CONSTRUCTION
ROBOTICS

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ORCHESTRA
A first Marketplace Concept for Collaborative Data Sharing

An ontology-driven information network for cross-company collaboration in the production chains of construction industry

Content

1 Abstract and Introduction

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Abstract

The construction industry is complex and constantly evolving, relying on effective resource management at construction sites. Effective information sharing in the construction industry can be likened to navigating a large marketplace. The semantic web is a promising approach to data exchange. This work explores how data needs and outputs in various use cases can be expressed by applying the extended Internet of Construction (IoC) ontology. The general usage scenarios are analysed in detail to outline the specific data inputs required for each process step. The practical applicability is demonstrated through an illustrative example.

1. Introduction

Researchers (e.g., Vrijhoef and Koskela (2000)) have observed that the construction sector tends to lag behind other industries in terms of productivity. The construction industry's complexity and dynamic nature—characterized by the need for effective on-site resource coordination present distinct challenges to improving efficiency. Unlike more standardized industries, construction often involves unique, project-specific conditions and fragmented stakeholder involvement, which complicate efforts to streamline processes.
Orchestra is a research-driven initiative demonstrating practical solutions for data exchange in the construction sector. It addresses the challenge by involving companies that play different roles in construction projects, such as construction companies, manufacturers of material transport systems (e.g., lifts), and providers of surveying and quality control technologies.
The conceptual model of effective information exchange in the construction industry can be compared to navigating a marketplace. In this marketplace, various stalls offer a wide range of information. However, it can be challenging to identify what is available, compare different offers, or determine whether they provide additional value.
Different partners provide distinct types of information regarding a construction site. While some of this information is shared, other details may remain inaccessible or unknown to relevant stakeholders. Successful collaboration relies on a shared understanding and a standardized method for describing and exchanging information.
The model for this information exchange can be visualized as illustrated in Figure 1. In this model, each participant in a construction project has a designated „stand," similar to a marketplace, where they can showcase their information and access information shared by others. The foundation of this collaboration is the use of a common language and adherence to standardized descriptions of the shared data.

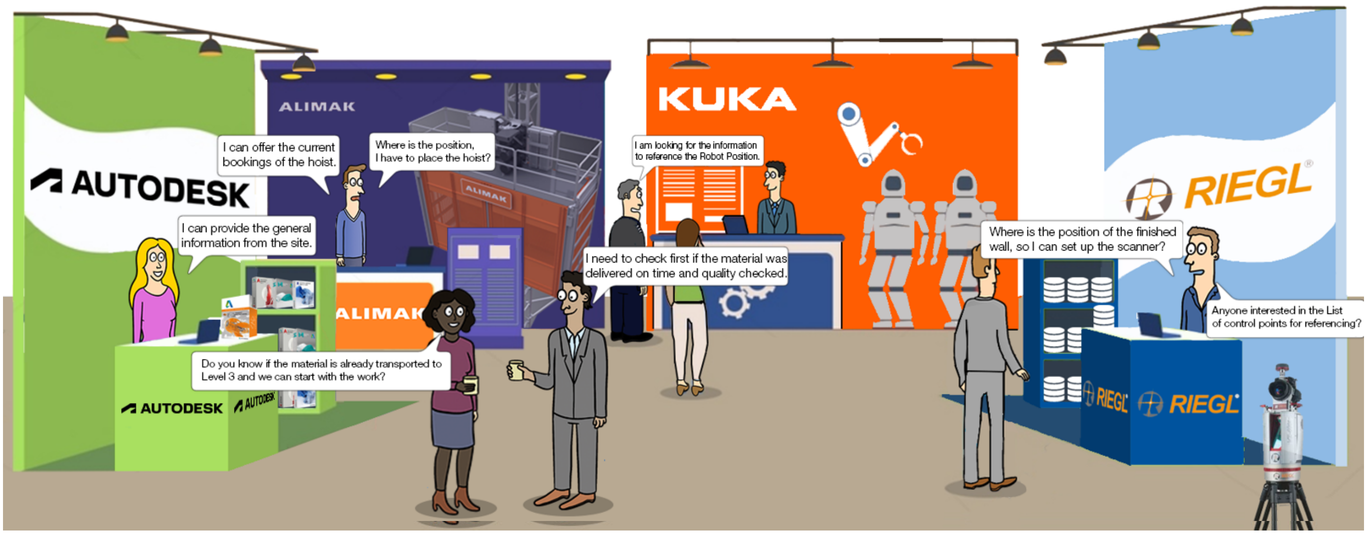

Figure 1: A conceptual model for information exchange visualised as a marketplace

Orchestra aims to establish an open, standardised, and secure framework for information sharing among project stakeholders. By creating a transparent and accessible structure, the objective is to facilitate seamless collaboration, allowing participants to easily locate, share, and integrate the data required for successful project execution.
The Semantic Web presents a promising approach for data exchange. Ontologies provide a framework for defining and standardizing common concepts within the construction industry. By using ontologies, different systems and applications can seamlessly interoperate, sharing a common vocabulary and data structure. The Semantic Web allows for data integration from diverse sources using the formats and protocols set by the World Wide Web Consortium (W3C). This facilitates the aggregation of data from various vendors and stakeholders into a cohesive and accessible format.
The Linked Data principles of the Semantic Web encourage the creation of a network of interconnected data. Additionally, these technologies enable data to be enriched with metadata, making it easier to search for and retrieve relevant information. This enhances discoverability, provides context, and eliminates data silos—isolated repositories of information that hinder collaboration and data sharing, which are often found in proprietary software.
It also improves data management, fosters knowledge discovery, and boosts interoperability. Moreover, the provenance of the information is clear.
The results and developments of the project are based on a consortium effort. This project is connected to a comprehensive overall process chain that aims to streamline the definition of information exchange within a scenario where the technologies and data of the project partners are integrated. Figure 2 illustrates this process.

Figure 2: Use Scenario Overview

The project aimed to establish a comprehensive framework for requirements gathering and information sharing. It began with the identification of key stakeholders, along with a clear definition of their roles and needs. Subsequently, general use scenarios were analyzed to determine the specific data inputs and outputs required at each stage of the process. These workflows, information pathways, and associated requirements were further refined through empirical analysis and close collaboration with project partners.

2 State of the Art

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2.1 Existing standards for Exchange Requirements

Existing standards such as PEPPOL (Pan-European Public Procurement Online), BEAST (Building Energy Asset Specification Template), and the Exchange Information Requirements (EIR) defined in ISO 19650 (International Organization for Standardization 2018) provide frameworks for structuring and exchanging information in various domains. PEPPOL standardises electronic procurement processes and enables seamless cross-border e-invoicing and procurement communication. BEAST focuses on defining specifications for building energy systems to improve interoperability and efficiency in Building Information Modelling (BIM). As outlined in ISO 19650, EIR specifies the information required to manage projects and assets throughout their lifecycle, ensuring clarity and consistency in BIM processes. Although these standards effectively define and communicate exchange requirements, they are limited in scope when capturing and describing the dynamic capabilities of machinery or processes. These frameworks lack the flexibility and granularity required to represent machine-specific capabilities, configurations, and interactions in a detailed, interoperable manner. To bridge this gap, ontologies can be applied as a formal approach to modelling and representing processes. They provide a structured way to define machine capabilities, contextual relationships, and workflows, supporting a more robust and adaptive integration of machine data into broader information ecosystems.

In addition, adherence to the principles of FAIR (Findable, Accessible, Interoperable, Reusable) (Wilkinson et al. 2016) is essential to ensure that data can be effectively shared, discovered, and reused between systems and domains. Ontologies directly support these principles by providing a semantic structure that enhances discoverability, ensures compatibility between systems, and facilitates the reuse of information in different contexts.

2.2 Linked Data

Linked Building Data (LBD) involves publishing building-related information as Linked Data (Curry et al. 2013; Pauwels, McGlinn, et al. 2018) and using it in architecture, engineering, and construction applications. One core aspect is following the Linked Data principles introduced by Tim Berners-Lee in 2009 (Bizer, Heath, and Berners-Lee 2009). At its core, these principles advocate for using uniform resource identifiers (URIs)(Berners-Lee, Fielding, and Masinter 2005) as unambiguous identifiers for objects, and that meaningful information should be available when a URI is accessed. The use of standards of the World Wide Web Consortium (W3C), such as the Resource Description Framework (RDF) (Lassila, Swick, et al. 1998), is encouraged. In addition, links to other related URIs should be included to facilitate further exploration.

