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BIM KNOWLEDGE IN CONTEXT: LINKED (META)DATA TOWARDS MACHINE-INTERPRETABLE STANDARDS

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Abstract

Despite advancements in data connectivity and regulations in the construction industry, integrating standards in daily workflows has seen limited progress. The industry necessitates easier access to standards to accelerate its digitalisation. This research enhances access to BIM-related standards by developing, aligning and validating an ontology that includes standards' metadata, terminology, and relationships. The proposed MNS ontology relates these standards to topics of interest for construction industry professionals, paving their easier access to relevant documents. It also makes first steps towards machine-interoperable standards. The ontology is open and queryable, to serve a broader community, and ultimately to integrate standards in construction practices.

Introduction

The body of knowledge which describes the topics of building information modelling (BIM), and generally digital construction, is increasing, and with that the number of standards which regulate its implementation. The users need to understand how they can efficiently benefit from standards in their everyday tasks (Bolpagni et al., 2022). Research on standards in the construction industry is generally very limited (Angelino, 2019), and especially regarding the implementation of standards (Jiang et al., 2021). Jiang et al. (2021) investigated the use of construction safety standards and the ways to access knowledge within them. They proposed a five-level structure to make analysis, querying, and sharing of standards easier and to save time in searching for the right standard.

BIM-related standards are still not widely implemented in the construction industry, and only some reach the end-users. Ahlemann et al. (2009) recognised deficiencies for standards diffusion as: the lack of acceptance, administrational overheads and associated costs. They emphasised that organisations should carefully choose and adopt the standards that are most appropriate for their specific situation. Our research aims on making this process smoother. With uneven adoption of BIM standards, and their slow integration into workflows (Sibenik et al., 2023), there is a need for more decision-support tools that overcome these challenges and encourage the uptake of standardised BIM workflows.

The European Council on Computing in Construction (EC3) BIM Standards Landscape Explorer (BIM SLE) was created to facilitate the access to standards (Bolpagni et al., 2022). It is a data-driven decision-support tool for BIM standards. The BIM SLE is a multi-year collaborative project intended to help users navigate and apply BIM-related standards (Bolpagni et al., 2022). With continuous refinement, the latest updates were performed in January 2025. A comprehensive database of well-known and relevant standards was compiled over four years. The database includes over 220 interconnected standards, of which 35 deal with BIM implementation.

While the BIM SLE is freely available on the Web, the database is static and relational. The standards' data lacks a representational structure that enables systematic queries for external users. As the continuation of this research, the need is identified to represent the BIM SLE in a manner which is more machine-interpretable and interoperable with the data on the Web. Despite some digitalisation initiatives, the standards still cannot be searched with complex queries. The structuring of underlying concepts is still insufficient and requires expert assessment. Thus, there is a need to develop an ontology that can represent the standards' (meta)data in line with the semantic web technology. This objective follows the format of the standard of the future, described as SMART (Standards, Machine Applicable, Readable and Transferrable) (Gribova & Shalfeeva, 2024). Human- and machine-readable and interpretable SMART standards are a trend in Industry 4.0. (Gribova & Shalfeeva, 2024). Such standards are used with the aim to support intelligent systems and automate the work which uses standards' (meta)data. The present study takes steps towards this aim by making metadata, granular contents, and contextual relationships between standards machine-readable and machine-interpretable.

The initial relational database serves as a foundation for the new ontology, which will facilitate intuitive and machine-interpretable relations, better organisation of knowledge on digital construction and BIM standards and more intelligent queries. A detailed methodology on the BIM SLE development was described in Bolpagni et al. (2022); the BIM SLE is revisited and mapped to the classes and links between standards for serialisation into Web Ontology Language (OWL). To place the ontology describing BIM standards in the industry context, it needs to be integrated with other ontologies in the construction industry and beyond, with the wider bibliographical context dealing with standards.

This paper continues with the background section describing the current state of BIM SLE with its dashboards and related existing ontologies. Further, the methodology for ontology development will be presented along with the testing procedure and queries. The proposed ontology, alignment with existing ontologies and tested queries are parts of the findings section. The discussion will focus on the implementation challenges, limitations and opportunities.

