Modelling Civil Engineered Systems

Individual Project Assessment-1

Ontological Modelling

Of

Structural Components in a One-Story RCC Building

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1. Introduction

An ontology is a formal description of concepts within a specific area. Let's break it down into its main parts: classes, properties and restrictions. In short and simple words, we develop an ontology to create a common structure of information, reuse of knowledge, clarity of assumptions and separation of specialized knowledge. This makes information easier to access and analyze. Nowadays, we can find ontology supporting effective communication between people and systems.

Purpose of the Ontology: Now, talking about this specific project work, the ontological modeling of civil engineering systems provides a logical framework to represent, analyze, and optimize its various components. In this project, I focus on modeling the **structural components of a one-story RCC (Reinforced Cement Concrete) building**. Structural components like beams, columns, foundations, and roofs form the backbone of any building. And, the purpose of this ontology is to logically decompose these components. Then, we define their properties, and analyze how they interact to address engineering challenges like **load capacity**, **seismic resistance** and **materials selection**. One more thing, this ontology can also be aimed as a reference for future building designs.

Scope: The scope of my ontology is limited to the structural aspects of a one-story RCC building. It focuses on key components like **beams, columns, foundations and roofs**. Only physical and functional properties related to these elements are included. It does not cover architectural, electrical or plumbing systems. For example, the ontology defines the dimensions and material properties of a column but excludes details like room layouts. So, the scope is aligned towards a targeted approach to reduce unnecessary complexity.

Intended Users: The main targeted users of my ontological model are civil engineers, structural engineers, architects. It helps them quickly access structural data and relationships for decision-making. For example, an engineer can use the ontology to check if the beam dimensions meet the load-bearing requirements. Students and researchers can also use it for educational and simulation purposes.

Intended Use: The intended use is to assist in the design, analysis and improvement of structural components. It allows users to parameterize elements like dimensions, materials and loads. It also enables comparison of different structural designs. Users can analyze whether a rectangular beam or circular column is better for load conditions. The ontology provides a proper way to model, document and reuse knowledge about building structures. It supports design workflows and decision-making.

2. Background Research: Understanding the Building Blocks of RCC Structures

A one-story Reinforced Concrete (RCC) building is like a complex puzzle, made up of many interconnected pieces. These pieces or structural components work together to make the building strong and stable.

Key Structural Components:

- Beams: These are long, horizontal elements that support the weight of the roof and floors. They transfer the load to the columns below.
- Columns: These are vertical elements that support the weight of the beams and transfer it to the foundation.
- Foundations: These are the base of the building. They transfer the entire weight of the structure to the ground.
- Roof Slabs: These form the top surface of the building, providing shelter and supporting other loads.

Designing an RCC building involves overcoming several engineering challenges:

- **Load Optimization**: Engineers must carefully calculate the loads that the building will have to bear, such as the weight of the structure itself, the weight of people and objects inside, and external forces like wind and snow. The goal is to design components that can efficiently support these loads while using the minimum amount of material.
- **Seismic Resistance**: Buildings in earthquake-prone areas must be designed to withstand seismic forces. This involves using special techniques to strengthen connections between components and selecting materials that can absorb energy during an earthquake.
- **Materials Selection**: Material selection is important in RCC building design. The strength and durability depend on the right materials. Engineers choose concrete and steel based on load and environment. For example, in coastal areas, M30 concrete resists corrosion better. Fe 500 steel is used for high strength and earthquakes. Wrong materials can cause cracks or failure. The goal is to balance cost, strength, and environment while following standards like EU.

3. Ontology Development

3.1 Ontological Hierarchy and Decomposition

The ontology is decomposed into the following class hierarchy:

- Thing
  - Building Domain
    - Substructure Building
      - Foundation Substructure
      - Ground Slab Substructure
    - Superstructure Building
      - Beam Superstructure
      - Column Superstructure
      - Roof Superstructure
  - Building Main Material
    - Concrete Material
    - Steel Material
  - Structural Properties
    - Dimensions
    - Load Capacity
    - Reinforcement Ratio
  - RCC Building
    - Designed Building
      - Building Option 1
      - Building Option 2

Talking about the **domain**, the ontology focuses on the **structural aspects** of a one-story RCC building. It models the physical components (e.g., beams, columns, roof), the materials used (e.g., concrete, steel) and key properties like dimensions, load capacities and reinforcement ratios. The reason focusing this ontology only towards structural modelling is to avoid unrelated aspects like architectural or functional design (like wall design).

