on the right-hand side of Figure 2. Within the ontology, a property is attributed with metadata for managing its lifecycle and further attributes for defining its corresponding value in terms of value ranges, units, data types, and more. In the preceding work, IDDO was renamed the ISOProps Ontology and harmonized with the LOIN and the Data Template Ontology (DT). Following the alignment, the ISOProps ontology underwent structural changes, particularly in handling property boundary values, aligning with ISO 23387 principles. Additionally, the management of dimensions, physical quantities, and units has been streamlined over the DT and the ISOProps to centralize the information on physical quantities. The subsequent assignment of properties collected in the data template to the corresponding Feature of Interest (FoI), such as `dice:Equipment` or `bot:-Building`, is still realized through the OPM property state pattern [16], as previously described by Zentgraf et al. [15].

3. Tracking changes in standardization

The methodology followed in this paper is similar to the methods presented in Mellenthin Filardo et al. [7]. It involves harmonizing the existing ontologies with the changes to the data formats made in the international standards. In addition, it must be examined whether the alignment needs to be adapted to respond to adjustments made within the ontologies. The updated ontology network is also demonstrated in a practical use case. First, the information requirements for a selected use case are defined using the three updated ontologies. For this purpose, a LOIN, with associated data templates and properties, is defined for a given object type. An IFC model is then generated, converted into a corresponding linked building data model, and attributed to the information needs defined within the LOIN. SPARQL-Queries are then executed on these objects attached to the model to demonstrate the

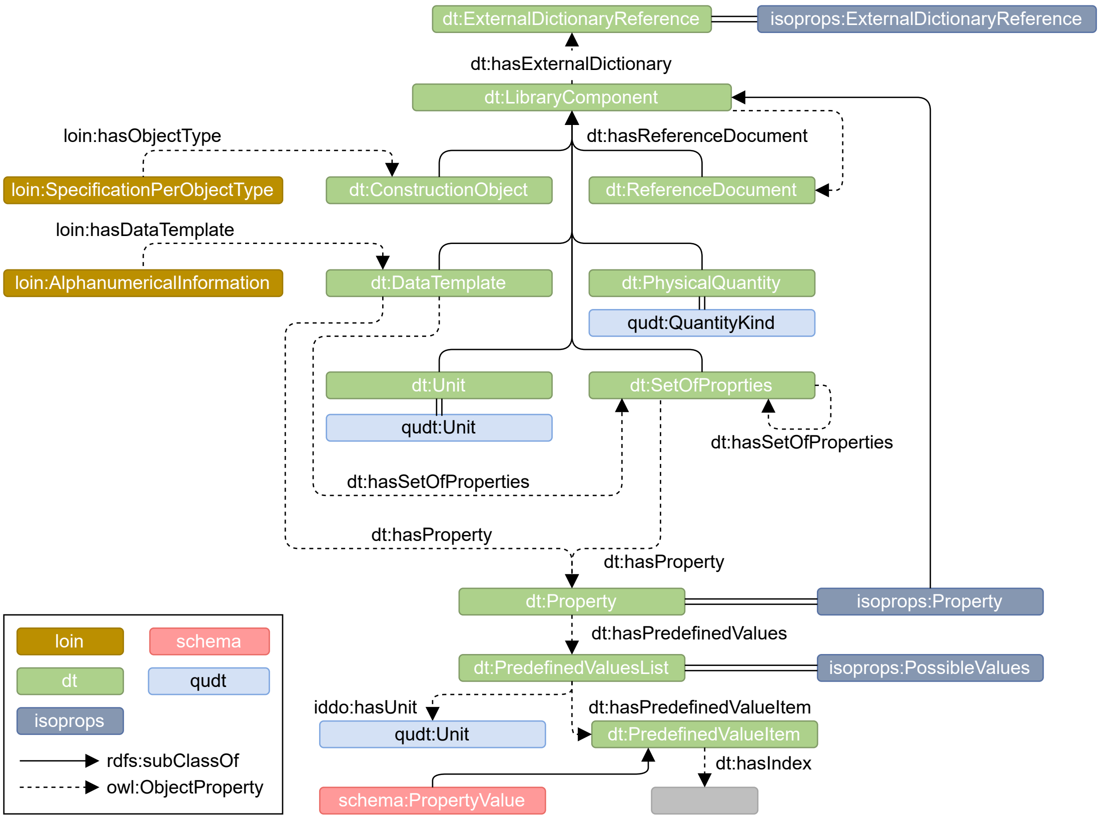

Figure 2: Overview of the main classes of the established ontology network [7]

applicability of the developed ontology network.

In the first step, the authors analyzed and discussed the changes to the XML schemas of both standards (ISO 7817-3 and ISO 23387), focusing on the effects on the alignment of the ontologies and the information delivery process. Subsequently, the changes were implemented and tested through a demonstrator. The updated schemas for LOINxml and data templates were accessed via a restricted GitHub repository created by the CEN/TC 442 working group. Since the IR-ontology network was first created, ISO 7817-3 and ISO 23387 schemas have undergone naming and structural changes. In contrast, the requirements for the ISOProps ontology arising from ISO 23386 have not changed, so potential changes can only occur through adjustments within the alignment points to the other two ontologies.