On construction sites, data sharing typically relies on a Common Data Environment (CDE), which centralizes project information and ensures that all stakeholders access consistent data. When linked data principles are applied, ontologies provide the semantic foundation that enables consistent interpretation, reduces misunderstandings, and improves the findability of relevant data across interconnected systems.

An ontology is a formal and explicit specification of a shared conceptualization that defines the types, properties, and interrelationships of concepts within a specific knowledge domain. Ontologies consist of classes that represent entities, properties that describe features or relationships, and individuals that are specific instances of those classes. By providing a common framework, ontologies facilitate the sharing, integration, and reuse of data across various applications and domains, ensuring consistency in how data is interpreted. This structured approach enhances data interoperability, making it easier to query, infer, and analyze information.

A key ontology in the building information domain is ifcOWL (Beetz, Van Leeuwen, and De Vries 2009; Pauwels and Berlo 2019; Pauwels and Terkaj 2016). IfcOWL is an ontology version of the Industry Foundation Classes (IFC), a standard for describing data exchange schemas intended for the architectural, building, and construction industries. However, the Linked Building Data Community Group, part of the World Wide Web Consortium (W3C), emphasises developing a more modular approach to improve data accessibility. It has created and maintained several ontologies, including the Building Topology Ontology (BOT), the Product Ontology (PRODUCT), the Properties Ontology (PROPS), and the Geometry Ontology (GEOM).

Ontologies crafted to delineate construction workflows exist. On the one hand, the Construction Tasks Ontology (CTO) exemplifies the tasks inherent in construction projects, such as installation, removal, modification, inspection, and repair. These tasks may be applied to elements, spatial zones, or damages (Bonduel 2021). On the other hand, the Digital Construction Ontologies (DiCon) (Zheng, Törmä, and Seppänen 2021) depict information on construction workflows within the realm of digital construction to address the challenge of information heterogeneity. It was conceived through a hybrid methodology and comprises six modules. They are Entities, Processes, Information, Agents, Variables, and Contexts.

Moreover, Benevolenskiy (2016) advocated using ontologies to depict construction processes. His work provides a general overview of the automatic generation of rudimentary construction processes utilizing existing building models.
Conversely, Roos (2020) builds upon Benevolenskiy's foundational research by introducing a semantic, knowledge-based framework for construction process modeling. Roos advances the methodology by decomposing complex construction workflows into smaller, logically inferred subprocesses using domain-specific ontologies and rule-based reasoning. This approach is designed to assist human planners by automatically generating coherent construction sequences, thereby reducing manual effort and improving planning consistency. Importantly, Roos's system focuses on structural and procedural organization rather than operational execution—it deliberately omits execution-level data such as resource allocations, durations, or cost parameters.
Kirner, Wildemann, and Brell-Cokcan (2024) devised the IoC Ontology, which has been disseminated as VDI-EE 2558 (VDI 2023). This ontology is a template for modelling diverse construction processes that require execution. Kirner et al. delineate construction processes by specifying relevant inputs, outputs, and other relevant information associated with the respective actors and resources. That aspect makes it the most suitable candidate to describe dynamic data exchange scenarios.

3 Ontology Development

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In this work, we have followed the general principles of the Methontology methodology described by Gomez-Perez, Corcho, and Fernández-López (2004) and Keet (2018). It follows an waterfall-type method with five steps: (1) defining the purpose, intended uses, and users of the ontology; (2) conceptualisation of the ideas using intermediate text like use cases or diagram representations; (3) Formalisation; (4) Implementation using an ontology language, and (5) fixing the model by feedback. In the first phase, we focused on creating a preliminary ontology for the express knowledge of the stakeholders using the following steps:

1. In collaborative workshops with experts, the use cases were detailed.

2. Specific scenarios, key concepts, and the relationships they envision were documented.

3. The use cases to identify common concepts and relationships were analysed.

4. Based on the common concepts, create a preliminary version of the ontology. For this, we used Chowlk Visual Notation for ontology conceptualisation (Poveda-Villalón et al. 2024) to visualise the created ontology in a standard way.

5. Generalising the idea to reflect the concept of the marketplace.

3.1 Defining the Ontology

To develop a suitable knowledge base, we followed the guidelines outlined in Ontology101 by Noy and McGuinness (2001). As the guide outlines, the first step in the iterative process is to clarify the ontology's focus and scope by answering four specific questions related to its scope (SQ).

SQ1 **What is the domain that is covered?**
The ontology domain defines information exchanges in construction site processes.

SQ2 **What kind of questions should it be able to answer?**
It should help answer questions such as what data or device capabilities a stakeholder offers, the process's perquisites, and what it produces.

SQ3 **Who will use and maintain the ontology?**
Construction companies should utilise the ontology to outline the processes and the available datasets, while machine manufacturers should apply it to describe available data or capabilities.

3.2 Conceptualisation of the ideas using Use cases

In line with the Kendall and McGuinness methodology (ElHassouni and Qadi 2021), we have collected a set of use cases to capture what is needed from the to-be-created ontology in terms of domain knowledge. Creating ontologies begins with a description of the specific use cases (US) illustrated in Figure 2 and explained as follows.

US1 **Material Delivery:** Construction material is delivered to the site and undergoes an inspection to ensure quality and compliance with the project specifications. Once checked, the material is stored on site. The task involving the material is then scheduled with the overall project timeline and linked with a specific construction process.

US2 **Transport Material from Storage to Hoist:** The task allocation system receives a transportation task that prompts the robot to navigate from its parking position to the storage area. A human then loads the material onto the robot, and once it is confirmed that the material is loaded, the robot automatically navigates from the storage spot to a hoist.

US3 **Hoist Transport:** The transportation robot, tasked with moving materials, communicates with the hoist to transport it to the ground floor. Upon arrival, the robot's identifier is verified, allowing it to enter the hoist. Considering the size and weight limitations, the robot enters the hoist. Once inside, the material is transported to the designated floor. Upon reaching the destination, the robot leaves the hoist.

US4 **Transport from hoist to Installation Spot:** The transportation robot begins the process by locating itself relative to the floor's plan to transport material from the hoist to the installation spot or associated storage location on the level. It performs path planning using existing knowledge or sensing of dynamic and static obstacles and carrier information. Once the path is determined, the material is transported from the hoist to the destined location. Finally, once the material has arrived at the goal position, the system sends confirmation that the position has been achieved.

US5 **Robotic Installation:** The robot installation begins with defining its position in the designated area. It then plans the movement of its arm to pick up and place an element accurately. Once the plan is set, the robot is placed in the installation spot. The operation time is defined, and the operation begins. The work is done, potentially with human assistance, to fix it as needed. Finally, the operation is completed, and the task allocation system is notified that the operation has been completed.

US6 **Scanning:** The scanning work scenario consists of four key steps: Setting up control points, measuring control points, setting up the scanner, and taking the scan. In the first step, control points are defined using random, non-perfect grid placements to ensure redundancy. Next, these points are measured with a Total Station, a surveying instrument used for land measurement and construction. The scanner is then set up by defining scan areas, specifying restricted zones, and configuring scanner details. Finally, the scanning process generates point cloud data in formats such as PLY, LAS, or other formats, which will be taken as input for the as-built comparison with the BIM model of the scanned structure.

US7 **As-Build Comparison:** In the use case of an as-built comparison, the process begins with aligning the coordinate system of the BIM model with the created point cloud. Once alignment is achieved, suitable software is selected to facilitate comparison work. The next step involves conducting an analysis comparing the BIM model with the point cloud to identify discrepancies or deviations. Finally, the results of this analysis are exported for further review and decisionmaking.

3.3 Formalisation of the ideas using diagrams and competency questions

The main actors, actions, required inputs, and expected outcomes were identified by analyzing the use cases. The use case was then broken down into specific tasks and processes, key concepts and relationships were pinpointed, and questions that needed to be answered to address them were considered.
Fifteen processes were recognised. Together with domain experts, the required input data and the corresponding output data were defined for each process. This groundwork is the foundation for determining the ontologies discussed in the following chapter. The input/output requirements for US6 and US7 are shown in Table 1.