Background

Metadata and queries in BIM SLE

All standards in the database used by BIM SLE include attributes such as standard number, abstract, links (when available), publication date of first and current versions. These attributes apply universally to standards, regardless of whether that specific standard pertains to the built environment or another domain.

The dataset was previously defined with a relational database and multiple tables defined in MS Excel (Bolpagni et al., 2022). Users can track database updates on the landing page of the BIM SLE, such as when new standards are added or existing information is updated. Further categorisations were developed by the EC3 Modelling and Standards Committee (M&S), including the type of standard, its affiliation with the European Committee for Standardization (CEN), the corresponding CEN committee, and whether it is International Organization for Standardization (ISO)-related, along with its associated ISO committee. Standards are interconnected through implicit, normative, and informative relationships, represented as directed graphs. BIM standards can be related to other standards regulating information and communication technology (ICT), not necessarily only belonging to BIM domain. The standards are categorised into various types (also known as domains), including BIM, ICT, geographic information systems (GIS), health information system (HIS), construction, industrial automation, facilities management (FM), project management (PM), quality management (QM), technical product description, and sustainability.

The "relevance" of a standard's content is further mapped to roles, phases, and topics. However, for the topics, not only relevant relationship or lack of it was established, but also it was given a weight. Therefore, the relevance to topic includes, from the lowest to highest, as: None, Relevant, Implicit, and Essential. These specific mappings and relationships are unique to the EC3 M&S dataset and are not found in other projects or ontologies.

Topics linked to standards encompass software implementation and information management concepts such as information delivery manual (IDM), Information Delivery Specification (IDS), model view definition (MVD), level of information need (LOIN), common data environment (CDE), information containers, BIM Execution Plan (BEP), classification, industry foundation classes (IFC), linked data, construction operations buildings information exchange (COBie), information model, data template, GIS, task/master information delivery plan (TIDP/MIDP), exchange/organizational/ asset/project information requirements (EIR/OIR/AIR/ PIR), and asset/project information model (AIM/PIM) (ISO, 2018; ISO, 2016; buildingSMART International, 2025).

The BIM SLE currently features eight distinct dashboards, each offering insights into various aspects of BIM standards and their interconnections:

1. BIM standards: provides an overview of BIM standards and their key attributes.
2. Relationship to Roles: maps BIM standards to specific roles in construction. The existing roles include contractor, client, designer, facility manager, manufacturer, permitting agency, project manager, and software developer. This ensures findability of standards that are relevant to specific stakeholders.
3. Relationship to Phases: connects BIM standards to project lifecycle phases based on the RIBA plan of work, including strategic definition, briefing, procurement, design, manufacturing and construction, handover, operation and maintenance, and decommissioning.
4. Relationship to Topics: links BIM standards to approximately 20 BIM-related topics as described above. This mapping enhances practitioners' understanding of which standards are most applicable to what topic. Each relationship is categorised into three relevance levels:
    - *Essential:* directly referred to in the standard.
    - *Relevant:* mentioned but not the primary focus.
    - *Implicit:* inferred based on context or application.

    Absence of any topical relationship is also captured in the database.
5. Interrelationships of BIM standards: provides a detailed network analysis and overview of relationships specifically between BIM standards. The direction and type of relationship was further analysed by the M&S committee and labelled as normative, and informative relationships:
    - *Normative Relationship:* one standard depends on another. It also means that the standard is in the normative text of the of the other standard.
    - *Informative Relationship:* Background material or standard shared for additional information. It also means that the standard is in the bibliographic reference section of the of the other standard.

6. Cross-domain relationships: examines interactions of BIM standards with other domains, such as GIS, HIS, FM, PM and QM. This mapping creates a network that supports multidisciplinary overflows and exchanges (or lack thereof) between digital construction standards and other domains.
7. Historical evolution: displays a timeline of the publication of the BIM standards, demonstrating trends and providing context for their development and adoption.