Addressing the XML schema of ISO 7817-3 (version from January 2025), it becomes evident that despite more minor changes in naming, the most significant changes were made to the *Alphanumerical Information* and the *Specification Per Object Type* (cf. Figure 2 & 4). The modifications to the *Alphanumerical Information* require adjustments to the alignment between the LOIN and the DT ontologies. In the previous XML schema version, the assignment of *Alphanumerical Information* was made through the *Data Template* element from ISO 23387, which has its own *Object Type*. In addition, the *Specification Per Object Type* element also includes, as depicted in Figure 2, an *Object Type* to which the *Geometrical Information*, *Alphanumerical Information*, and *Documentation* are linked. The presence of both *Object Types* can lead to potential inconsistencies in the current version. Having two separate *Object Types* within the same schema, as described above, may lead to several problems, most notably inconsistencies in data structuring, redundancy, and ambiguity in the assignment and interpretation of information. When *Alphanumerical Information* is associated with two different *Object Types*, it becomes unclear which Object Type is authoritative or how they precisely relate to each other. Such ambiguities can lead to discrepancies during data exchange, hinder interoperability between different systems, and complicate validation processes. Therefore, a new approach has been adopted within ISO 7817-3 for formulating the *Alphanumerical Information*, presented in detail in Section **??**.

The updates made to the element *Specification Per Object Type* primarily emerge from adapting the central superclass in line with ISO 23387. To better align with ISO 12006-3, the former superclass, *Library Component* (see Figure 2 top), has been replaced by the class *Concept Type* **??** top). This new class includes metadata for identifying and managing the lifecycle of elements of its subordinate classes. Effects of the changes to the *Concept Type* element within the ontology network are further discussed in Section **??**.

Significant changes have been made to the structure and presentation of the ISO 23387 specification compared to the previous version. In the new version, the previously central *Library Component* element now acts exclusively as a container element within the schema. In accordance with ISO 12006-3, the elements *Concept Type* and *Subject Type* have been introduced, serving as the central superclasses of the specification and, therefore, also for the updated ontology. Additionally, the *External Dictionary Reference* from the previous version (cf. Figure 2 top right) has been removed and incorporated into the *Concept Type*, along with other metadata based on the ISO 12006-3 data model. A newly created connection between the *Data Template* and the *Object Type* (formerly *Construction Object*) requires the aforementioned revision of the alignment between the LOIN and the DT ontologies. Finally, the mapping of the value expression of the properties was combined within the *Datatype* element.

Regarding the ISO 23386 and the corresponding ISOProps ontology, it must be analyzed, as mentioned before, how the alignment with the DT Ontology needs to be adjusted due to the replacement of the *Library Component* as it also serves as a superclass for the *Property* class. The alignment of ontologies is further enhanced through the visualization of vocabulary using standardized notations, as outlined in the ontology design template by Donkers [17].

4. IR-Ontology network update

After analyzing the new XML data schemas for ISO 7817-3 and ISO 23387, the elements requiring special attention for the revision were identified. Consequently, all three ontologies within the information requirement network were updated. The results of this revision are detailed below. Here, Figure 3 shows the newly developed tempO (formerly DT Ontology), and Figure 4 shows the new version of the LOIN Ontology. In addition, Table 1 provides an overview of which classes were newly added, renamed, or replaced during the revision.

During the use of the Data Template Ontology, abbreviated as DT, within a use case dealing with mapping information requirements of digital twins (also abbreviated as DT), it was noticed that the previously selected ontology prefix DT can lead to confusion, especially in the AECOM application area. For this reason, the prefix of the data template ontology was adapted to tempO.

The first content-wise change was the replacement of the original `dt:LibraryComponent` (see Figure 2) as the central superclass of the ontology and converting this into a container class. In its new function, the `tempo:Library` contains all information elements relevant to the data templates. A class equivalence with the `tempo:Library` with existing ontologies was also formed to increase the interoperability of the `dcat:Catalog` class. The DCAT ontology (Data Catalog Vocabulary) is already used within the ISOProps ontology and was developed to make data catalogs of any kind interoperable and machine-readable [18]. It can be used to describe metadata about datasets, data services, and catalogs to make them more findable, searchable, and accessible. Within the IR ontology network, the mechanisms of the DCAT ontology can be used to represent relationships and dependencies between LOINs, tempO libraries, and the data dictionaries of ISOProps.

As a result of the previously mentioned approach to align with ISO 12003-3 specifications, the `dt:LibraryComponent` is replaced by the `tempo:ConceptType` (see Figure 3 top) as the central superclass. The class `tempo:ConceptType` contains a set of metadata (a concept ID, name, description, version numbers, etc.) essential for managing its subordinate elements' life cycles. Within tempO, these are the classes *Unit*, *Quantitiy Kind*, *Reference Document*, *Property* and *Subject Type*.

