Universidad Politécnica de Madrid

Escuela Técnica Superior de Ingenieros Informáticos

Ontology engineering

Identifying Knowledge Patterns and Developing an Ontology

Author:

José Antonio Ruiz Heredia

Joseph Tartivel

Teacher:

Maria del Carmen Suárez de Figueroa Baonza

Date:
September 4, 2025

Contents

1 Modeling N-ary relationship patterns

The objective of this part is to identify at least 4 situations that should be modeled using an N-ary relation pattern. Situations should be identified on Wikipedia pages about urban planning, building construction, or language teaching as a second language.

1.1 Urban Planning

1.1.1 *Situation 1*: Public Transportation System Design

This scenario demonstrates how difficult it is to build high-speed rail networks to improve regional connectivity, requiring collaboration between cities and regions. The Madrid-Levante high-speed rail route in Spain, which connects Madrid with Valencia, Alicante, and Murcia, is one example. These relationships are modeled using a N-ary relation pattern, which captures how the rail line enhances connectivity, integrates areas and links cities.

- **General Situation**

  A country develops a high-speed rail line to improve connectivity.

- **Specific Situation**

  Spain develops the Madrid-Levante high-speed rail line to connect Madrid to Valencia, Alicante, and Murcia to improve connectivity between both regions.

- **Source**

  This situation, involving the development of the Madrid-Levante high-speed rail line, was based on information from the Wikipedia entry on the Madrid-Levante High-Speed Rail Line [1].

- **Graphical Representation**

  The graphical representation for the *Public Transportation System Design* situation can be observed in Figure 1.

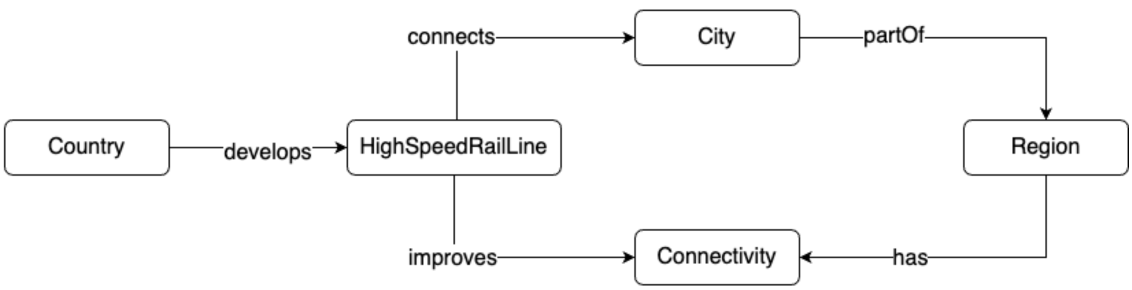

Figure 1: Public Transportation System Design with Draw.io.

- **Classification in the N-ary Relation Pattern Taxonomy**

  It is classified as **Transportation System Development Pattern** as it reflects the focus on infrastructure projects that enhance connectivity. The N-ary relations capture interactions between entities like countries, rail lines, cities, and regions.

1.2 Building Construction

1.2.1 *Situation 2*: Stadium Renovation

Renovating a stadium involves a variety of interactions, such as the addition of features that increase its usefulness. This is best shown at the Santiago Bernabéu Stadium in Madrid, where multidisciplinary events are made possible by innovations such as a 360-degree scoreboard and a retractable roof. These relationships are modeled using a N-ary relation pattern, which connects the new features, and remodeling with the new events that the stadium can host.

- **General Situation**

  A football stadium is renovated to improve its facilities.

- **Specific Situation**

  The Santiago Bernabéu Stadium in Madrid was renovated with a retractable pitch, a 360-degree scoreboard and a retractable roof, enabling it to host multidisciplinary events.

- **Source**

  The renovation of the Santiago Bernabéu Stadium in Madrid, was developed from details obtained in the Wikipedia article on the Santiago Bernabéu Stadium [2].

- **Graphical Representation**

  The graphical representation for the *Stadium Renovation* situation can be observed in Figure 2.

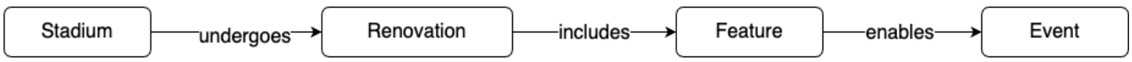

Figure 2: Stadium Renovation with Draw.io.

- **Classification in the N-ary Relation Pattern Taxonomy**

  It is classified as **Renovation Pattern**. This is the pattern chosen because the situation involves upgrading an existing structure to improve functionality. The N-ary relations link renovations, added features, and their impact on events.