Ontologies for BIM concepts

An ontology is a formal and explicit conceptualisation of a specific domain of interest, enabling machine-readable information based on agreed rules and relationships (Pauwels et al., 2017). Ontologies play a vital role in making data understandable for machines, supporting logical queries across heterogeneous datasets, and facilitating the creation of knowledge graphs that contribute to the growing linked data ecosystem.

Ontologies serve as a stepping stone for transforming natural language content into machine-readable, contextualised data within the greater universe of discourse. In the built environment, significant efforts have been made to structure construction knowledge through ontologies (Farghaly et al., 2023). Additionally, progress has been achieved in making machine-interpretable and automating BIM procedures described in standards (reaching Level 4 of SMART standards). Some examples include ontologies like the Interconnected Data Dictionary Ontology (IDDO) (Zentgraf et al., 2022), the Information Delivery Processes Ontology (IDPO) (Hagedorn & Konig, 2021), ISO 23386 Property Ontology (isoprops) (Mellenthin Filardo et al., 2024), Level of Information Need Ontology (LOIN) (Liu et al., 2023) and BIM Collaboration Format Ontology (bcfOWL) (Schulz et al., 2021). These ontologies attempt to formalise procedural and contextual aspects of BIM processes that are articulated in standards. However, these efforts remain fragmented and largely disconnected from broader standardisation frameworks. While these ontologies were designed to support compliance checking, automation, and integration, they lack systematic connections to the source documents (i.e., standards) they originate from. This disconnection between standardised procedural semantics and the documents defining these standards creates challenges in ensuring consistency, machine readability, and automated compliance checking.

Addressing this gap requires more than simply aligning existing ontologies with domain-specific applications. It necessitates strategic thinking to establish a plug-and-play approach between ontologies and standard documents. Such integration could significantly improve the discoverability and usability of BIM standard-related ontologies, enhancing their practical application. Currently, these ontologies are underutilised, partly due to their limited discoverability and the lack of user understanding regarding their purpose and usage.

A mechanism similar to the BIM SLE which could identify relevant ontologies for various project phases would derive substantial benefits. Such a structured approach would bridge the gap between procedural semantics and standards, enabling users to achieve better compliance, automation, and integration.

Despite the relative maturity of ontologies and vocabularies in the built environment (Farghaly et al., 2023), few efforts have directly targeted the standards themselves. This represents a critical gap where standards, often written in natural language and challenging to interpret, remain disconnected from ontology-driven advancements that could make them more accessible, interoperable, and actionable in practice.

Ontologies for standards and regulating documents

A literature review was performed to investigate ontologies used for structuring the metadata about standards and those specific to construction standardisation.

The Standards Specific Ontology (SSOS) (National Information Standards Organization, 2024) is currently a work in progress, focusing on various aspects related to standards. It includes classes such as *ssos:Standard* and *ssos:StandardReference*, with several subclasses, e.g., *ssos:DatedStandardReference*, *ssos:NormativeReference*, *ssos:InformativeReference*, *ssos:UpdatedStandardReference* and *ssos:StandardsDevelopmentOrganization*. Key data properties include *ssos:ID*, which serves as a unique identifier; *ssos:approvalYear*, denoting the year a standard was approved; *ssos:DOI*, a Digital Object Identifier for referencing; *ssos:productCode*, associated with specific products; and keywords used to classify the standards.

In contrast, the Standards Ontology (STO) (Grangel-González et al., 2017) is more developed and emphasises relationships among existing standards. It defines the class *sto:Standard* as a *foaf:Document* and introduces several key relations. For instance, *sto:relatedTo* connects one standard to another, while *sto:hasPublicationDate* specifies the publication date of the standard using xsd:date. The ontology also includes the classes *sto:TechnicalCommittee* and *sto:Domain,* which relate to the technical committees and domains relevant to standards, respectively. Moreover, it identifies *sto:developer* and *sto:publisher,* representing organizations involved in the development and publishing of standards.

The Digital Construction (DiCon) ontologies focus on various agents involved in construction and design, including roles such as architectural designer, construction worker, general contractor, and project manager (Zheng et al., 2021). These ontologies provide a comprehensive list of agents, highlighting their specific functions within the construction process. Although stages are not explicitly defined, the framework allows for the relational mapping of different standards, suggesting a flexible approach to integrating various processes in construction.