Table 1
Overview of classes including reasons that were added, removed, or renamed during the ontology update

LOIN Ontology		
Version 2024	**Version 2025**	**Comment**
-	*Level of Information Need*	Container element for ontology instances Class equivalent to `dcat:Catalog`
-	*Specification*	New parent class for the *Prerequisites* and the *Specification Per Object Type*
-	*Prerequisites*	Encapsulates the classes and objects for contextual information
TempO		
Version 2024	**Version 2025**	**Comment**
Library Component	*Library*	Serves only as a container element in the new Class equivalent to `dcat:Catalog`
-	*Concept Type*	Added as a new central superclass of the ontology Ensures alignment with the mechanisms defined in ISO 12006-3
-	*Subject Type*	Subordinate super class for *Object Type*, *Data Template* and *Group of Properties* Provides subclasses a comprehensible self-referencing mechanism
Set Of Properties	*Group Of Properties*	*Set Of Properties* omitted to improve alignment with ISO 23386
Construction Object	*Object Type*	Renamed
Predefined Values	*Data Type*	*Possible values* of the property are combined within the *Data Type*
External Dictionary Reference	-	Was removed because external references are possible via the attributes of the Concept Type

The class `tempo:SubjectType` recreates a superordinate role, as it is the superclass for `tempo:ObjectType`, `tempo:DataTemplate` and `tempo:GroupOfProperties`. The `tempo:SubjectType` provides its subclasses with a standardized and comprehensible mechanism for self-referencing. For example, the object properties `tempo:hasParts` and `tempo:isSubtypeOf` can be used to show that a data template consists of several data templates (`tempo:hasParts`) or that it is part of a superordinate template (tempo:isSubtypeOf). In addition to the self-reference, an instance of the class `tempo:isAssignedToObjectType` can be assigned directly to a data template after the ontology has been revised via the object property `tempo:isAssignedToObjectType`.

The newly added abstracted class `tempo:GroupOfProperties` (cf. Figure 3) replaces the formerly used `SetOfProperties`. This is done to better align with the paradigms of the ISO 23386 data schema and serves as a further link to the ISOProps ontology within the ontology network. The class `tempo:Property` remains almost unchanged within the tempO compared to the DT ontology. Only the self-referencing within the class is no longer implemented via the object property `tempo:hasProperty` but has been adapted to the self-referencing mechanism of the class `tempo:SubjectType` via the object properties `isDependentOn` and `tempo:isSpecializationOf`. In addition, the possible values of the `tempo:Property` (value ranges, patterns, enumerations) have been combined in the new version in the `tempo:Datatype` class.

Analogous to the tempO and the ISOProps ontology, the LOIN ontology also contains a higher-level container class (cf. Figure 4 `loin:LevelOfInformationNeed`), which is set to be equivalent to the `dcat:Catalog` class to increase the findability of LOIN content within and outside the information requirement ontology network. Elements of the newly created `loin:LevelOfInformationNeed` class contain any number of instances of the newly added class `Specification`, which refers to the *Prerequisites* on the one hand and to the *Specification Per Object Type* on the other. The `loin:Prerequisites` class contains all prerequisites and for the associated *loin:Specification*. The structure of