Task	Details	Input Information	Output Information	Status Options
Set Up Control Points	Define a random, non-perfect grid for redundancy.	Coordinates, Date, Time	Date	Not started, In progress, Finished
Measure Control Points	Use Total Station to measure based on control points.	Type of Machine, Definition COS	List of control points (CSV), Date	Not started, In progress, Finished
Set Up Scanner	Define scanning area and set up scanner	Coordinates, Scanner Type	Scanning position list, Date	Not started, In progress, Finished
Take Scan	Perform scans, generate point clouds	Scanning Instructions	Point Cloud File (PLY/LAS, etc.), Date	Not started, In progress, Finished
As-built Comparison	Comparison of BIM model & as-built	Point Cloud, BIM Model, Software for comparisons, Aligned COS	Deviations (Head Map), Report, Clash Detection	Not started, In progress, Finished

Table 1: Required Information for Scanning & as-built Comparison

For the definition shown, the associated ontology competency questions would be for the Set up control points task:

1. Input Information:
   - What coordinates define the control points? Ficiet ad et omnihil modi temporent.
   - What is the planned date and time for setting up control points?

2. Output Information:
   - When the control points were set?

3. Status Options
   - What is the current status of the task?

Imagine a scenario where a technician is setting up control points in a new area. They need to input the coordinates of each control point, specify the date and time of the setup, and monitor and update the status of the setup task from 'Not started' to 'Finished'. The ontology must be able to represent these details to support the technician effectively. The other tasks and use cases are handled similarly.

3.3.1 First visual representation

Figure 3 illustrates the connections between each process, the related material, the building element, and the BIM model. Different colours in the figure highlight the used ontologies. The prefixes for the Building Topology Ontology (BOT), the Built Element Ontology (BEO), and the Internet of Construction Process Ontology (IoC) are defined in prefix.cc[1].

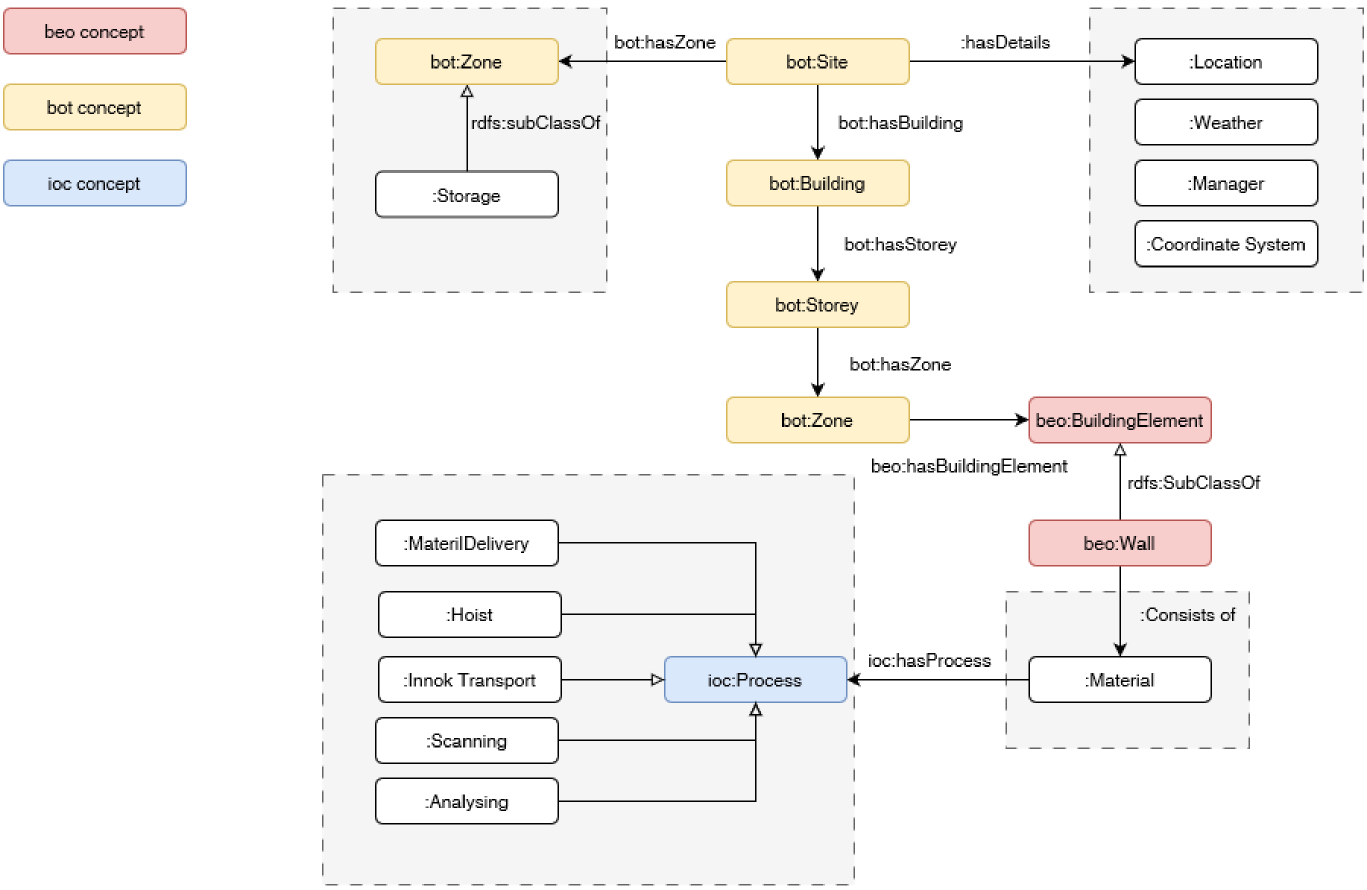


Figure 3: First visual representation

[1] https://prefix.cc/

3.4 Implementation of the ontology for the use cases

Consider an automated trading system „selling" data and offers that specify the clients' required information. If you think of a knowledge system, the basic questions that people would like to be able to find answers to are:

1. What data are available for processes?

2. What are the required data for process X?

Here, we have selected to detail the Material Delivery (US1), Scanning (US6), and As-Build Comparison (US7) use scenarios. Considering the use cases listed in Section 3.2, we applied the principle of reusing existing ontology resources, as detailed in NeOn Scenario 4 for building networks of ontologies (Gómez-Pérez and Suárez-Figueroa 2008). We have used the Internet of Construction Process Ontology (IoC) (Lukas Kirner and Brell-Cokcan 2024) and selected the relevant classes and properties that express the information exchange of a process. That was used to create an ontology pattern for a generic information exchange shown in Figure 4. The ioc:isvalid property denotes the input's current value if there are many. Then, using that pattern, we created sub-ontologies that describe the cases in selected use scenarios. The detailed Material Delivery is shown in Figures 6 and 7. In blue are shown data that is hosted by the provider and can be accessed only with the necessary access rights.
For the Scanning and As-Built Comparison use scenarios, the sub-ontologies of the processes Setup Control Points, Scan, Map Control Points, and As-Built Comparison were crafted as shown in Figures 8, 9, and 10. The crafting was based on the initial work on finding processes and their needed inputs and producing outputs as shown in Section 3.3.
The sub-ontologies share elements, which makes it possible for the processes to use the output of the other processes. They are shown separately to emphasise the idea that the sequence of operations scenario is an example, and that the core concept of the marketplace is to enable the making of new matches of offerings and needs.