1.2.2 *Situation 3*: Museum Construction

The process of building a museum includes design, exhibitions and the cultural and financial effects of the project. This is demonstrated at the Guggenheim Museum in Bilbao, which increased both cultural value and tourism of the city These relationships are well-modeled by an N-ary relation pattern, which illustrates the interrelationships between architecture, exhibitions and tourism.

- **General Situation**

  An architect designs a museum that hosts exhibitions to improve cultural tourisim.

- **Specific Situation**

  Frank Gehry designed the Guggenheim Museum in Bilbao, which hosts modern and contemporary art exhibitions, enhancing the cultural value of the city and boosting its tourism.

- **Source**

  The example of the Guggenheim Museum in Bilbao, was sourced from the Wikipedia page on the Guggenheim Museum Bilbao [3].

- **Graphical Representation**

  The graphical representation for the *Museum Construction* situation can be observed in Figure 3.

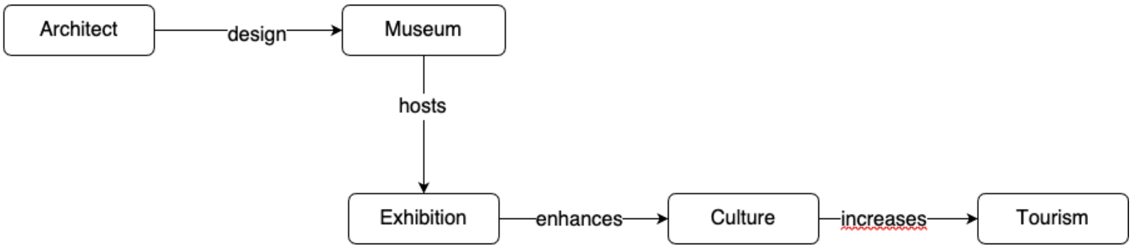

Figure 3: Museum Construction with Draw.io.

- **Classification in the N-ary Relation Pattern Taxonomy**

  We can classify it as **Cultural Construction Pattern**. This classification highlights the construction that focuses on cultural enrichment and tourism growth. The N-ary relations model connections between the architect, museum, exhibitions, and tourism.

1.3 Language Teaching

1.3.1 *Situation 4*: Language Test

Language proficiency tests evaluate diverse skills using interconnected parts and scores that indicate overall proficiency. The TOEFL test demonstrates this by testing reading, writing, listening and speaking abilities, which are combined to get a total score. The test structure is modeled using a N-ary relation pattern to demonstrate how sections contribute to the global proficiency level.

- **General Situation**

  A language test is designed to assess the proficiency level of non-native speakers.

- **Specific Situation**

  The TOEFL determines the English proficiency of non-native speakers by the score obtained in the Writing, Listening, Speaking and Reading Sections.

- **Source**

  The situation describing the TOEFL test, was based on information from the Wikipedia entry on the Test of English as a Foreign Language [4].

- **Graphical Representation**

  The graphical representation for the *Language Test* situation can be observed in Figure 4.

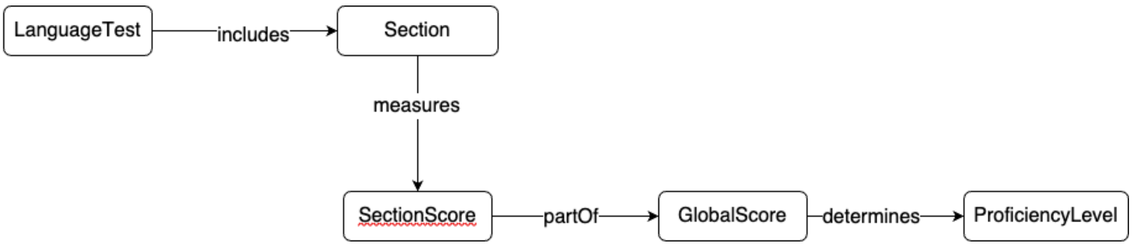

Figure 4: Language Test with Draw.io.

- **Classification in the N-ary Relation Pattern Taxonomy**

  This is classified as **Language Assessment Pattern** as it emphasizes language evaluation. The N-ary relations illustrate how sections and scores contribute to determining proficiency levels.

2 Urban Planning Ontology

The development of ontologies plays a crucial role in organizing and representing complex knowledge domains in a structured and reusable way. Among the various domains proposed for this ontology development project, urban planning was chosen because it represents a multifaceted field that combines physical infrastructure, social considerations, and regulatory frameworks, making it particularly well-suited for ontological modeling.

2.1 Knowledge Sources Selection

The following Wikipedia pages were selected as primary knowledge sources for the ontology development:

- Urban Planning [6]
- Sustainable City [7]
- Transit-oriented Development[8]
- Mixed-use Development[9]

These pages were chosen because they provide comprehensive and width coverage of modern urban planning concepts, with particular emphasis on sustainability and integrated development approaches. The selection ensures the ontology captures both traditional urban planning elements and contemporary sustainable development practices.