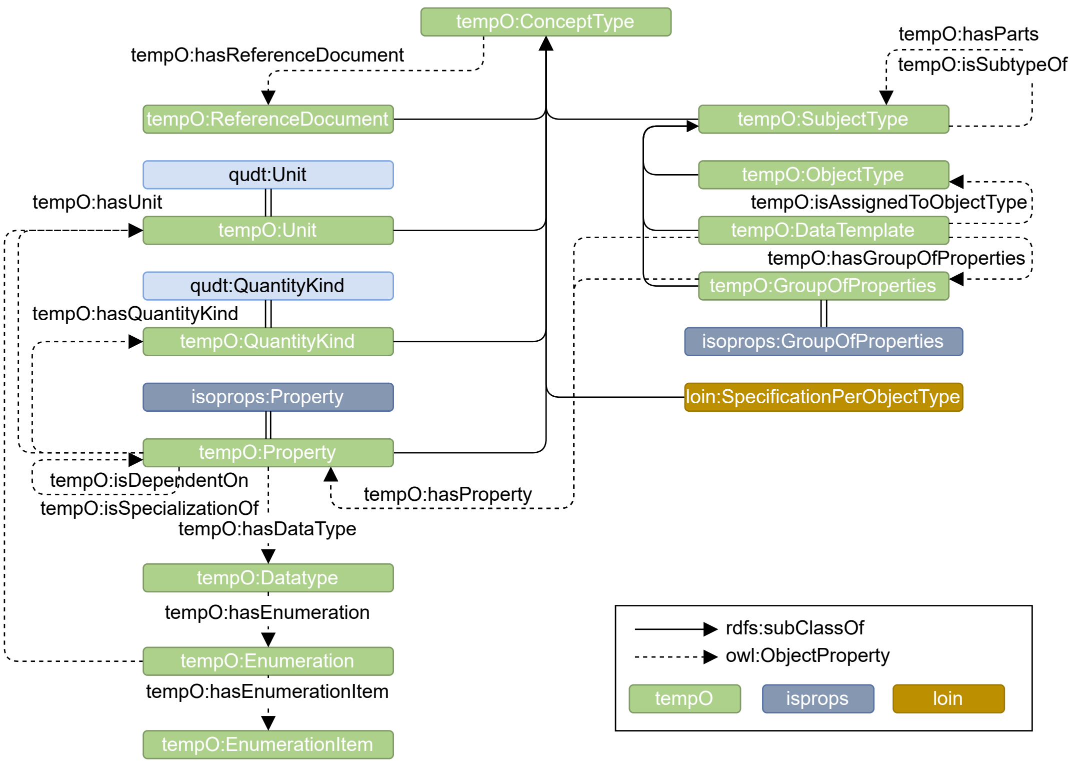

Figure 3: tempO class schema and the alignment with the LOIN and the ISOProps ontologies

the `loin:SpecificationPerObjectType` class remains almost unchanged compared to the previous version. The class has only been subordinated to the `tempo:ConceptType` class as part of the alignment process.

The most significant change made within the LOIN Ontology regards the class `loin:-AlphanumericalInformation`. This class previously contained an *Object Type* as a flexible reference and a variable amount of *Sets Of Properties* and *Properties* (see Figure 2). These references left room for the definition of two different *Object Types* within one instance of the class `loin:SpecificationPer-ObjectType`, which can lead to potential inconsistencies and, therefore, had to be changed. Therefore, the Alphanumerical Information now includes all elements of the `tempo:Library` class of the tempO except the ObjectType and DataTemplate elements (*Property, QuantityKind, GroupOfProperties, ReferenceDocument, Dimension, Unit*), thus mimicking the options available to the data template without creating the mentioned inconsistencies.

The relevant changes made to the ISOProps ontology occurred during the readjustment of the alignment of the three ontologies. Due to recent modifications in tempO regarding the *Concept Type* defined in ISO 12006-3, the aim is to maintain interchangeability between the *Property* classes of the tempO and ISOProps ontologies. Consequently, the `isoprops:Property` class has also been made a subclass of the `tempo:ConceptType` class. The newly established class `tempo:GroupOfProperties` creates a more explicit connection between the ISOProps ontology and tempO through an equivalence between the classes `tempo:GroupOfProperties` and `isoprops:GroupOfProperties`. In addition, the `isoprops:GroupOfProperties` is also assigned to the new superclass `tempo:SubjectType` due to the replacement of the formal superclass `dt:LibraryComponent` as mentioned above.

The alignment between the LOIN ontology and the tempO has been updated and now includes an additional alignment point compared to the previous version. The reference from LOIN to the relevant object type now directs to an element within the class `tempo:ObjectType` (previously `dt:ConstructionObject`), following the recent renaming within tempO. Additionally, the class