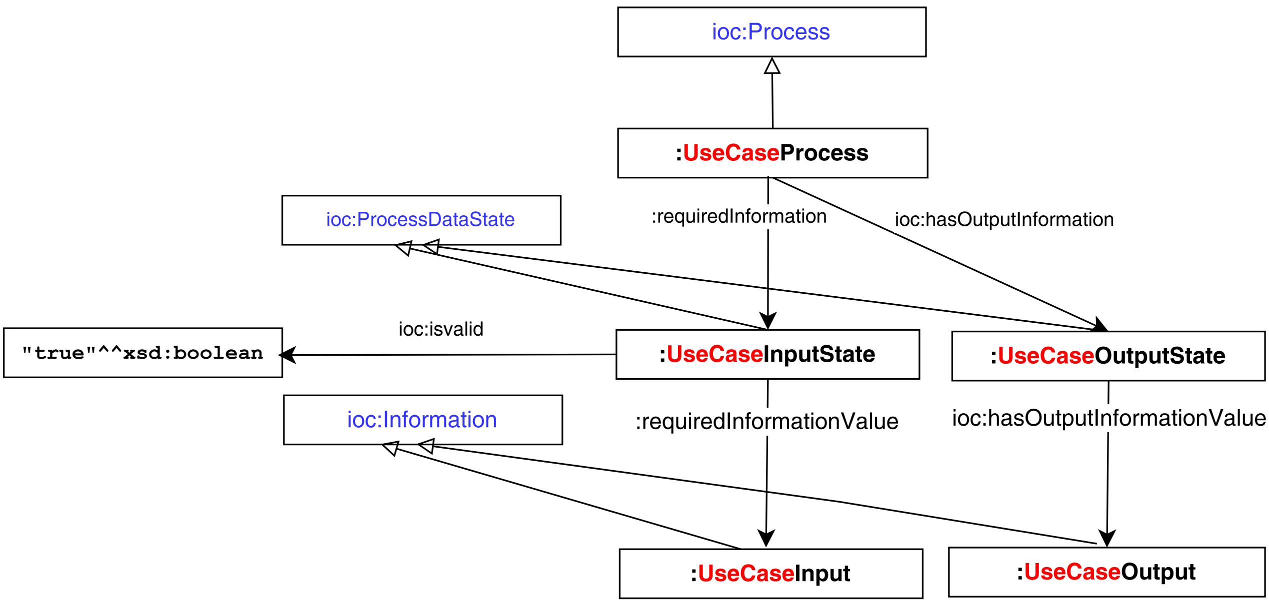
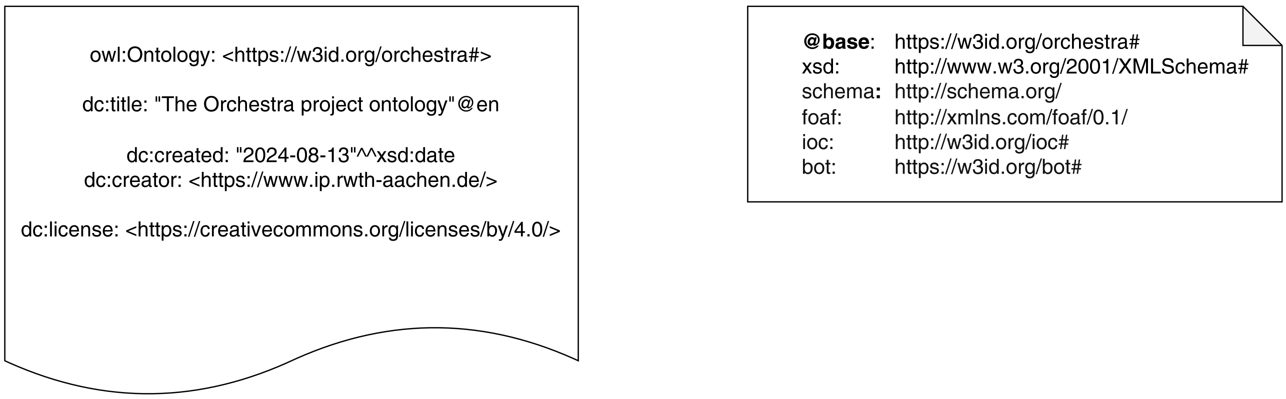


Figure 4: The general IoC ontology pattern.