In terms of relationships, the STO ontology allows standards to relate to themselves, enabling a reflexive behaviour. To address how these relations interact, it is essential to define clear relation types, use annotations for clarification, and create a framework that accommodates various relations while allowing flexibility in application across different contexts or domains. The proposed ontology developed in this research will help integrate the existing work in the SSOS, STO, DiCon and Ontology Metadata Vocabulary (OMV), (Hartmann et al., 2005), ontologies into a cohesive and functional new ontology.

Methodology

Methodology consists of three main parts: defining the new ontology, reformatting the relational dataset into a knowledge graph and evaluating the ontology through it.

The first part was the development of the ontology. The principles outlined in "Ontology 101" (Noy & McGuinness, 2001) were followed. As such, the present study followed seven steps to develop a new ontology:

Setting domain and scope: This ontology primarily pertains to the field of bibliography, focusing specifically on standards and regulations within the construction industry, particularly BIM-related standards. The scope will be tested for general topics within the construction industry. It is defined using a list of standards from the BIM SLE.

Reusing existing ontologies: After a thorough search on ontologies relevant to standards and their metadata, the following were considered for reference and alignment: STO, SSOS and OMV. Although there has been no work specific to metadata of standards for the built environment, additional alignment was made with DiCon (Zheng et al., 2021), that unify multiple ontologies in the construction industry. Another aim in this work is to consider and align the new proposal with ontologies that integrate the procedural content (described in Background).

Important terms: Key terms identified include standard, lifecycle stages, agents, relevance, topic, technical committee and standard organisation, date of first publishing and current year, abstract and title, URL and relations to another standard. These were the divisions that existed in the M&S dataset in the backend of the BIM SLE. This step also involved devising the competency questions, as presented in Table 1.

Classes and the class hierarchy: The resulting classes are derived from the BIM SLE. When possible, the classes are aligned with existing ontologies. A detailed description is provided in the Findings section.

Properties of classes: The properties of classes (data or object) are primarily based on the BIM SLE. Most of the data properties related to BIM standards were also found in the metadata pertaining to any standard document. Such details can be found, for example, on the ISO website. Therefore, to adhere to Linked Data best practices, no new terminology was introduced to existing data properties. Instead, the focus was on creating object properties that best describe the details of various relationships in the M&S dataset.

Facets of slots: Facets are summarised based on the results already present in the basic dataset, with cardinality determined from previously analysed examples.

Instances: Instances are mapped from the existing database and compared to ensure that the new ontology covers all relevant information.

The initial list of classes and properties was modelled in Protégé ontology editor. To align the list to the existing ontologies, the STO, SSOS and OMV ontologies were imported into the Protégé environment. Alignments with classes from other ontologies were manually coded in the RDF file (i.e. DiCon). The syntax of the resulted ontology was evaluated in the OOPS OntOlogy Pitfall Scanner! platform (Poveda-Villalón et al., 2014), where no major were issues found. The proposed ontology is called Modelling and Standards Ontology (MNS).

The second part involved data import. After developing the MNS ontology, a Python script was created to transform the static BIM SLE dataset into RDF format based on the MNS ontology. After processing the data, the script serialised the RDF graph into Terse RDF Triple Language (Turtle) file format. The script utilised the RDFLib and pandas packages. RDFLib is a Python package that facilitates interaction with RDF data, serialisation, and semantic querying. This script automated the creation of a knowledge graph out of the BIM SLE dataset, which contains instances of BIM standards and related standards.

Table 1: Competency Questions of the proposed MNS ontology

Level	Competency Questions
Basic	What standards are related to topic X?
	What standards are related to role X?
	What standards are related to project phase X?
	What standards are ISO?
	What standards are from a specific technical committee?
	Does standard X have a relationship with standard Y, and what kind of relationship?
Complex	What are the standards that are related to both topic X and role Y?
	Which standards are related to topic X but are not essentially related to topic Y?
	What standards that are from CEN and related to phase X?
	What are the relationship details between standard X and any other standards?
	Which ISO standards have normative relationships to standards in phase Y?
Cross-domain	Which ontologies are related to topic Y that is also related to standards X?