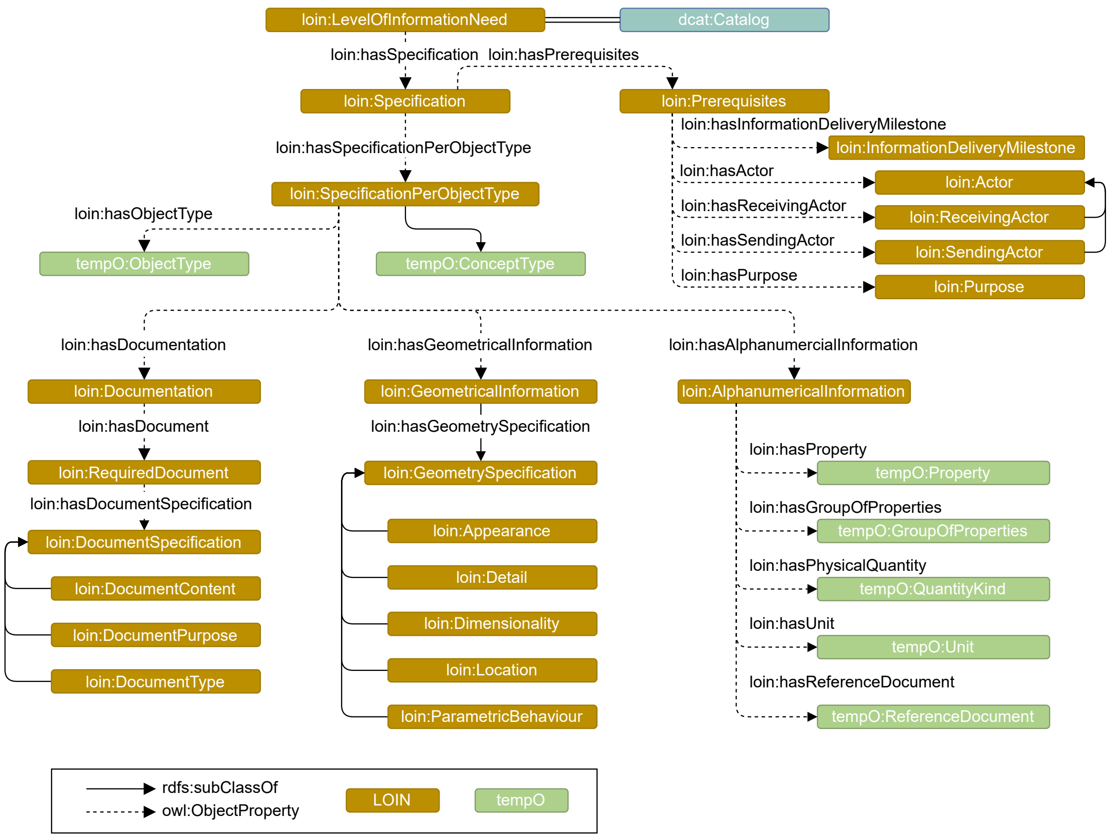

Figure 4: LOIN class schema and the alignment with the LOIN and the ISOProps ontology

`loin:AlphanumericalInformation` no longer directly references an instance of `tempo:Data-Template` as mentioned before. Instead, it points to the individual components of the template. Similar to ISOProps, the new alignment point has been established due to the introduction of the ISO 12006-3 paradigms within tempO. As a result, the class `loin:SpecificationPerObjectType` has also been subordinated to the class `tempo:ConceptType`, facilitating uniformity in handling across the main classes of all three ontologies.

In addition to the alignment steps already mentioned and the changes made to the content of the information requirement ontology network, further content, and editorial adjustments were implemented during the update. However, providing comprehensive documentation of all the adjustments made during the update and the corresponding alignment process would exceed the scope of this paper. Therefore, the authors refer readers to the documentation of the ontologies, which can be found in Section 7.

5. Demonstration

The upcoming use case demonstrates the applicability of the updated and adjusted ontology network for defining standard-compliant information requirements, using the Global Warming Potential (GWP) within the life cycle assessment (LCA) during the design phase of a new building as an example. The GWP was chosen as an exemplary yet meaningful indicator that reflects the increasing relevance of environmental aspects within design practices. By demonstrating the functionality of the updated and adapted information requirement ontology network using a factual example, not only is the methodological progress in the definition of standard-compliant information requirements documented, but the practical significance of the approach is also emphasized.

This use case focuses on determining the GWP value for building elements made out of concrete. The specific emphasis on concrete elements was intentionally chosen due to concrete's significant relevance in the construction sector and its associated environmental impacts. As one of the most commonly used building materials, concrete is responsible for considerable CO_2 emissions, making an accurate assessment of its GWP crucial for informed, environmentally conscious building decisions and the advancement of sustainable construction practices. The GWP, which is defined in ISO 14040 [19], is a measure that indicates how much a substance contributes to the warming of the Earth's atmosphere. Its value is determined by comparing the substance's effects to those of carbon dioxide (CO_2). A reference period of 100 years is typically used for this measurement. Since GWP represents a CO_2 equivalent, it is expressed in kilograms of CO_2 equivalent per square meter per year. The GWP of concrete elements can be calculated using the following formula:

$$\text{GWP} = V \cdot \sum_{m=1}^{n} GWP_{total}$$

To realize the assessment of the GWP, the LOIN Ontology and the TempO are used to specify the information requirements for the building design, in which the relevant properties for a certain *Object Type* can be demanded as shown in Figure 5. Using ISOProps, the required parameters for the standardized calculation for GWP are defined as properties. `:GWPtotal` is defined with the unit `unit:KiloGM` for kilograms of CO_2 equivalent as mentioned above. The concrete type is necessary to determine the `:GWPtotal`. Therefore, the property `:Concrete_Strength_Class` is defined and linked with `:GWPtotal` using the object property `isoprops:hasConnectedProperty`. The property `:Volume` is intended to assign the volume of each concrete building element measured in cubic meters (`unit:M3`).

