# Modelling Civil Engineered Systems

Technische Universität Berlin
Institut für Bauingenieurwesen

1st Assigment-Ontological Modelling

Framed structural engineering

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# 1. Backgrund

In today's complex and ever-changing field of civil engineering, there are numerous factors involved in the design, analysis and construction of buildings, of which the selection and modeling of structures is a crucial aspect. Frame structures have significant advantages in the field of civil engineering, their strong structural stability, flexibility and economy make them ideal for a wide range of building and infrastructure projects, so creating an ontology for use in frame structure engineering is necessary, which is why I chose frame structures.

Using ontology modeling techniques to create a structurally explicit and consistent knowledge framework, modeling through an ontology not only provides engineering professionals with a standardized representation of structural engineering knowledge, but also simplifies communication between engineering professionals by formalizing key concepts, relationships, and attributes.

# 2. Building an ontology

Before starting ontology development, in-depth domain research is essential, which includes a careful understanding of the relevant literature, codes, and standards in the field of frame structures in civil engineering. Defining a clear objective and scope, and clarifying the purpose of the ontology is key to ensuring that the modeling process is relevant. At the same time, the practical use of the ontology is taken into account to make the ontology tangible. With this thorough preparation, the ontology development process will be smoother and more efficient, ensuring that the final ontology built meets expectations and is feasible for practical application.

The ontology building steps for this assignment will be implemented one by one following the seven detailed steps provided in [1], and Protégé will be chosen as the modeling tool. The guidance in [2] will be incorporated during the execution to ensure a smooth modeling process.

## 2.1 Define the domain and establish the scope of the ontology

Start by identifying the key questions to define the goals of the ontology

| Question | Answer |
|---|---|
| purpose | is to depict the essential concepts required for the conceptual design of frame structures, with a primary emphasis on structural engineering. |
| scope | Physical components of frame structures, potential materials, and potential applications of frame structures along with their interrelations. |
| intended end-users | designers and engineers involved in the design process |
| intended use | is to serve as a knowledge representation aiding in the development of parametric models, specifically designed for application in structural analysis. |

*Tab.1*

This assignment will focus on the basic elements of frame structures such as beams, slabs, columns, and foundations, loads, range of use, and materials.

## 2.2 Contemplate the reuse of already-existing ontologies

When developing a new ontology, it is an important strategy to consider reusing an already existing ontology, and for this time the design intent of the ontology, which primarily serves structural design, then IFC can be considered. IFC is an open standard maintained by BuildingSMART International, a professional organization for the building industry. IFC documents use an object-oriented data model to describe the various elements, components, and their properties in a building, including walls, floors, windows, doors, and more. This information can be used in different phases of structural design, construction, operation and maintenance.The use of IFC facilitates data interoperability between different building information modeling software and empowers the IFC import and export functionality of software tools. As given in [3] the representation of the main building structural elements.

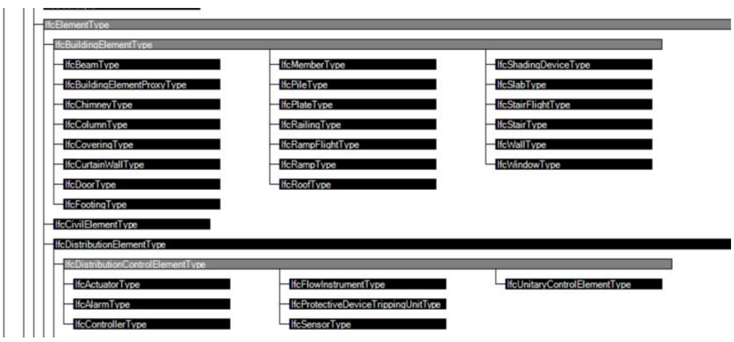


*fig.1 Reference IFC entities for structural members[3]*

However, when these certified software tools use IFC data format for BIM interoperability in real projects, due to the differences in the internal data schema of these software tools, all the information can not be mapped correctly, which leads to some interoperability problems, such as data loss and false positives [3]. Therefore, in this ontology modeling, the names are created in a more readable way, removing the IFC and using the "Camel-back style" method as described in the manual.