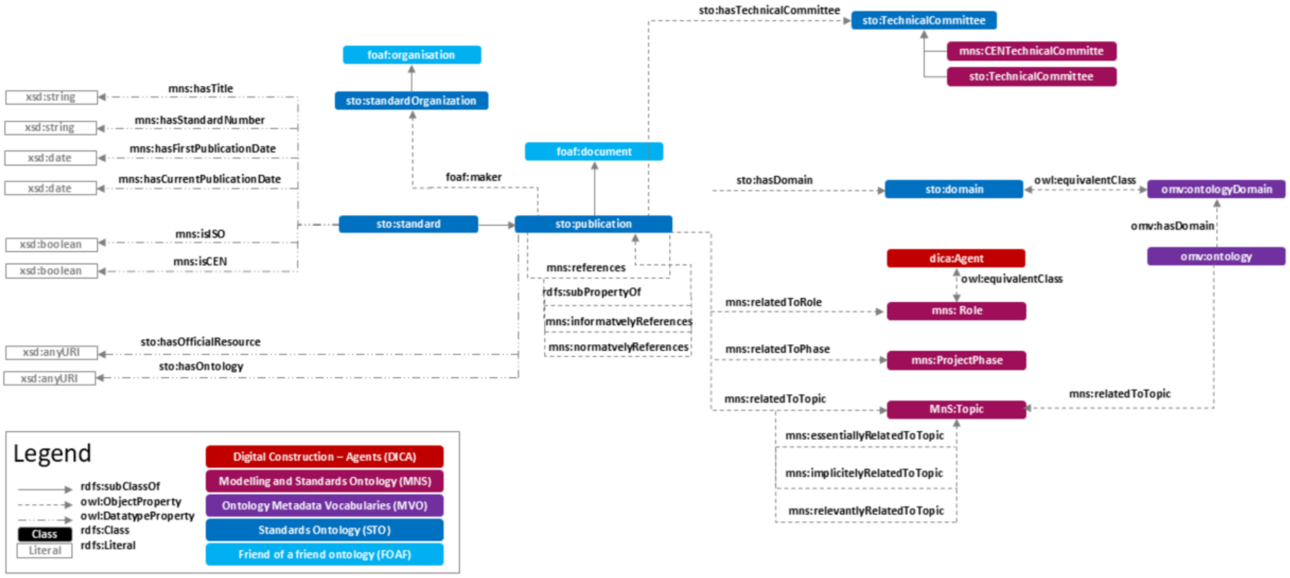


Figure 1: Overview of the Modelling and Standards Ontology (MNS) and alignment with other ontologies

The third part involves testing the ontology. SPARQL Protocol and RDF Query Language (SPARQL), (DuCharme, 2013), queries were written, again using RDFLib, within the VS Code integrated development environment. The queries tested whether the competency questions are answered by the proposed ontology. Six of these queries replicate those in the BIM SLE dashboards, the remaining ones are new and more complex. It was also evaluated whether such queries were previously feasible and if they represent added value stemming from the new data format.

Developing and validating an ontology is an iterative process. The steps outlined above were repeated multiple times to achieve a logically consistent ontology. Additionally, there were several considerations and discussions on how best to model various types of information and the extent to which existing ontologies should be relied upon.

Results and Findings

Modelling and Standards Ontology (MNS)

The existing relational database contains only variable types, which are integers, strings and dates, lacking object representation. In the new ontology, preexisting formats define values, while classes from established ontologies are contextualised. The ontology is available at: https://w3id.org/mns

The ontology incorporates topics and primary topics aligned with the STO ontology and the Friend of a Friend (FOAF) ontology (Figure 1). Standards are categorised based on their affiliations with organizations such as ISO or CEN and can also reference specific technical committees.

Publisher and technical committee classes are recognised within the STO ontology. The relevance of each standard to construction industry actors is aligned with the DiCon ontology, where MNS Roles relate to the dica (agents) ontology. This new ontology uniquely maps standards to various project lifecycle phases, such as briefing.