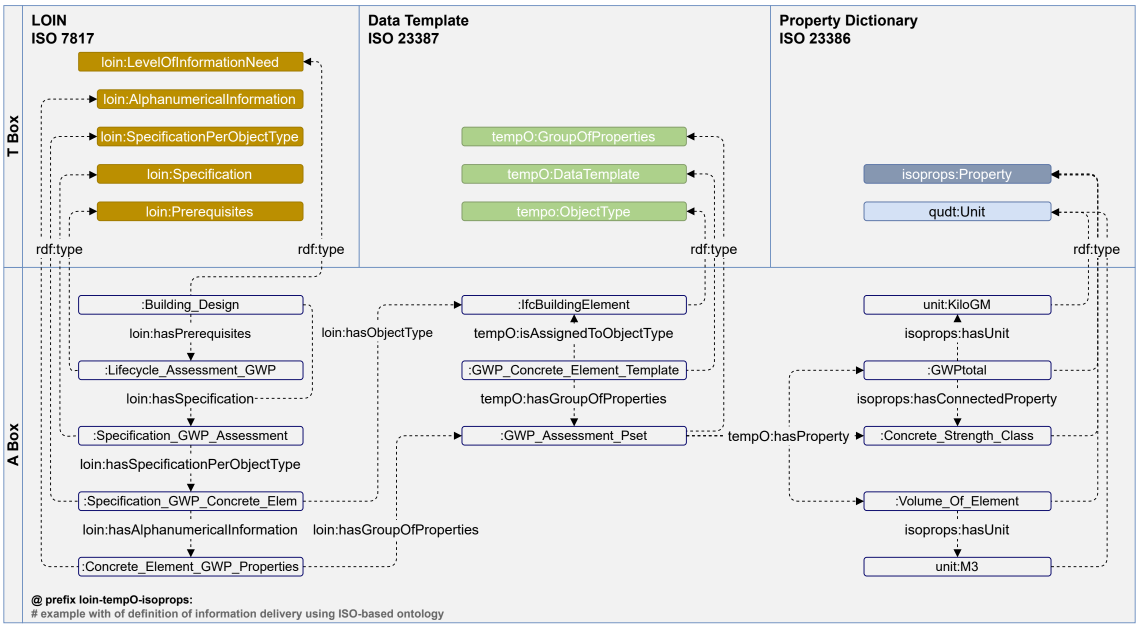

Figure 5: Information requirements definition using the updated ontology network

Using tempO, the instance `:GWP_Concrete_Element_Template` of the class `tempo:DataTemplate` can be specified for the `:IfcBuildingElement`. The data template contains the group of properties `:GWP_Assessment_Pset`, to which all of the aforementioned properties for the assessment of GWP defined by ISOProps are assigned. The specification per object type `:Specification_GWP_Concrete_Elem` is connected with the `:IFC_Building_Element` using the object property `loin:hasObjectType`. In addition, its alphanumerical information is detailed with `:GWP_Assessment_Pset` using `loin:hasGroupOfProperties`.

The created instances are validated using a concrete column example. The column itself is made of grade C30/37 concrete, has a base area of 30 x 30 cm, a height of 2.8 m, and a resulting volume of 0.252 cubic meters. The equivalent amount of CO_2 for producing such a column is 175.2 kg. An IFC model was created for the described column and converted into a Linked Building Data (LBD) model using the IFC to LBD converter from Oraskari et al. [20]. Once the model had been created, the data template previously defined within the LOIN was mapped to the column within the model. This mapping is achieved by linking the relevant properties from the LBD model with the ones from the data template by using the object property `rdfs:seeAlso`. The connection created in this way can now be used to assign the properties of the LBD model to those of the data template, enriching the LBD model with the corresponding properties of the data template. With a model enriched in this way, it is now also possible, for example, to calculate the GWP for concrete columns directly from the LBD model. An example of such a query is shown in Listing 1.

```
1  SELECT ?column ?gwpTotalValue ?volumeValue ?GWP
2  WHERE {
3    ?column rdf:type beo:Column.
4
5    # Retrieval of the GWPtotal value
6    ?column isoprops:hasProperty :GWPtotal.
7    :GWPtotal opm:hasPropertyState ?stateGWP.
8    ?stateGWP schema:value ?gwpTotalValue.
9
10   # Retrieving the Volume_Of_Element value
11   ?column isoprops:hasProperty :Volume_Of_Element.
12   :Volume_Of_Element opm:hasPropertyState ?stateVolume.
13   ?stateVolume schema:value ?volumeValue.
14
15   # Calculation of the GWP value
16   BIND(?volumeValue * ?gwpTotalValue AS ?GWP)
17 }
```

Listing 1: SPARQL query for the calculation of the GWP value of a Column in the construction phase

The query first filters for all valid instances of the class `beo:Column`. The values previously stored in the column for the GWP total value and the volume are then collected (cf. Listing 1 line 5-8 and 10-13). The query shown here results from the property assignment pattern used within the ISOProps ontology and developed by Zentgraf et al. [15]. Within this approach, an instance of the classes `isoProps:Property:Assignment` and `opm:Property` is assigned to an FoI with the object property `isoprops:has:Property`. An individual of the class `opm:Current:Property:State`, which contains the value of the property, and an individual of the class `isoprops:Property`, which includes the reference to the property instance, is then assigned to this empty node. From the values obtained in this way, the query shown finally calculates the GWP value for the component under consideration and outputs this together with the previously determined values. The approach shown could be extended in the future to consider several life cycle phases in the calculation. It would also be possible for such a GWP calculation to provide the values for individual building materials, i.e., an A-Box Ontology based on the ISOProps ontology, in order to enable automatic retrieval of the relevant GWP values for the required building materials. The approach shown for the targeted specification and attribution of a building model for the selected LCA use case demonstrates the applicability of the updated ontology.