## 2.3 List key terms within the ontology.

The importance of enumerating key terms in an ontology is to create a clear and structured framework that defines the concepts and the relationships between them. This not only helps to understand the underlying knowledge structure, but also ensures a precise understanding and application of the ontology model. By enumerating the key terms, a foundation is laid for effective and consistent knowledge management. A list of specific terms is provided below.

| concepts | detailed |
|---|---|
| **physical components** | beams, slabs, one-way-slab, two-way-slab, columns, walls, braced column, unbraced column, stairs, elevators, foundations |

| | |
|---|---|
| **main material** | steel, concrete, wood, masonry, other |
| **Load** | dead loads， live load， dynamic loads， wind Loads， earthquake loads |
| **uses (functions)** | residential, commercial buildings, schools, hotels, parking lots |

*Tab 2. key terms*

The reasons for including these four categories in the main this ontological consideration of the object are as follows:

Physical components: For frame structures, these are usually divided into two main subcategories, primary and secondary structures, with the primary structures being beams, slabs, columns, and foundations, and the secondary structures walls, stairs, and elevators

Primary Materials: Although most materials can be of many types, this category primarily defines the primary materials of a frame structure, i.e., the materials of the major structural components.

Loads: For a structure to carry a variety of loads, the types of loads are listed here, and the combination of loads needs to be further analyzed based on the requirements of the structural design.

Use: The use of the frame structure will affect the configuration of each structural component, and its scope of application needs to be considered according to the actual situation.

## 2.4 Define the classes and the class hierarchy

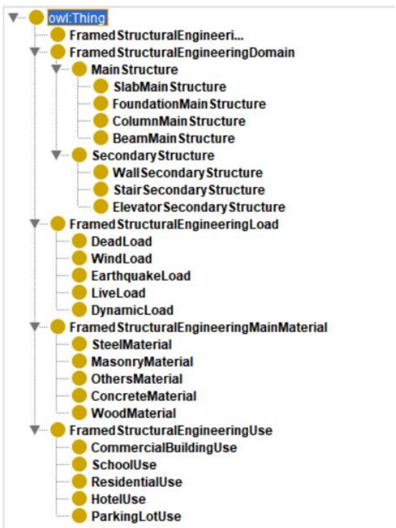


*fig. 2:class hierarchy*

For this ontology construction, a top-down development approach was chosen, starting with the most generic concepts and then specializing concepts from that domain. The frame structure project was set up as a generic concept, and then some subclasses were created to specialize it, specific subclasses were main components, materials, use, and loads. Then move on to layering. In fact, in the previous step, through the creation of keywords, there has been an overall class and class hierarchy, so it is directly based on the keywords identified in the previous step as well as the class and class hierarchy in the software. Specifically as shown in the figure.

## 2.5 Specify the properties of classes—slots.

Separate classes do not characterize some specific attributes in detail, such as the ranges we identified in step 1, so we must define the attribute relationships between the classes in the ontology, i.e., the connections between the concepts, which will help to refine the structure of the ontology so that it more accurately and comprehensively represents things and their associations in the real world. This step focuses on defining the basic relationships between categories and slots. The focus is on the overall structure of the ontology, building the conceptual hierarchy, and the basic properties of the slots.

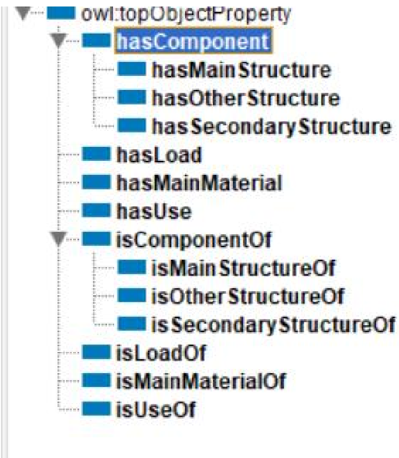


*fig. 3: Object property hierarchy after defining more sub-properties and its inverse sub-properties*

## 2.6 Define the facets of the slots

This step is more specific and focuses on defining facets of each slot in detail. This mainly consists of determining the details of the slot's data type, value characteristics, association characteristics, domain and scope. The focus is on ensuring that the representation of the slot in the ontology is accurate, clear, and meaningful. For example, determining the data type of a property, e.g., string; or placing some constraints on the property, e.g., determining the value range of the property, whether it is allowed to be null, etc., to ensure the integrity of the ontology.