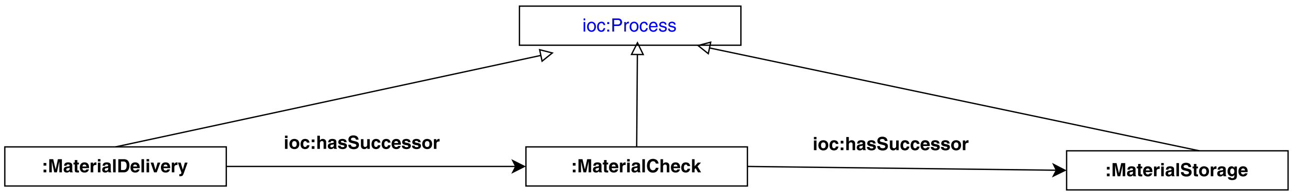


Figure 5: Ontology Sketch Material Delivery Overview

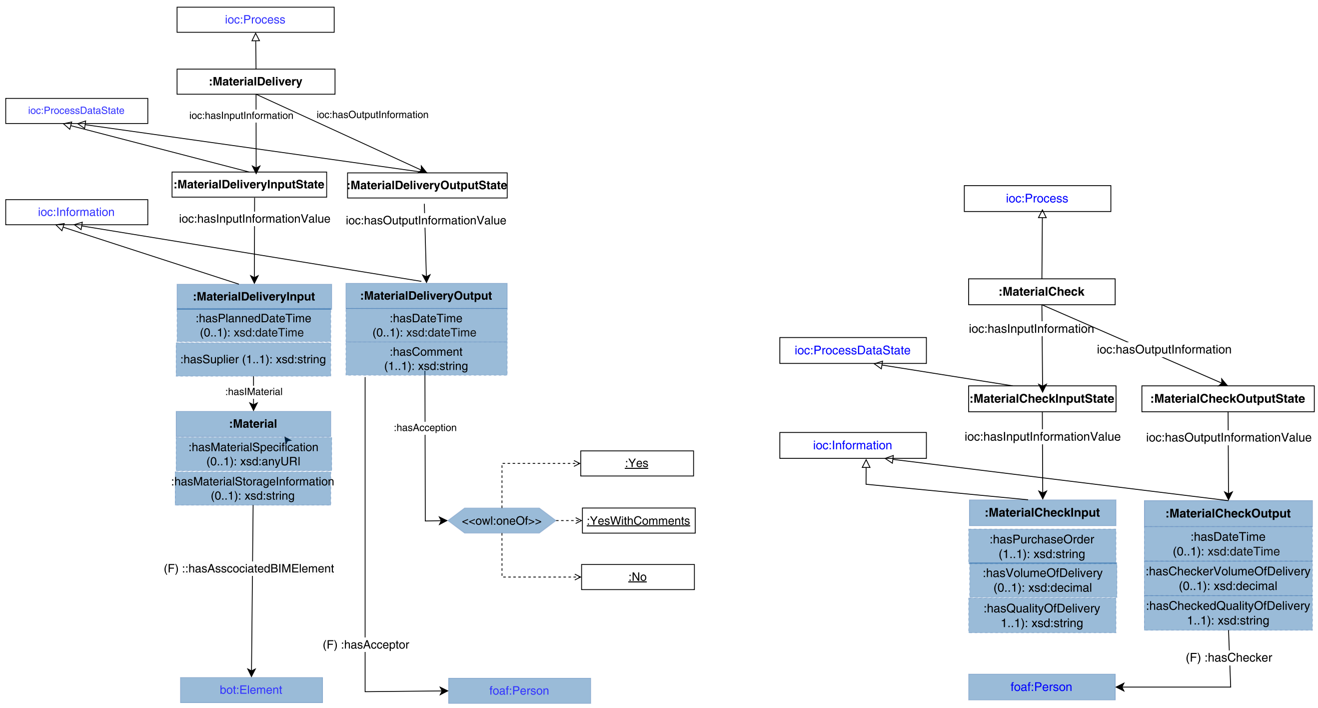


Figure 6: The detailed sub ontologies for the material delivery 1/2

[1] https://prefix.cc/

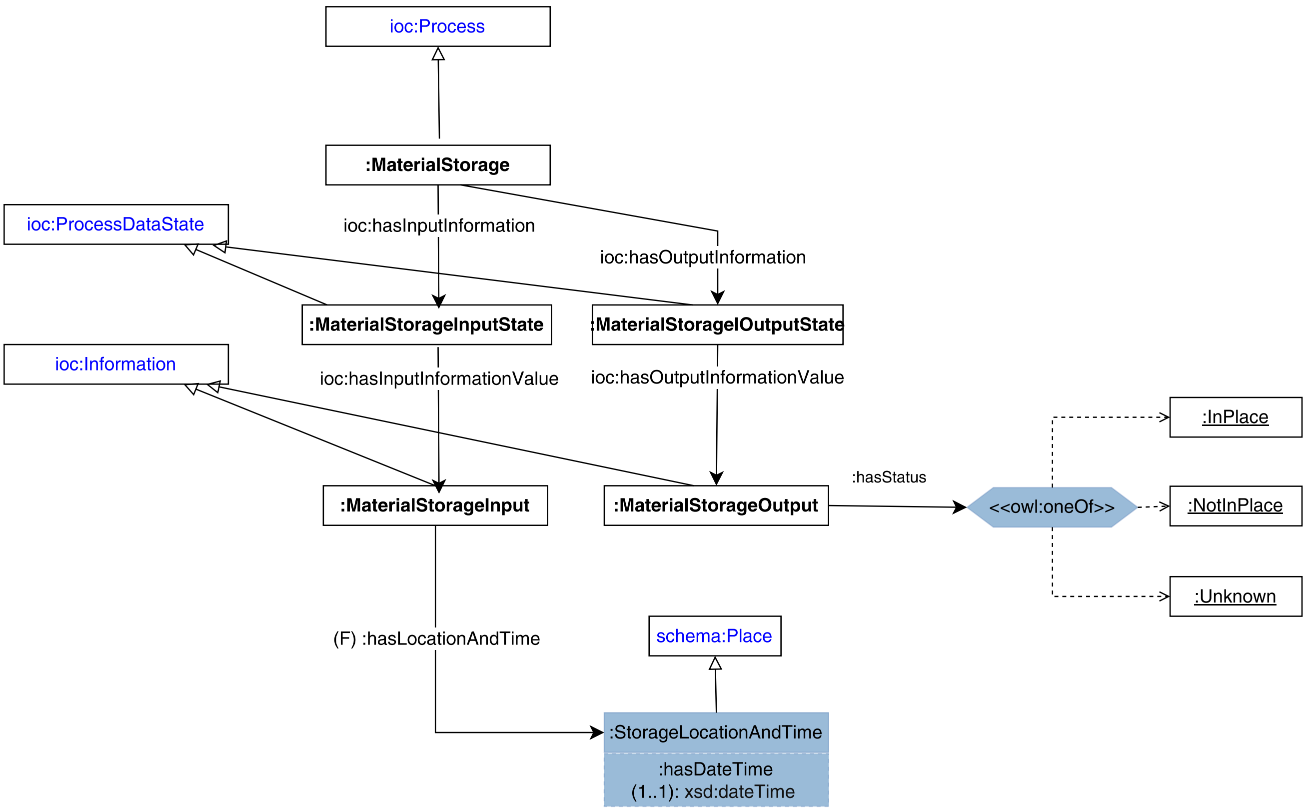


Figure 7: The detailed sub ontologies for the material delivery 2/2

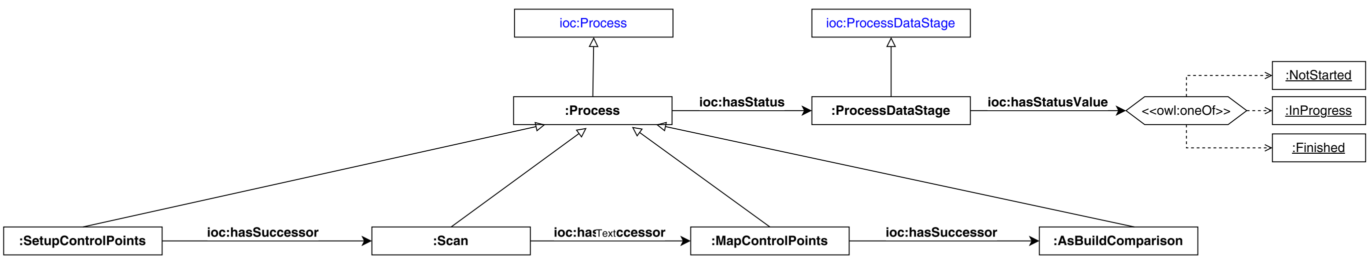


Figure 8: Ontology for the scan use scenario

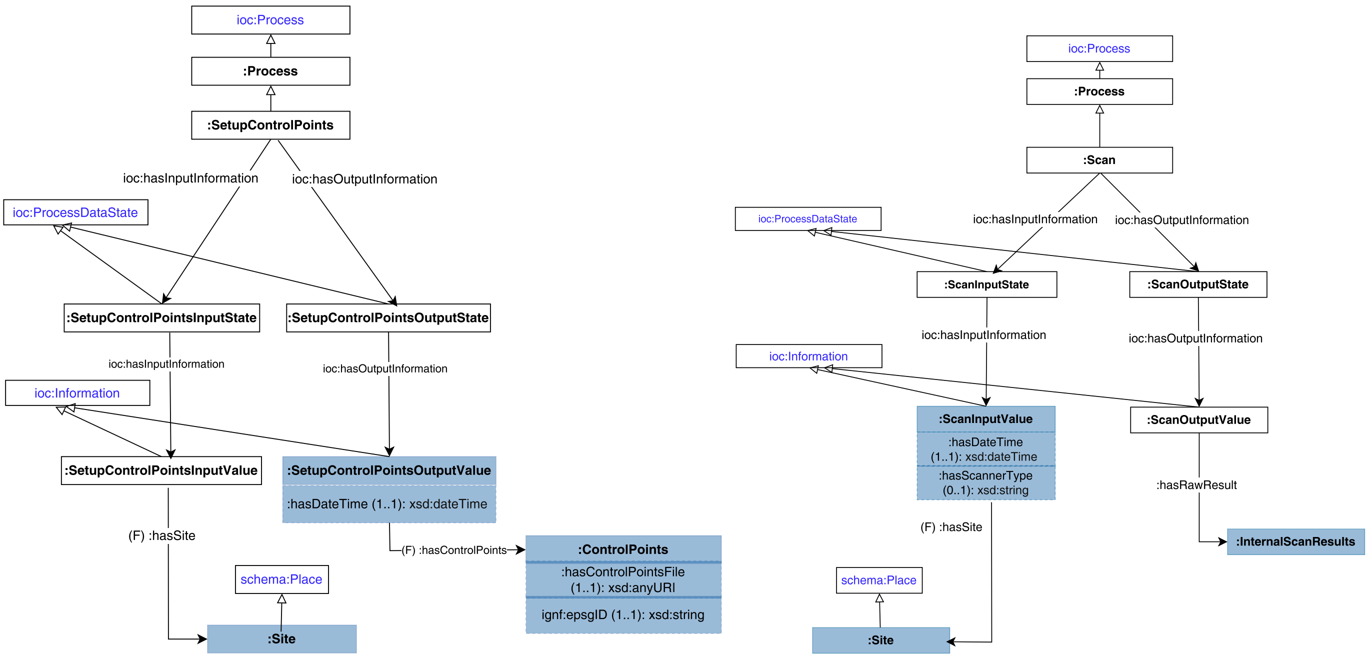


Figure 9: The detailed sub ontologies for the scan 1/2

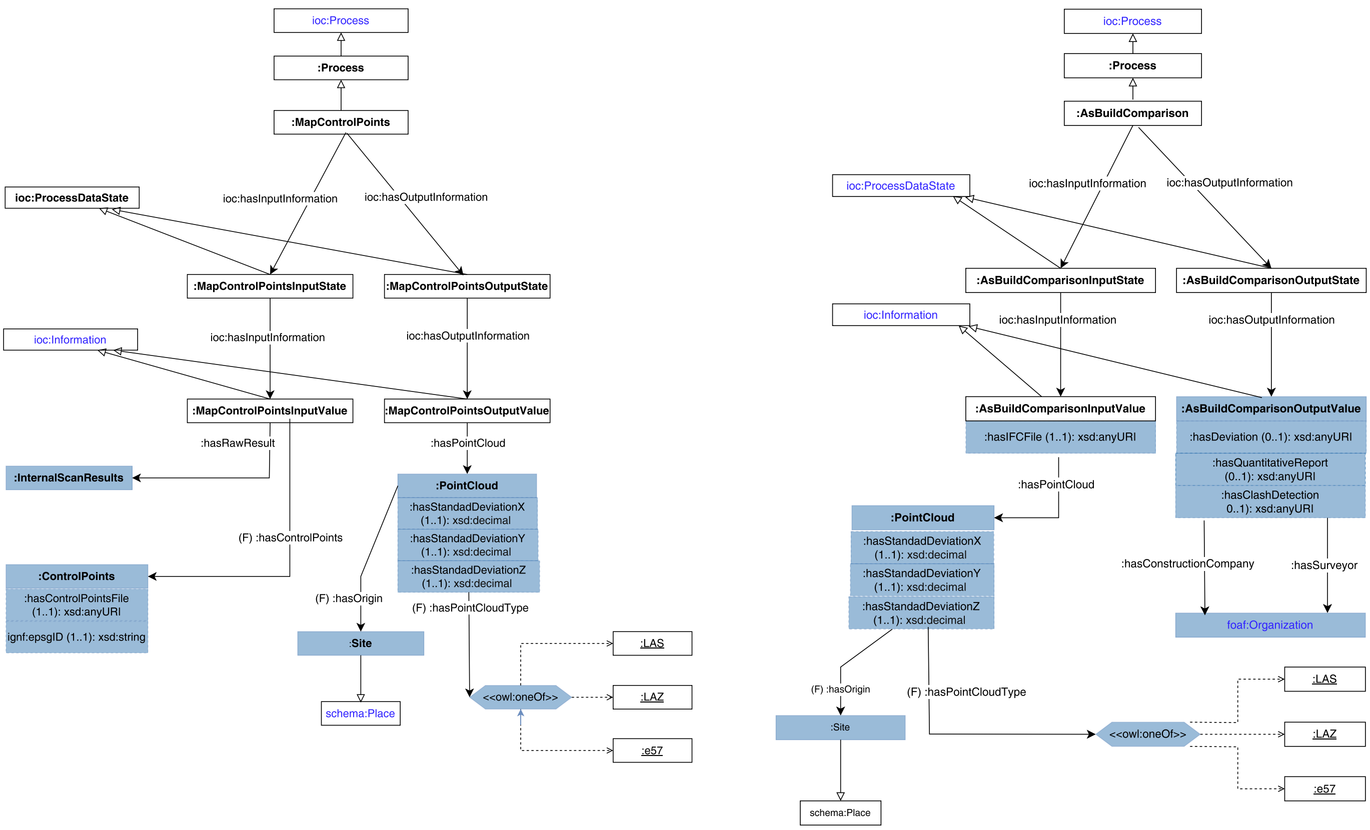


Figure 10: The detailed sub ontologies for the scan 2/2

4 Application Study

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As described above, the approach and practical applicability of the developed framework are illustrated through an example in Figure 11. Following the scenarios presented in this paper, the application demonstrates a material transport process on site.

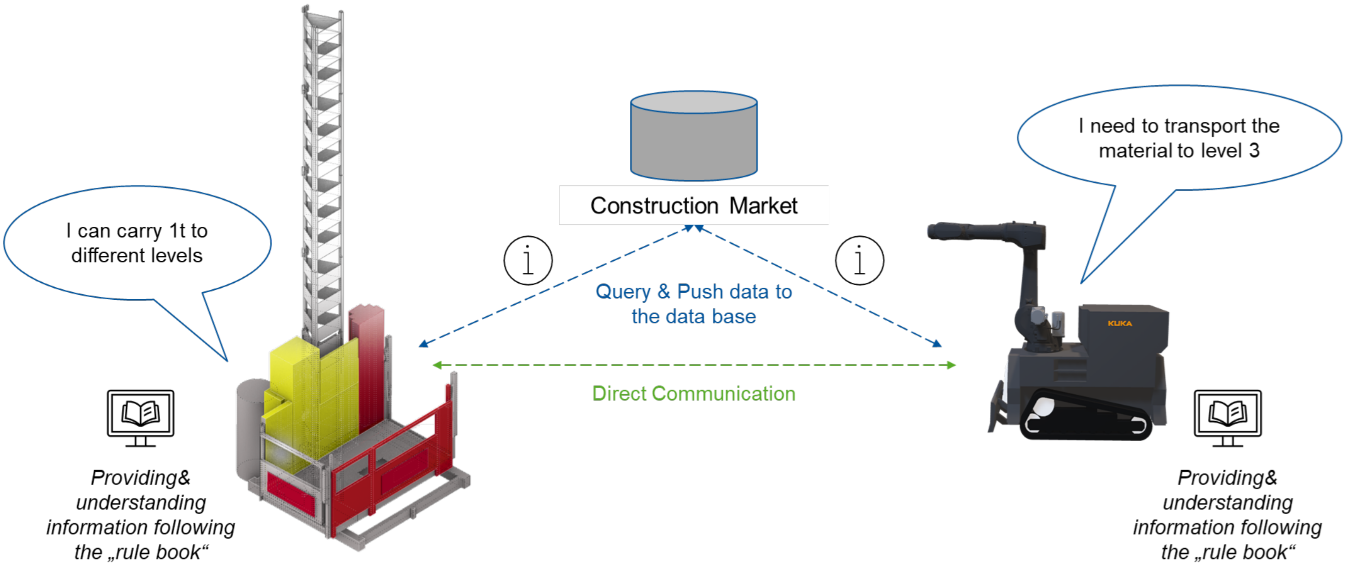

Figure 11: Sketch of Illustrative Example

A lift and a mobile robot are available on-site to assist with the task. The robot must use the lift to transport the loaded material to the designated floor. Communication occurs between the two machines to facilitate this process. This communication depends on a standardised description of the information that each machine can provide. This includes predefined data such as name, manufacturer, and capacities or loads, as well as dynamic data such as current load status or location. The following sections provide a technical backend description of the case study. The process and information are machine- and human-readable.