6. Discussion

This analysis examines revisions to the XML-based schemas and ontology network architecture. This revision demonstrates a more modular relationship between the LOIN, tempO, and ISOProps ontologies compared to the previous version. While earlier implementations featured direct integration of `tempo:DataTemplate` within `loin:AlphanumericalInformation`, the revised LOIN ontology adopts a refined approach, utilizing only essential tempO elements for the alphanumerical information definition, thus also connecting it to the ISOProps ontology. This motion gives the LOIN ontology access to the necessary mechanisms of tempO and an alignment with the ISO 12006, rooted in the underlying abstract elements `tempo:ConceptType` and `tempo:SubjectType`. The `tempo:ConceptType` element is closely aligned with the concepts of ISO 12006 and the central intersection of all three ontologies. The class `tempo:ConceptType` underpins the ISOProps ontology's property class and the LOIN ontology's `loin:SpecificationPerObjectType`. The updated data template schema and, therefore, the tempO also introduces the `tempoSubjectType`, a child of the `tempo:ConceptType`, with mechanisms to create self-dependencies, also rooted in ISO 12006. This `tempo:SubjectType` class is also the parent class of the `isoprops:GroupOfProperties`, enabling subtyping and aggregations.

An additional change in the XML schemas on which this work is based is the replacement of the class *Set Of Properties*. While not explicitly addressed in the previous paper, this change was a recurring topic of discussion among the authors during implementation since the difference between a *Group of Properties* and a *Set of Properties*, which were available in previous versions, isn't always unambiguous.

A further topic to be discussed is the widely used mechanism of equivalences. Examples include the `isoprops:Property` and `tempo:Property` as well as `qudt:Unit` and `tempo:Unit`. While equivalences can be helpful, the content of the classes must be considered to prevent error-inducing divergences. Another aspect that was not addressed in the first paper, albeit known to the authors, was the fact that in ISOProps, the class `isoprops:GroupsOfProperties` doesn't know its properties, while the `tempo:GroupOfProperties` does.

Future developments may incorporate reusable requirements for specific use cases, as shown in the demonstration using LCA requirements. Data templates for a wide range of object types and materials defined as A-box ontologies for specific use cases could enhance automation capabilities. The framework could support distinct templates for varying concrete specifications (e.g., C 30/37, C 20/25), enabling streamlined requirement definition and management through object type references.

7. Conclusion and outlook

This research updated and extended the existing ontology network for information requirements to reflect current developments in standardization, specifically integrating standards for Level of Information Need (LOIN), Data Templates (tempO), and interconnected data dictionary properties (ISOProps). Through modular ontology alignment using class and property equivalencies, a unified ontology framework compliant with ISO standards 7817, 23386, 23387, as well as elements from ISO 12006 and ISO 19650, was established. This alignment eliminates taxonomic inconsistencies and supports standardized information delivery. A case study on building design addressing GWP calculations demonstrated the practical applicability and flexibility of the developed ontologies for a particular use case, highlighting their ability to handle industry-specific and future requirements efficiently.

While the case study has demonstrated the usability of the presented ontologies, the methodological approach has to be critically reflected. The procedure of updating the ontology network, its terminology, and interconnections was largely manual, based on the updated standards. Therefore, this work is ineffective, and in the future, there should be a strong focus on standardization and the implementation of SMART standards. These SMART standards can at least be machine-readable, and in higher development stages, they can also be used ontologically so that standard-related deliverables can be versioned more easily.

Despite its valuable outcomes, this research is subject to certain limitations, including potential scalability challenges when applied to highly complex projects with extensive data volumes and varied data requirements. Another impediment to industry adoption of the presented approach is the interoperability between modeling environments, data templates, and property databases, which must be provided through dedicated interface implementations. Additionally, this study does not prove the ontology's broad applicability. Future research should address these limitations by conducting comprehensive validation studies across diverse industry scenarios.

Data availability

The aligned and harmonized ontologies, the TempO ontology, and demo data are available via GitHub: https://rub-informatik-im-bauwesen.github.io/ir-ontologies/

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Declaration on Generative AI

During the preparation of this work, the author(s) used ChatGPT and Grammarly in order to: grammar and spelling check, paraphrase, and reword. After using this tool/service, the author(s) reviewed and edited the content as needed and take(s) full responsibility for the publication's content.

References

[1] E. Nuyts, M. Bonduel, R. Verstraeten, Comparative analysis of approaches for automated compliance checking of construction data, Advanced Engineering Informatics 60 (2024) 102443. doi:10.1016/j.aei.2024.102443.