The weighing of links requires further refinement, which represents the future work. Links are assigned weights based on their normative or informative connection to standards, as defined in the BIM SLE tool. Originally, the relationship between a standard and its domain is determined by the M&S Committee's experts' assessments.

Queries and validation

To validate the ontology, multiple SPARQL queries were made. Two are presented in this paper. Figure 2 shows a SPARQL query that successfully retrieves standards that are related to the topic "Data Dictionary" but excludes those linked to the topic "Information Container." This query aims to exemplify how both the super-property *mns:relatedToTopic* and sub-property *mns:essentiallyRelatedToTopic* are used. Figure 3 illustrates another query, which finds the data about standards that are relevant to a specific topic. This proves that it is possible, to create greater connectivity between standards' data over the Web.

Discussion

This work aims to transform static, human-readable standards' metadata, currently captured in an excel file, into a dynamic, machine-interpretable format. This transformation is essential to enable more advanced queries of the valuable dataset provided by the M&S committee and connect it to the wider open linked data. To enable this transformation, a new formal ontology is developed and evaluated. The ontology representation of standards' metadata is a machine-interpretable format which allows more context-aware structuring than the existing relational data. Compared to the existing collection of standards, the new data format allows custom queries for the existing information and new information on the Web.

The dataset is transformed into a knowledge graph. As such, another contribution of this work is its end-user-oriented structure, which emphasises the importance of inter-disciplinary considerations for practical implementation. Implementation of the system allows the involvement of a wider community. Transition and enrichment from the previous system adds value and nears the standards to the industry professionals.

Strategic vision

Rather than developing another isolated ontology, this work seeks to enhance the broader standardisation landscape by providing structured, machine-interpretable data that facilitates automation, compliance, and cross-domain integration. Since the ontology is defined in a generic way, with topics, roles, and phases represented as individuals of the classes, we believe that the ontology can be adapted to other industrial contexts. Integrating standards through knowledge graphs addresses a key challenge in digital construction - making diverse and constantly evolving standards understandable and actionable.

While existing ontologies provide general frameworks for describing standards, little effort has been made to align built environment standards and their metadata. Higher level of integration of metadata and contextual data in a semantic manner improves interoperability, which in turn strengthens the uptake of using BIM standards in the construction industry. As industry increasingly relies on semantic technologies for heterogeneous data integration, modelling, and exchange, the need for such alignment becomes even more pressing.

The promise of linked data lies in its ability to query heterogeneous and decentralised datasets. Having procedural and technical data modelled in a linked data framework would allow users to query geometrical, semantic, legal, and procedural information simultaneously. This vision aligns with the European Interoperability Framework (EIF) (European Commission, 2017), which advocates for procedural and organisational interoperability alongside semantic and technical interoperability. This work makes a first step in this direction in the digital construction field.

While ongoing efforts make the geometric and semantic data of built environment assets machine-interpretable and vendor-neutral, a more ambitious future vision involves extending these efforts to legal and procedural frameworks. Modelling and structuring legal and procedural information in OWL would allow establishing semantic connections between technical, regulatory, and procedural data. This integration would facilitate intelligent compliance automation, enhanced decision-making, and improved traceability. This is in line with the SMART standards concept. Specifically, the MNS ontology supports Level 2 (Machine-readable document) and partially Level 3 (Machine-readable content) of the SMART standards, as long as no copyright is infringed (QI Digital, 2025).

```python
from rdflib import Graph, Namespace, URIRef, Literal

def query():
    mns = Namespace("http://example.org/ontology#")
    sto = Namespace("https://w3id.org/i40/sto#")
    BASE = Namespace("http://example.org/data#")

    graph = Graph()
    graph.parse("mns-ontology.rdf", format="xml")
    graph.parse("KnowledgeGraph", format="turtle")

    query_2 = """
    PREFIX mns: <http://example.org/ontology#>
    PREFIX sto: <https://w3id.org/i40/sto#>
    PREFIX base: <http://example.org/data#>

    SELECT DISTINCT ?standard ?number ?title
    WHERE {
      ?standard a sto:standard ;
                mns:hasStandardNumber ?number ;
                mns:hasTitle ?title ;
                mns:EssentiallyRelatedToTopic mns
                    :Data_Dictionary .
      FILTER NOT EXISTS { ?standard mns:relatedToTopic mns
          :Information_Container . }
    }
    """

    results = graph.query(query_2)
    print("Results of query 2:\n")
    for row in results:
        number = row.number.replace("\u2011", "-")
        title = row.title.replace("\u2011", "-")
        print(f"{number};\n{title}")
```