The general ontology pattern for capability matching is shown in Figure 12. In it, we have on the left the description for the requirements, and on the right, an ontology pattern for a service provider. Figure 13 shows how the pattern can be used to create a sub-ontology that describes the capabilities of an elevator. The following section shows how this can be instantiated.

4.1 Machine Capability Description

We promote semantic consistency and improve integration with other systems by utilising established ontologies such as FOAF (Friend of a Friend)2 and QUDT (Quantities, Units, Dimensions, and Types)3. The FOAF ontology describes people, their activities, and their relationships with other people and objects. In contrast, the QUDT ontologies provide a way to represent measurable quantities, units of measure, and their dimensions.
Listing 1 outlines an elevator system used within a building. The class ':Elevator' is a system designed to transport people or goods between floors and is associated with the term "elevator." A specific instance, ':Elevator1', represents an elevator named „ALIMAK SC" with several attributes: it operates on multiple floors, including ':floor1', as well as floors 0, 1, and 2; it has a maximum weight capacity of 1,000 kilograms, specified using the QUDT ontology for standardized units; and it is produced by ':ProducerA', an organization identified as „Alimak," described using the FOAF ontology.

[2] http://xmlns.com/foaf/spec/
[3] https://www.qudt.org/

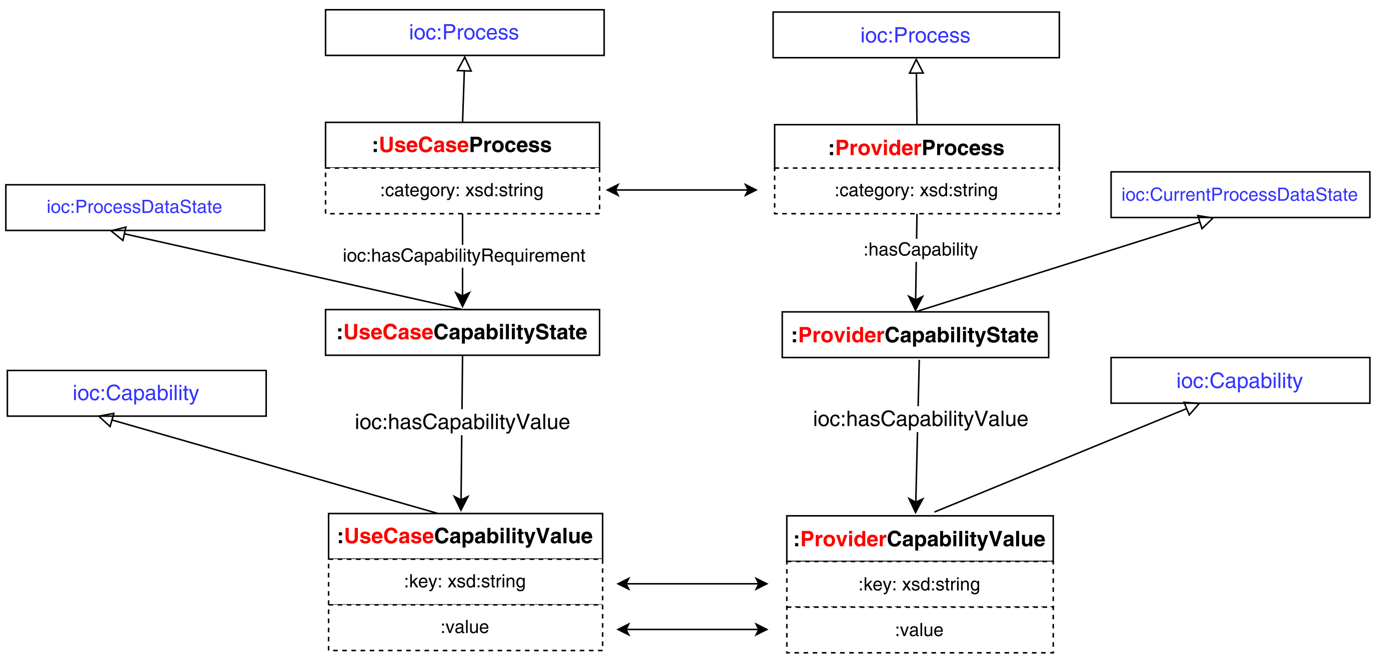

Figure 12: The general IoC capability match ontology pattern.