3.2 Logical Axioms

The following logical axioms are implemented to define relationships:

Logical Axiom	Description	Domain	Range	Example
hasComponent	Links an entity to its subcomponents	RCC_Building	Building_Domain	RCC_Building hasComponent BeamSuperstructure
hasMainMaterial	Defines the material used by structural components.	Building_Domain	Building_Main_Material	BeamSuperstructure hasMainMaterial Concrete
hasProperty	Defines the structural property of the components.	Building_Domain	Structural_Properties	ColumnSuperstructure hasProperty
supports	Explains which component rests on which component.	SubstructureBuilding	SuperstructureBuilding	FoundationSubstructure supports ColumnSuperstructure
transfersLoadTo	Provides information on load transfer mechanism.	Building_Domain	Building_Domain	BeamSuperstructure transfersLoadTo ColumnSuperstructure
isSupportedBy	Inverse of 'supports' axiom.	SuperstructureBuilding	SubstructureBuilding	ColumnSuperstructure isSupportedBy FoundationSubstructure
isComponentof	Inverse of 'hasComponent'	Building_Domain	RCC_Building	BeamSuperstructure isComponentof RCC_Building

3.3 Development Process

Following the guidelines of **Noy and McGuinness**:

I. **Define Classes**: We define the main structural components of the RCC building. These include Beam Superstructure, Column Superstructure, Foundation Substructure, etc.

II. **Define Object Properties**: Relationships between the classes are created. For example, 'hasComponent' links the building to its components. 'hasMaterial**'** connects structural components like beams and columns to their materials (e.g., Concrete, Steel).

III. **Define Data Properties**: We add numerical attributes to the classes. Examples include Dimensions (Length, Width, Height), Reinforcement Ratio and Load Capacity.

IV. **Apply Existential and Universal Restrictions**: Existential Restrictions ensure that specific relationships must exist in the ontology. For example, the 'RCC Building' class has restrictions like '*hasMainMaterial* some *BuildingMainMaterial'*. Universal Restrictions define exclusive relationships. For instance, in the beam and column classes, '*hasMainMaterial* only *BuildingMainMaterial'* is added.

V. **Add Individuals**: Specific examples of components are added as individuals. For instance, Beam and Column individuals are created under Beam Superstructure and Column Superstructure respectively. To understand more about the individual, we assert object property and data property for each of them.

VI. **Protégé Onto-Graf Visualization:**
The Onto-Graf plugin is used to generate a visual graph of the ontology, showing how components are interconnected. Following is the Onto-Graf generated in this ontological modelling:

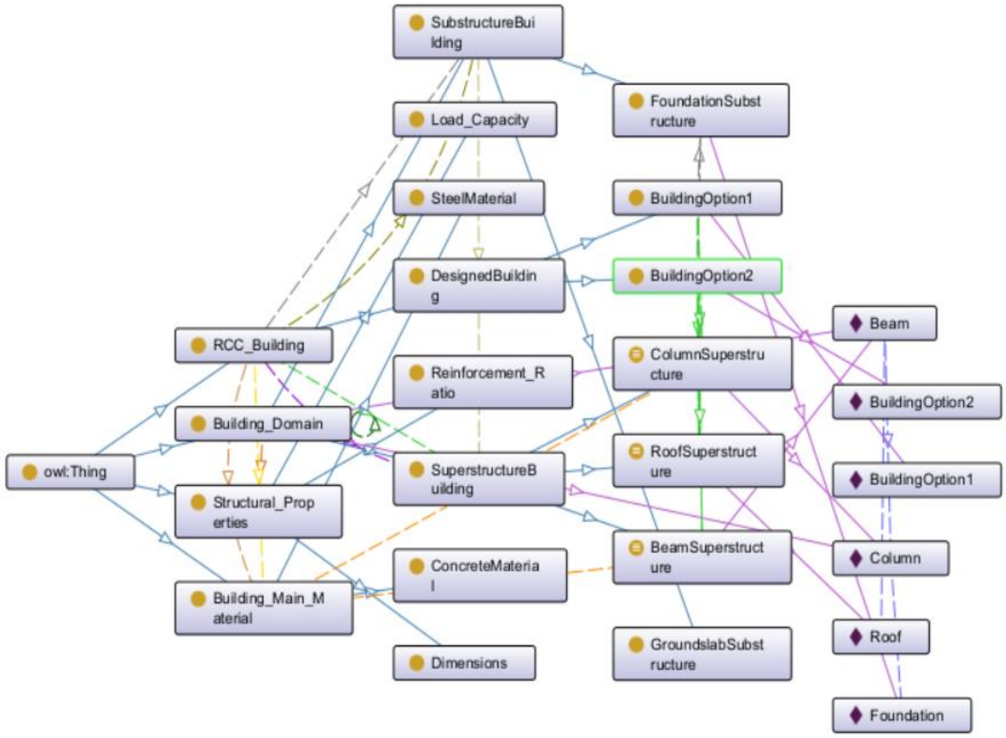


Fig: Onto-Graf model of RCC building

i. The RCC Building is the main class representing the entire building system.

ii. Substructure classes, like Foundation and Ground Slab, form the base, while Superstructure classes, such as Column, Beam, and Roof, handle loads.

iii. Structural Properties include attributes like Load Capacity, Dimensions, and Reinforcement Ratio, linked to Concrete and Steel materials.

iv. Object properties, like hasComponent and hasMainMaterial, connect components and materials.

v. BuildingOption1 and BuildingOption2 offer alternative designs for substructure and superstructure.