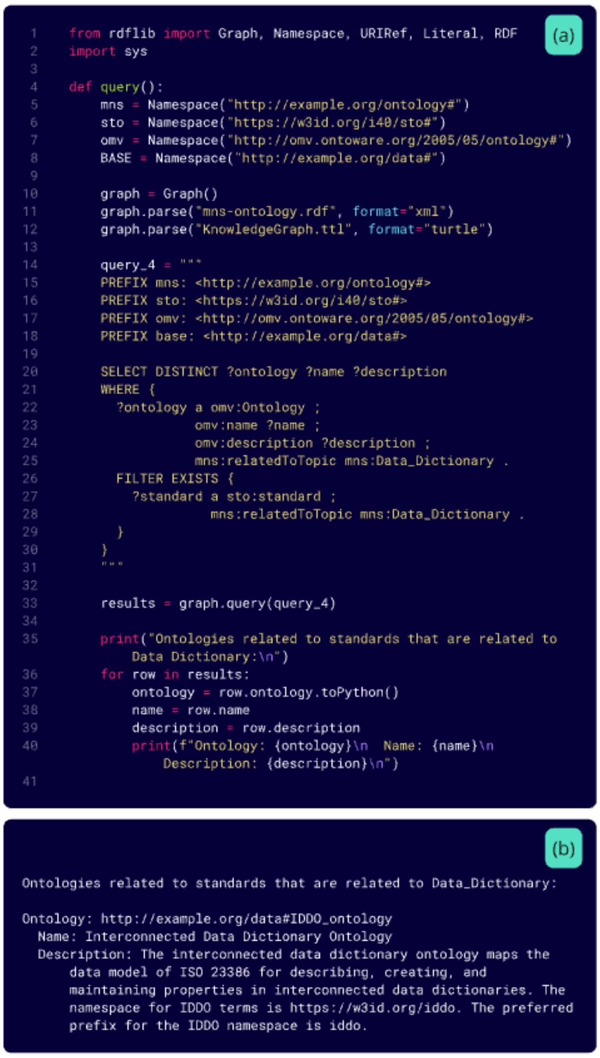
```
Results of query 1:

EN 17549-2;
BIM - Information structure based on EN ISO 16739 1 to exchange data
    templates and data sheets for construction objects Part 2.
    Configurable construction objects and requirements
ISO 23386;
BIM and other digital processes used in construction - Methodology to
    describe, author and maintain properties in interconnected data
    dictionaries
ISO 12006-3;
Building construction - Organization of information about construction
    works - Part 3: Framework for object-oriented information
```

Figure 2: (a) a SPARQL script using RDFLib and (b) the results of query for standards related to various topics