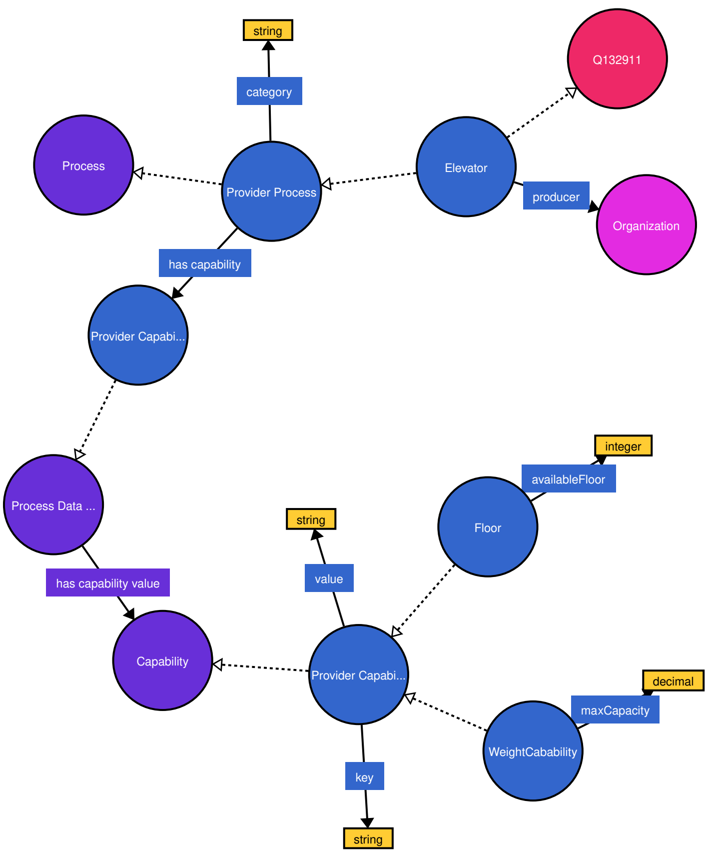

Figure 13: The capability ontology for an elevator.

```
:ProducerA a foaf:Organization ;
    foaf:name "Alimak" .
:elevator1 a :Elevator ;
    rdfs:label "ALIMAK SC" ;
    :producer :ProducerA ;
    :category "Elevator" ;
   :hasCapability :elevator1_cabability_state1 .

:elevator1_cabability_state1 a ioc:CurrentProcessDataState ;
        ioc:hasCapabilityValue :available_floor0 ,
        :available_floor1, :available_floor2, :max_capacity1 .


:available_floor0 a ioc:Capability;
    :key "floor" ;
    :value 0 .
:available_floor1 a ioc:Capability;
    :key "floor" ;
    :value 1 .
:available_floor2 a ioc:Capability;
    :key "floor" ;
    :value 2 .

:max_capacity1 a ioc:Capability;
    :key "max weight" ;
    :value [
        qudt:Unit qudt:KiloGM ;
        qudt:numericValue 1000
    ] .
```

Listing 1: The instance description of the elevators on a construction site.

4.2 Query
4.2.1 Traditional Semantic Queries

The query in Figure 14 retrieves the names of elevators associated with the category keyword „elevator“ and can go from the ground floor to the second floor. The query identifies the provider using the category „Elevator“ and then filters out the results with the capabilities. The query provides a URL to find more information, such as instructions on operating the elevator. That is located at the provider's end and secured by them.

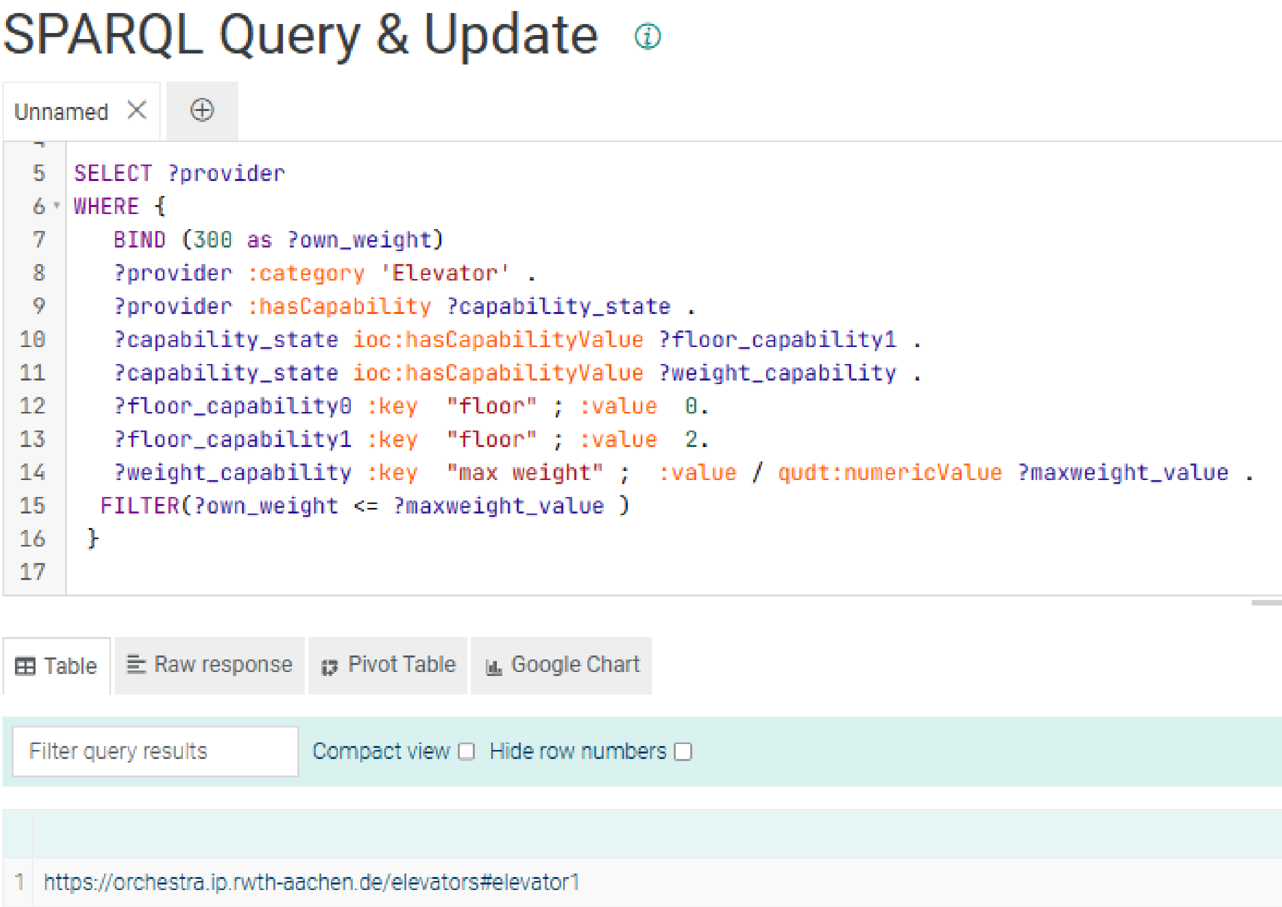

Figure 14: The query by category keywords.

Then, a suitable provider can also be found using the global Wikidata taxonomy. The beginning of the same query would look as shown in Listing 2.

```
SELECT ?provider
WHERE {
   BIND (300 as ?own_weight)
   ?provider a ?providerclass.
   ?providerclass rdfs:subClassOf <https://www.wikidata.org/wiki/Q132911>.
   ...
```

Listing 2: The example query for the suitable elevator.