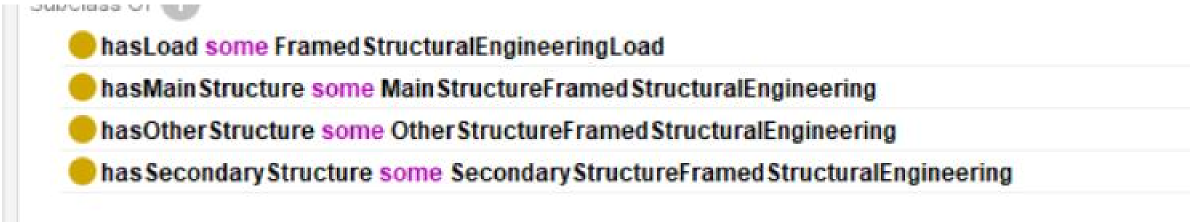


*fig.4: existential restrictions*


*fig.5: individual and Data properties*

In the end, the following figure shows the final result of this ontology modeling, please see the attached Protege .owl file for more details.

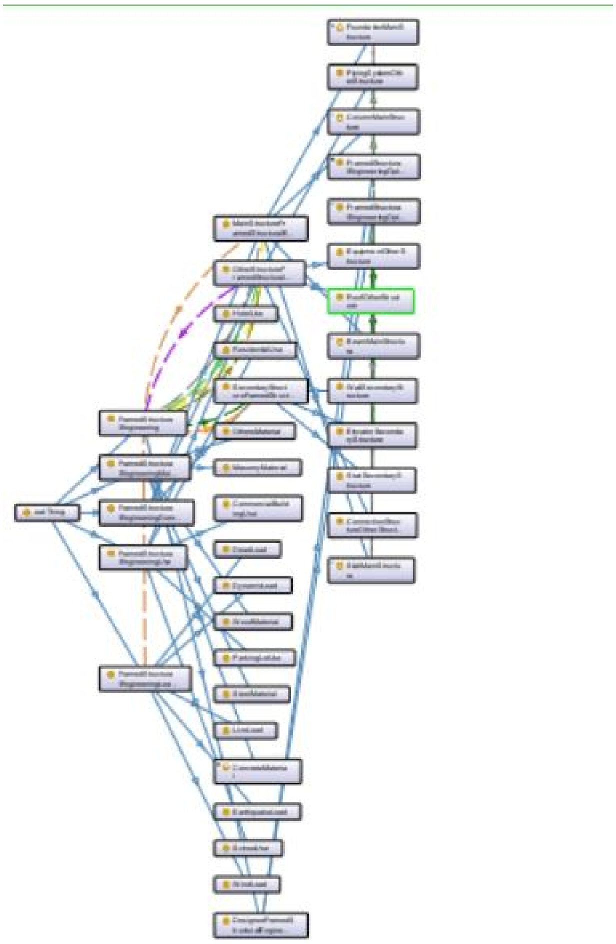

*Fig.6: final result of ontology modeling*

## 2.7 Creating an Example

The final step involves generating individual instances for classes within the hierarchy.This time the example is chosen from a reinforced concrete frame structure high-rise hotel that I designed during my undergraduate graduation design. According to Chinese regulations, some dimensional requirements for the main structure, i.e. beams, slabs and columns, have been added to FramedStructuralEngineeringOption1/2. It is only for demonstration.