2.2 Ontology Reuse Strategy

2.2.1 SOSA/SSN Ontology

- **Source:** *W3C Recommendation*
- **Selection Rationale:**
  - Provides well-established patterns for representing organizational structures
  - Highly maintained and widely adopted in the domain
  - Offers flexible extensions for urban monitoring systems
- **Reused Elements:** *Organization* class and related patterns

2.2.2 GeoSPARQL

- **Source:** *OGC Standard*
- **Selection Rationale:**

  - Industry standard for spatial data representation
  - Enables integration with GIS systems
  - Supports complex spatial queries
- **Reused Elements:** *Feature* and *SpatialObject* classes

2.2.3 Time Ontology

- **Source:** *W3C Recommendation*
- **Selection Rationale:**
  - Essential for representing temporal aspects of urban planning
  - Well-documented and widely used
  - Compatible with existing urban planning systems
- **Reused Elements:** *TemporalEntity* and *Interval* classes

2.3 Design Decisions and Implementation

2.3.1 Core Design Principles

The ontology is structured into distinct modules such as zones, facilities, and regulations, enabling easier maintenance and reuse. Core classes have been designed with extensibility in mind to allow adaptation for specific urban planning applications. Additionally, alignment with W3C and OGC standards ensures compliance and interoperability with existing systems.

2.3.2 Key Implementation Decisions

Class Hierarchy. A three-tier classification system was created, consisting of abstract concepts (e.g., *Feature, SpatialObject*), domain concepts (e.g., *UrbanArea, PublicFacility*), and specific implementations (e.g., *ResidentialZone, TransportHub*).

Property Design. Both object and data properties were implemented to capture various aspects of urban planning. Spatial relationships such as *adjacentTo* and *connectsTo*, temporal aspects like *hasConstructionDate* and *hasOperatingHours*, and administrative data including *maintainedBy* and *requiresPermit* were incorporated.

Environmental Considerations. Environmental impact tracking was integrated across multiple classes. Dedicated properties for sustainability metrics were implemented, and green spaces were connected with impact assessment capabilities to ensure a holistic approach.

2.3.3 Notable Design Patterns

Facility Management Pattern. A comprehensive facility management structure was implemented, linking physical infrastructure (e.g., *PublicFacility*), operational aspects (e.g., *hasOperatingHours, hasCapacity*), and maintenance relationships (e.g., *maintainedBy*).

Zoning Pattern. A flexible zoning system was developed to support multiple land use types, ensure regulatory compliance, and track property value influences effectively.

2.4 Implementation Highlights

2.4.1 Core Elements

The ontology includes 30 carefully selected elements. This consists of 10 primary classes that represent key urban planning concepts and 20 properties that capture relationships and attributes in detail. The list of all 30 elements is attached to this report.

2.4.2 Documentation Approach

All elements have been documented with English labels and descriptions. Properties include domain and range information, and classes are accompanied by usage examples and descriptions of their relationships.

2.4.3 Visualization

The graphical visualization of the ontology was first made with OntoGraph inside of Protégé, but this tool does not display properties name once the image rendered, so a second visualization was made using the online versatile tool draw.io.

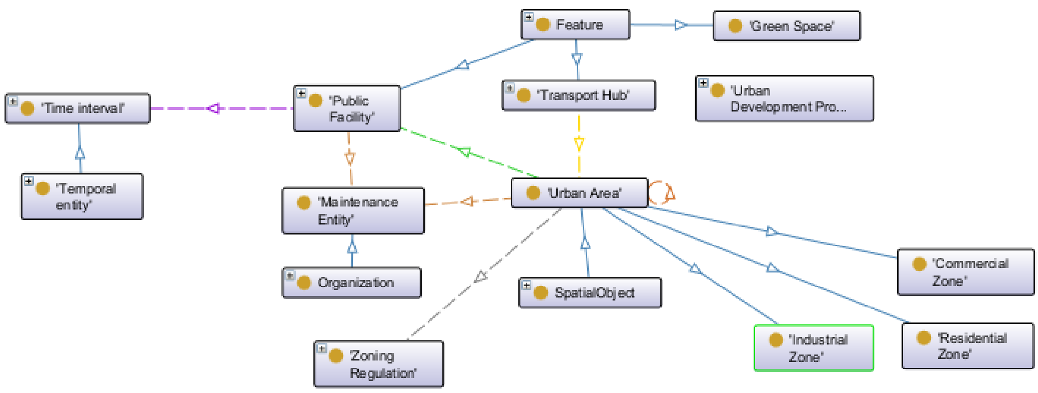

Figure 5: Ontology visualization with OntoGraph/Protégé.