4.2.2 The Use of Natural Language Processing

Besides a SPARQL query (or any graph query), natural language processing (NLP) can match the provided ontology or data. One way is to create a similarity index for comments or literals. Information retrieval utilises the semantic similarity between a given sentence and the information sought. Such methods are latent semantic analysis (LSA) and Random Projection, where vectors representing sentences are pinpointed in a multidimensional space and then projected onto smaller dimensions. Alternatively, trained neural networks such as BERT or all-MiniLM-L6-v2 can transform texts into vectors that reflect their semantic meaning. Random Projection is available in GraphDB[4] using the indexing of the Semantic Similarity Searches plugin.

For the application study, we created a similarity index using the similarity plugin of GraphDB, as shown in Listing 3. The query in Figure 15 shows how a user-given piece of text can be used to query a service provider using the semantic index. This proof of concept shows that it is possible to implement simple marketplace matching using verbal and inexact descriptions of the needs expressed by a user. Still, a robot can also use it for a fuzzy search.

```
SELECT ?documentID ?documentText {
  ?documentID rdfs:comment ?documentText .
}
```

Listing 3: The query to create the semantic similarity index.

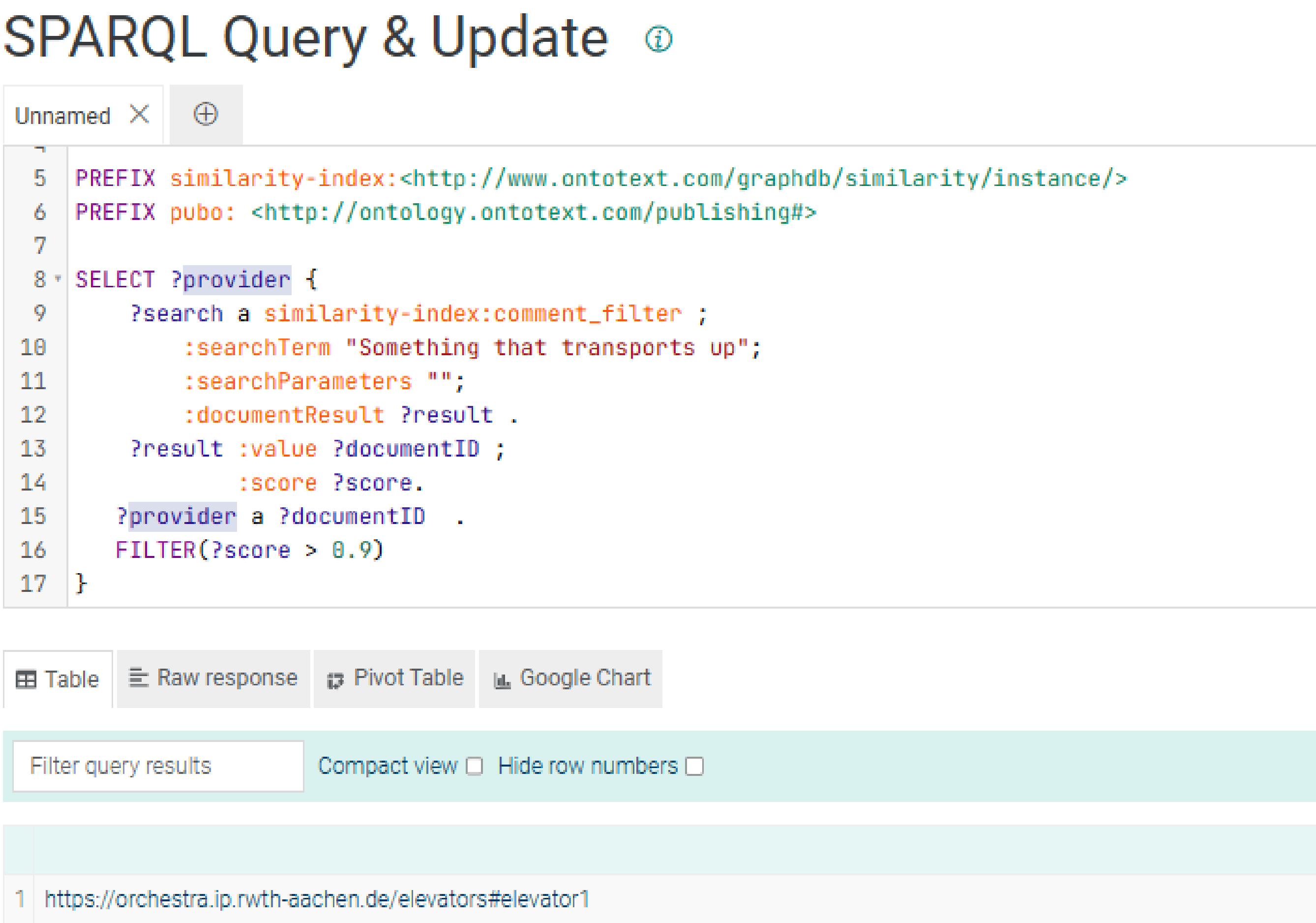

Figure 15: A query using semantic similarity.

[4] https://www.ontotext.com/products/graphdb/

5 Conclusion and Outlook

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In light of the fact that construction projects and construction sites are characterised by the coexistence of disparate data sets and the parties responsible for their generation, this project has demonstrated that the implementation of standardised data descriptions can facilitate the provision and retrieval of data systematically and efficiently. Building upon the Internet of Construction (IoC) ontologies, a standardised description of the data from the project partners within the use scenarios has been developed in the form of new sub-ontologies. These ontologies serve as a framework for facilitating data management within construction projects.
The concept of a marketplace is central to our approach. It provides a structured environment where data exchange and capability matching can occur on construction sites. This marketplace is designed to improve data sharing among different stakeholders involved in construction projects. To illustrate the practical application of our approach, we employed a query as an example. This query demonstrates that an ontology can be used in matching operations.
Our work allows for the publication of sub-ontologies that provide detailed descriptions of services available. The process of finding the necessary data involves two main steps:

1. Input Information: Ontology Matching: Initially, the ontology is matched using either keywords or semantic matching techniques. This step ensures that the ontology aligns with the user's requirements.

2. Data Retrieval: Once the appropriate ontology is identified, it is used to obtain the required data for the task.

Formal languages such as RDF or OWL and standard vocabularies such as Dublin Core or schema.org have been adopted to ensure interoperability. Clear licensing, provenance details, and adherence to community standards can improve reusability when publishing work online. The project's findings demonstrate industry partners' and researchers' significant collaborative efforts in developing a pertinent representation and utilisation of stakeholder data within the domain, essential for fostering collaboration and exchange. While providing a robust foundation, scaling the framework to accommodate large, complex projects or evolving industry needs may present challenges. The success of such frameworks is contingent upon the willingness and capacity of stakeholders to adopt and adapt to new standards and technologies.
In future work, persistent, well-maintained, and openly accessible identifiers, such as IRLs from w3id.org or DOIs from Zenodo, should be used for the ontology. Enriching ontologies and datasets with metadata—including title, creator, subject, date, and type—will also improve discoverability. Efforts should also focus on indexing resources on platforms like Linked Open Vocabularies (LOV)5 and prefix.cc while employing safe protocols (e.g., HTTPS) for reliable data retrieval. As part of the subsequent obligatory stages, which entail validating and distributing the specified data structures, it is imperative to integrate the ontologies with genuine data and evaluate their efficacy in authentic projects. The findings generated by steps four and five of Corcho and Lopez's methodology (Gomez-Perez, Corcho, and Fernández-López 2004; Keet 2018), which are derived from real applications, indicate which optimisations are necessary in the modelling of the data to meet the requirements concerning the provision and retrieval of the data.
The data framework has been developed following the requirements of the project partners. The system provides them with access to a robust system to organise, share, and retrieve project data more efficiently across teams and systems. In addition, it facilitates improved communication and coordination among stakeholders through the use of a unified data language, which serves to mitigate misunderstandings and data silos.
The framework can be integrated into standardisation practices by aligning it with existing industry standards or contributing to developing new ones, thereby ensuring broader applicability across the construction sector. The project partners are encouraged to actively participate in these standardisation efforts by sharing their insights, use cases, and practical experiences, thereby assisting in the shaping of guidelines and best practices for industry-wide adoption.

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[5] https://lov.linkeddata.es/dataset/lov/

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