4. Engineering Examples

This ontology models a single-story RCC building, focusing on structural components like beams, columns, roofs, and foundations with their materials. Relationships such as supports and transfersLoadTo enable engineers to analyze and optimize structural performance.

Example 1: Beam Design Optimization

The beam must support the roof's load while minimizing material usage and maintaining safety standards.

Solution Using Ontology:

I. The *hasProperty* relationship defines the beam's dimensions, load capacity and reinforcement ratio (e.g., Width = 0.225 m, depth = 0.45 m, load capacity = 20 KN). The *hasMaterial* property specifies the beam material, such as Concrete and Steel. In the same way, other relationships like *supports* and *transfersLoadTo* are used to link the respective domain and range of our ontological modelling.

II. By querying the ontology, engineers can explore multiple combinations of beam dimensions and material grades to find the most efficient configuration that balances load-bearing capacity with material economy.

III. If the query shows excessive deflection or insufficient strength, adjustments in the dimensions or grade of concrete and steel reinforcement can be made.

Example 2: Column Reinforcement Analysis

Columns must safely transfer axial loads from beams to the foundation while maintaining stability.

Solution Using Ontology:

I. The *hasProperty* relationship describes key attributes, such as Load Capacity (e.g., 250 kN), Width (e.g., 0.25 m), Height (e.g., 3.2 m), and Reinforcement Ratio (e.g., 3%). The *supports* relationship links the column to beams above it and the foundation below it showing how loads are distributed.

II. Engineers can query the ontology to ensure the column's dimensions and reinforcement are adequate for the applied loads. For instance, they can check whether the column's width, height, and reinforcement ratio can handle the axial load while avoiding buckling or shear failure.

III. If the current configuration fails to meet the requirements, the query can suggest increasing the column dimensions or adjusting the reinforcement ratio.

Example 3: Seismic Resistance Improvement

The building must withstand seismic forces without catastrophic failure.

Solution Using Ontology:

I. The *supports* and *transfersLoadTo* relationships define load paths during seismic events, illustrating how forces travel from the roof to beams, then to columns, and finally to the foundation.

II. Engineers can query the ontology to identify weak links, such as undersized beams or insufficient column reinforcement that may fail during seismic activity.

III. Properties like Reinforcement Ratio and Load Capacity are analyzed to determine if additional reinforcements are required for critical structural elements.

IV. By introducing cross-bracing in beams or increasing the foundation's width, the ontology can be updated to reflect the improved seismic design.

5. Environmental Interfaces

The ontology shows how the building system interacts with its environment. These interactions are important for safety and stability.

I. **Foundation-Soil Interaction:**

- The foundation moves the building's load to the soil.
- It includes properties like *Load Capacity* and *Soil Type*.
- Engineers use this to check if the soil can handle the load.

II. **Load Transfers:**

- The roof transfers its load to beams. Beams send the load to columns. Columns pass the load to the foundation.
- The *transfersLoadTo* relationship shows this path.
- Engineers can see weak areas in the load transfer and fix them.