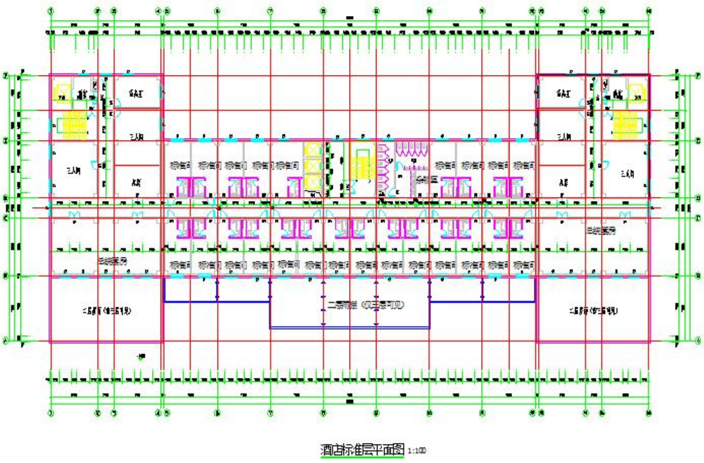

*Fig.7: plane figure of high-rise hotel*

Because the purpose of this ontology modeling is to facilitate people in the structural design, choose a reasonable structure, and the frame structure as one of the choices, rather than the specific design of a building, to this point, the main direction for the listing of a series of frame structure of the relevant composition, materials, requirements and so on. Therefore, when choosing frame structure as the main structure for different purposes, such as hotels, schools, hospitals, the standards are different, such as the limit of storey height, span requirements, the range of main beams, the range of secondary beams, etc., which are based on the actual situation, and look up the relevant local regulations.

# 3. Logical axiom and applications

Here are the logical axioms used in this ontology:

| Axiom | Semantics DL | Protégé syntax for axioms implementation |
|---|---|---|
| **Individuals** | | **Individuals** |
| Atomic concept | $A'$ | Frame Structure |
| Individual name | $a'$ | BeamOption1 |
| **Roles** | | **Object Properties** |
| Atomic role | $R'$ | hasComponent |
| Inverse role | $\{ \langle x,y\rangle \mid \langle y,x\rangle = R' \}$ | IsComponentOf |
| **Concepts** | | **Classes** |

| | | |
|---|---|---|
| Intersection | $C' \cap D'$ | All Frame Structures made from Concrete |
| Union | $C' \cup D'$ | All Elements of Frame Structures as options for crossing other infrastructure networks |
| Complement | $\Delta' \backslash C'$ | not $D'$<br>●notproduct |
| Top concept | $\Delta'$ | Domains (intersection) of $R'$ is $C'$ |
| Bottom concept | $\varnothing$ | Ranges (intersections) of $R'$ is $D'$ |
| Existential restriction | {x\| some $R'$ -successor of x is in $C'$} | $R'$ some $C'$<br>●hascomponentsomeFramedStructuralEngineering Domain |

*Tab.3: Logical axiom*

# 4. Engineering Examples

➢ Structural design of a multi-story office building:

Scenario: a new multi-storey office building is planned for which a structural design is required to ensure its safety and sustainability.

Use case: The ontology provides information about the structural elements of a multi-storey building, such as beams, columns and floor slabs, as well as possible building materials and connections. Designers can use the ontology to create a structural model of the building and verify its stability through structural analysis.

➢ Design of frame structure for residential area:

Scenario: A new residential area is planned and frame-structured residential buildings need to be designed to provide safe, durable and habitable standard homes.

Use Case: The ontology includes information about the structure of the dwellings, such as framing elements like beams, columns and floor slabs, as well as commonly used building materials. Designers can use the ontology to create different types of residential structures and select appropriate materials and designs taking into account local climate and occupancy needs.

➢ Structural design of a school building:

Scenario: The school is planning to build a new school building and needs to optimize the structural design to accommodate the classroom and office spaces.

Use Case: An ontology contains information about the structure of a school building, including possible structural components, materials and floor layouts. Designers can use the ontology to create a structural model of the building and parameterize the design to meet different needs.

## References


[1] Natalya F. Noy, Deborah L. McGuinness, Ontology Development 101: A Guide to Creating Your First Ontology, Stanford University,

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[3] "buildingSMART, 'IFC 4 ADD2 Documentation.'" [Online]. Available: https://standards.buildingsmart.org/IFC/RELEASE/IFC4/ADD2/HTML/link/annex-d.htm.[Accessed: 15-Nov-2023].

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[5] Haroglu, Hasan & Glass, Jacqueline & Thorpe, Antony & Goodchild, Charles. (2008). Critical factors influencing the choice of frame type at early design. 4. 2189-2198.

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