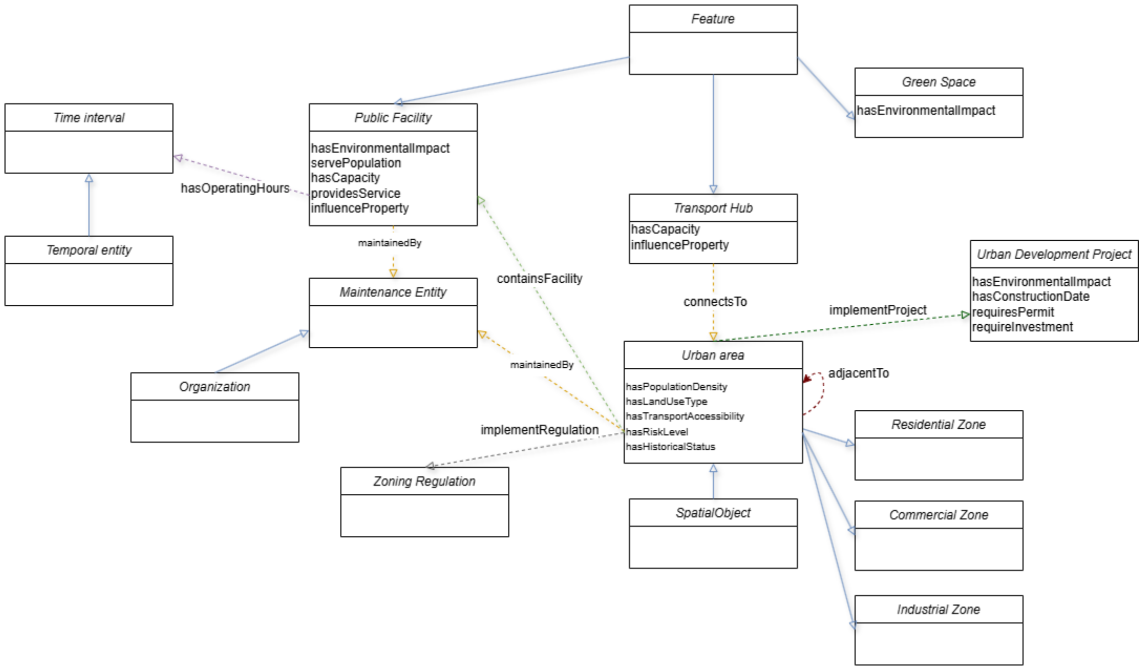

Figure 6: Ontology visualization with Draw.io.

2.5 Integration Considerations

2.5.1 External System Integration

The ontology was designed for compatibility with GIS systems through GeoSPARQL alignment, urban planning software via standard properties, and municipal databases through commonly used data patterns.

2.5.2 Scalability Features

Flexible property chains were implemented to handle complex queries efficiently. The ontology supports reasoning with large datasets and allows for incremental data updates, ensuring scalability.

2.6 Future Extensibility

The ontology's design permits the addition of new zone types, the integration of smart city concepts, the extension of environmental impact metrics, and the implementation of detailed accessibility measures.

2.7 Conclusions

The developed ontology successfully meets the project requirements by maintaining strong alignment with standard ontologies, providing comprehensive coverage of urban planning concepts, and ensuring a flexible and extensible design. Furthermore, professional documentation standards were upheld. The implementation offers a solid foundation for urban planning knowledge representation while ensuring practical applicability in real-world scenarios.

References

[1] Madrid-Levante High-Speed Rail Line - Wikipedia. (n.d.). 2025, from https://en.wikipedia.org/wiki/Madrid-Levante_High-Speed_Rail_Line

[2] Santiago Bernabéu Stadium - Wikipedia. (n.d.). 225, from https://en.wikipedia.org/wiki/Santiago_Bernabu_Stadium

[3] Museo Guggenheim Bilbao - Wikipedia. (n.d.). 2025, from https://en.wikipedia.org/wiki/Guggenheim_Museum_Bilbao

[4] Test of English as a Foreign Language - Wikipedia. (n.d.). 2025, from https://en.wikipedia.org/wiki/Test_of_English_as_a_Foreign_Language

[5] Diagrams.net. (n.d.). 2025, from https://app.diagrams.net

[6] Urban Planning - Wikipedia. (n.d.). 2025, from https://en.wikipedia.org/wiki/Urban_planning

[7] Sustainable City - Wikipedia. (n.d.). 2025, from https://en.wikipedia.org/wiki/Sustainable_city

[8] Transit Oriented Development - Wikipedia. (n.d.). 2025, from https://en.wikipedia.org/wiki/Transit-oriented_development

[9] Mixed-Use Development - Wikipedia. (n.d.). 2025, from https://en.wikipedia.org/wiki/Mixed-use_development