[2] P. Pauwels, S. Zhang, Y.-C. Lee, Semantic web technologies in aec industry: A literature overview, Automation in Construction 73 (2017) 145–165. doi:10.1016/j.autcon.2016.10.003.

[3] S. Son, G. Lee, J. Jung, J. Kim, K. Jeon, Automated generation of a model view definition from an information delivery manual using idmXSD and buildingSMART data dictionary, Advanced Engineering Informatics 54 (2022) 101731. doi:10.1016/j.aei.2022.101731.

[4] L. van Berlo, D. Moult, R. de Laat, C. Benghi, P. Paasiala, E. Alfieri, J. Brouwer, K. Helland, Information Delivery Specification (IDS) Technical Documentation: How do specifications work?, 2022. URL: https://github.com/buildingSMART/IDS/blob/master/Documentation/specifications.md, last accessed: 05.02.2024.

[5] W. Solihin, C. Eastman, Y.-C. Lee, D.-H. Yang, A simplified relational database schema for transformation of bim data into a query-efficient and spatially enabled database, Automation in Construction 118 (2020) 103289. doi:10.1016/j.autcon.2020.103289.

[6] A. Borrmann, M. König, C. Koch, J. Beetz, Building Information Modeling: Technology Foundations and Industry Practice, Springer International Publishing, 2018. doi:10.1007/978-3-319-92862-3.

[7] M. Mellenthin Filardo, L. Liu, P. Hagedorn, S. Zentgraf, J. Melzner, M. König, A standard-based ontology network for information requirements in digital construction projects: Forthcoming, Proceedings of the 12th Linked Data in Architecture and Construction Workshop (LDAC2024), June 13–14, 2024, Bochum, Germany (2024).

[8] ISO 23386, Building information modelling and other digital processes used in construction: Methodology to describe, author and maintain properties in interconnected data dictionaries, 1 ed., International Organization for Standardization, Geneva, CH, 2020.
[9] ISO 23387, Building information modelling (BIM) — Data templates for construction objects used in the life cycle of built assets: Concepts and principles, 1 ed., International Organization for Standardization, Geneva, CH, 2020.
[10] ISO 7817-1, Building information modelling— Level of information need: Part 1: Concepts and principles, 1 ed., International Organization for Standardization, Geneva, CH, 2024.
[11] M. Bolpagni, F. Bosché, A. de Boissieu, A. Akbarieh, C. Shaw, P. Mêda, R. Puust, M. Medineckiene, V. Popov, R. Sacks, An explorative analysis of european standards on building information modelling, in: Proceedings of the 2022 European Conference on Computing in Construction, volume 3 of *Computing in Construction*, 2022. doi:10.35490/EC3.2022.170.
[12] ISO 12006-3, Building construction— Organization of information about construction works: Part 3: Framework for object-oriented information, 1 ed., International Organization for Standardization, Geneva, CH, 2023.
[13] L. Liu, P. Hagedorn, M. König, Definition of a container-based machine-readable idm integrating level of information needs, in: Proceedings of the 2023 European Conference on Computing in Construction and the 40th International CIB W78 Conference, volume 4 of *Computing in Construction*, European Council on Computing in Construction, Heraklion, Greece, 2023. doi:10.35490/EC3.2023.221.
[14] R. Hodgson, Quantities, Units, Dimensions and Types (QUDT) Schema - Version 2.1.35, 2024. URL: https://www.qudt.org/doc/DOC_SCHEMA-QUDT.html, last accessed: 05.02.2024.
[15] S. Zentgraf, P. Hagedorn, M. König, Multi-requirements ontology engineering for automated processing of document-based building codes to linked building data properties, IOP Conference Series: Earth and Environmental Science 1101 (2022). doi:10.1088/1755-1315/1101/9/092007.
[16] M. H. Rasmussen, M. Lefrançois, P. Pauwels, C. A. Hviid, J. Karlshøj, Managing interrelated project information in AEC Knowledge Graphs, Automation in Construction 108 (2019) 102956. doi:10.1016/j.autcon.2019.102956.
[17] A. Donkers, Ontology Design Template, 2022. doi:10.5281/zenodo.6816899, Publishing Date: 11-07-2022, Version: v1.0.
[18] R. Albertoni, D. Browning, S. Cox, A. Gonzalez Beltran, A. Perego, P. Winstanley, Data Catalog Vocabulary (DCAT), 2020. URL: https://www.w3.org/TR/vocab-dcat-2/.
[19] ISO 14040, Environmental management - Life cycle assessment - Principles and framework, International Organization for Standardization, Geneva, CH, 2021. doi:10.31030/3179655.
[20] M. Bonduel, J. Oraskari, P. Pauwels, M. Vergauwen, R. Klein, The IFC to linked building data converter : current status, in: Proceedings of the 6th Linked Data in Architecture and Construction Workshop (LDAC), volume 2159, 2018, pp. 34–43. URL: http://ceur-ws.org/Vol-2159/04paper.pdf.