Alignment challenges

Initially, the goal was to reuse the *ssos:StandardReference* class, which comprises the *NormativeReference* and *InformativeReference* subclasses. SSOS acknowledges the normative and informative relationships between documents so does the BIM SLE. However, after initial ontology modelling and through SPARQL queries, it became apparent that the M&S dataset is not well-suited to such class distinctions. For example, ISO 21597-2 references ISO 21597-1, which serves as an informative reference for ISO 21597-2. Conversely, ISO 19650-4 references ISO 21597-1, for which it is considered a normative reference. Thus, one standard may be a normative reference for one document while simultaneously serving as an informative reference for another. When modelled using SSOT, such simultaneous referencing is not possible, which could be attributed to the fact that SSOT was proposed for describing a single standard, not for the relationship between standards documents. To resolve this issue, the MNS ontology was equipped with object property-based relationships, i.e., *mns:normativelyReferences* and *mns:informativelyReference*, which effectively addressed the problem.



```
from rdflib import Graph, Namespace, URIRef, Literal, RDF
import sys

def query():
    mns = Namespace("http://example.org/ontology#")
    sto = Namespace("https://w3id.org/i40/sto#")
    omv = Namespace("http://omv.ontoware.org/2005/05/ontology#")
    BASE = Namespace("http://example.org/data#")

    graph = Graph()
    graph.parse("mns-ontology.rdf", format="xml")
    graph.parse("KnowledgeGraph.ttl", format="turtle")

    query_4 = """
    PREFIX mns: <http://example.org/ontology#>
    PREFIX sto: <https://w3id.org/i40/sto#>
    PREFIX omv: <http://omv.ontoware.org/2005/05/ontology#>
    PREFIX base: <http://example.org/data#>

    SELECT DISTINCT ?ontology ?name ?description
    WHERE {
      ?ontology a omv:Ontology ;
                omv:name ?name ;
                omv:description ?description ;
                mns:relatedToTopic mns:Data_Dictionary .
      FILTER EXISTS {
        ?standard a sto:standard ;
                  mns:relatedToTopic mns:Data_Dictionary .
      }
    }
    """

    results = graph.query(query_4)

    print("Ontologies related to standards that are related to
        Data Dictionary:\n")
    for row in results:
        ontology = row.ontology.toPython()
        name = row.name
        description = row.description
        print(f"Ontology: {ontology}\n  Name: {name}\n
            Description: {description}\n")

```

```
Ontologies related to standards that are related to Data_Dictionary:

Ontology: http://example.org/data#IDDO_ontology
  Name: Interconnected Data Dictionary Ontology
  Description: The interconnected data dictionary ontology maps the
      data model of ISO 23386 for describing, creating, and
      maintaining properties in interconnected data dictionaries. The
      namespace for IDDO terms is https://w3id.org/iddo. The preferred
      prefix for the IDDO namespace is iddo.
```

Figure 3: (a) a SPARQL script using RDFLib and (b) results of a query for ontologies related to standards related to a specific topic

Limitations and future work

Amongst limitations of this study is that the ontology consists of authors' own evaluation that may have introduced some subjectivity. The scope of the ontology is currently BIM SLE standards. Further on, the list of standards used, and evaluation is based on the work of the CEN/TC442 committee. Other BIM standards from other organisations might be added in the future. The current SLE is built with Power BI. In future steps, this work will continue by adding a new tab connecting to the new machine-readable data, thereby making it available for public queries.

This effort, although primarily focused on ISO and CEN standards, can later be extended to and adopted by national standardisation bodies. By linking international and national standards through linked data and enabling reasoning capabilities via the resulting knowledge graph, a more context-aware standards ecosystem can be achieved. This allows the knowledge graph to support reasoning over applicability, e.g., inferring whether a given standard is valid or recommended within a specific country, sector, or project phase or has a national variant. Such reasoning can also account for language requirements or regional adaptations. These capabilities significantly strengthen the motivation for developing knowledge graphs in this context: not only to structure metadata, but also to enable intelligent queries.

Finally, the connection made between topic, domain, ontologies and standards through the alignment of SSOS, STO, OMV ontologies and the proposed MNS ontology set the scene to connect the content of the BIM Standards Landscape Explorer to the newly developed Built Environment Lookup Service (BE-OLS) that is also developed by the M&S committee.

Conclusions

While the importance of standards for the digitalisation of the construction industry is widely acknowledged, their adoption among practitioners remains low. The BIM SLE is an openly available online tool that enhances the discoverability of BIM and digital construction standards, offers customised insights, better visibility, and a foundational understanding for construction professionals. Despite these advancements, the dataset connected to the tool is static and not machine-interpretable, which limits external access and querying across heterogenous data. This paper presents an ontology developed for BIM standards' metadata and specific BIM SLE analysis and a step towards greater interoperability and SMART standards in the built environment. However, additional barriers significantly hinder access for the target audience, such as standards unavailable in native languages, often having complex content, structure, and high cost. The increasing volume of published standards could be better used through improved search options and more efficient connections to end-users.

Acknowledgments

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