III. **Seismic Forces:**

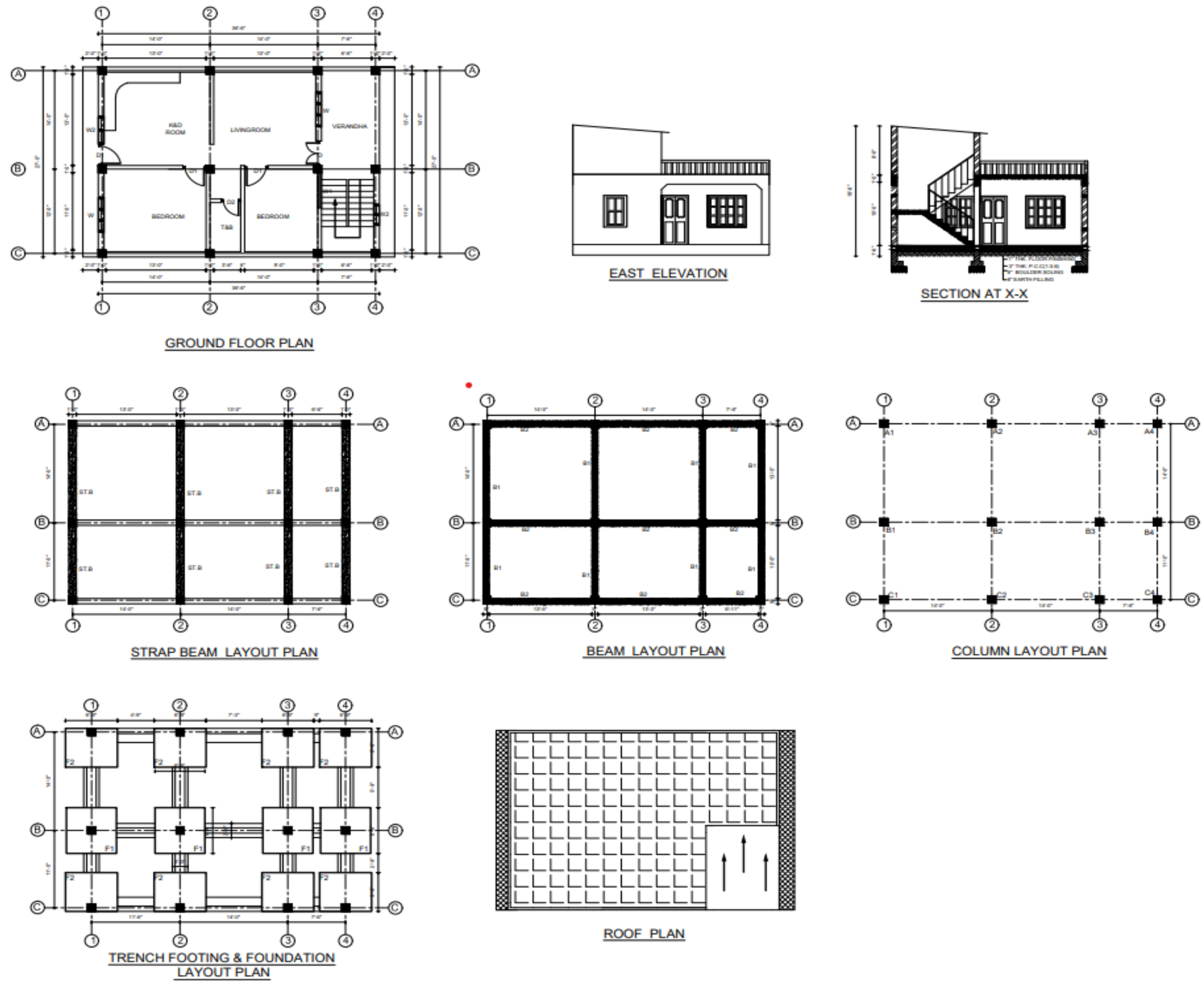
- Seismic forces move through beams, columns, and the foundation.
- Relationships like *supports* and *transfersLoadTo* explain this.
- Engineers can find weak points and make stronger connections.

6. Parameterization

Practical values are assigned to data properties for each structural component. We keep sure that the values remain aligned with the standard codes of practices like **IS Codes (IS 456:2000)** for concrete design, **Eurocode 2 (EN 1992)** for structural design standards and books like ***Reinforced Concrete Design*** by Pillai & Menon.

- **Beam**:
  - Length = 4.5m, Width = 0.225m, Depth = 0.45m, B/D ratio = 0.5, Shape = Rectangular, Steel Grade = B500C, Concrete Grade = C25, Load Capacity = 100kN, Rebar Diameter = 16mm, Reinforcement Ratio = 2.5%
- **Column**:
  - Length = 3.2m, Width = 0.4m, Depth = 0.4m, B/D ratio = 1, Shape = Circular, Steel Grade = B500C, Concrete Grade = C30, Load Capacity = 250kN, Rebar Diameter = 20mm, Reinforcement Ratio = 2.5%
- **Roof:**
  - Thickness = 150mm, Steel grade = B500C, Concrete Grade = C30, Load Capacity = 5 KN/m^2, Reinforcement ratio = 1.5%
- **Foundation**:
  - Depth = 3m, Type = Isolated, Soil type = Sandy

7. Overview of the Sketch of the RCC Building



The sketch represents a single-story RCC building with a well-organized layout. It includes plans for the ground floor, roof, foundation, columns, and beams focusing on the structural system's arrangement. The beam and column layouts emphasize load distribution, while the foundation and trench layouts show how loads are transferred to the soil. Although the staircase is shown in the sketch, it is not modeled in the ontology to maintain clarity and focus on primary structural elements.

8. Conclusion

This ontology logically decomposes the structural components of a one-story RCC building. By focusing on load optimization and seismic resistance, it provides practical benefits for engineers and architects. The ontology can be further extended to multi-story buildings or integrated with BIM tools for enhanced functionality.

9. References

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