Technische Universität Berlin

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Whole Life Civil Systems Analysis WS 23/24
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1st Assignment (Individual)

Ontological Modeling

Multi-story Building

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Summary

1. Introduction

Designing, planning, constructing and maintaining a building are tasks that involve not only the designers involved in the project but multiple stakeholders each having their own interpretations and requirements for the common dataset. Based on what we grasp from the suggestions of Noy and McGuinness in the Ontology development paper, an ontology can serve as a comprehensive guideline, facilitate the decision making processes and shorten the design phase significantly. They enable stakeholders to evaluate design options, material choices, and construction methods by providing a structured basis for analysis, thereby leading to more informed decisions. This represents the importance of ontologies, as they are considered as guidebooks for every product, from the simplest ones to the most complex and interconnected systems.

During the present assignment, an ontology was created for our system of interest which is a multi-story building. Basically, building projects require collaboration among various experts from different disciplines such as civil engineers, architects, mechanical engineers, and contractors. An ontology facilitates integration by providing a common language and framework for these diverse fields, ensuring seamless communication and collaboration. Furthermore, this can be used as a reliable reference in future probable modification, maintenance interventions as well as designing similar projects.

Purpose:

The purpose of this ontology is to provide a guideline for the designers as well as the stakeholders of multi-story buildings. Using this ontology they can decide on the best suitable system, sub-system and elements on their projects. Additionally, this ontology can be used as a reference for projects like rehabilitation, expansion, and maintenance interventions. This ontology also can be used as a source for research in the multi-story domain.

Scope:

This ontology includes concepts such as Building physical components, possible materials, and possible building uses and their relations.Nonetheless, considering that building systems include several sub-systems and thousands of elements, providing an ontology which can cover all of these subclasses is beyond our assignment. Therefore, this ontology mainly focuses on the structural integrity of the multi-story buildings. However, for providing a comprehensive overview and also to facilitate future expansion of this ontology, other interconnected and influential subsystems such as architectural subsystems and utility services are added into the overall view of the ontology.

Intended users:

The intended users encompass engineers and designers involved in the design of multi-story buildings for diverse purposes such as residential, commercial, offices, education, and more. Additionally, stakeholders and engineers can leverage this ontology for rehabilitation and expansion projects within existing buildings. Concurrently, university researchers can utilize this ontology to gain a comprehensive understanding of various building subsystems and components, thereby expanding the domain of the current ontology or creating additional ontologies within this domain. Finally, software developers seeking to create tools for structural analysis and design can derive significant value by using this ontology as a reference or foundation for their applications.

Intended Use:

This ontology can be utilized as a specialized tool facilitating understanding of the complex interactions sustaining structural integrity and the intertwined relationships between various components in a multi-story building. It provides valuable guidelines and constraints during the design phase, leading to more informed insights. Additionally, it could be a valuable tool in strategic decision-making, particularly in material selection and construction methodologies. Moreover, it can be used as a foundational platform for developing computer models, enhancing structural analysis, and predictive simulations.

2. Methodology

To create the ontology, and in order to base the foundation of this research, an extensive review of existing literature was conducted aiming to find the most suitable physical components classification, main materials used for the building structure, and probable functions. This involved studying previous works related to the system and identifying relevant sources that shaped the foundation of this ontology.

2.1. Physical Components

Initially, to the main physical components of the ontology, I used the research findings from M. Fischer and J. Basbagill in 2013, which introduced a classification method for various subsystems and components in buildings. The results are illustrated in Fig.1. Additionally, I got inspiration from another study by Vachara Peansupapa and Rothmony Ly in 2015, focusing on Evaluating the impact level of design errors in structural and other building components in building construction projects. Fig.2, represents the findings of Vachara and Rothmony study in a schematic form.

Table 1
Building component classification framework showing building components, number of materials, and thickness parameters considered. Sources used for thickness ranges (by Uniformat element): A [36,38]; B [36,39]; C [36].

Uniformat element	Assembly	Sub-components	Number of material choices	[a]Thickness	
				Minimum (m)	Maximum (m)
[b]A: Substructure	Piles	Piles, *vapor barrier*, caps, *slab-on-grade*, grade beam, rebar, *formwork*	2, 2, 1, 1, 1, 1, 1	0.1	0.4
	Footings	Footings, *vapor barrier*, *slab-on-grade*, grade beam, rebar, *formwork*	1, 2, 1, 1, 1, 1	0.1	0.4
	Mat foundation	*Foundation*, *vapor barrier*	1, 2	0.2	1.8
B: Shell	Columns and beams		10	n/a	n/a
	Floor structure		12	n/a	n/a
	Roof	Roof structure, membrane, insulation, paint	10, 5, 1, 1	n/a	n/a
	Stairs	Stairs, railings	3, 3	n/a	n/a
	Cladding		7	0.02	0.08
	Exterior walls	Wall structure, insulation, membrane, gypsum, paint	5, 1, 1, 1, 1	n/a	n/a
	Glazing	*Glass*, *polyvinyl butyral*, frame, hardware	1, 1, 5, 1	0.007	0.02
	Doors	Door, hardware	3, 1	n/a	n/a
C: Interiors	Partitions	*Partition structure*, *gypsum*, *paint*	2, 1, 1	0.2	0.6
	Doors	Door, hardware	2, 1	n/a	n/a
	Wall finishes	*Covering*, *paint*	2, 1	0.005	0.02
	Flooring	*Surface*, *insulation*	9, 13	0.1	0.2
	Ceiling	*Plaster*, *gypsum*, *paint*	1, 1, 1	0.006	0.02
[c]D: Services	Mechanical	17 Sub-components	[d]13	n/a	n/a
	Electrical	16 Sub-components	1	n/a	n/a
	Plumbing	22 Sub-components	1	n/a	n/a
	Fire	4 Sub-components	1	n/a	n/a
	Conveying	Elevator	1	n/a	n/a

[a] Thickness ranges correspond to italicized sub-component and all material choices for that sub-component. For assemblies with multiple italic sub-components, ranges represent combined thicknesses.
[b] Substructure consists of one of the three listed assemblies. Remaining three elements consist of all listed assemblies.
[c] Large numbers of services sub-components preclude enumeration.
[d] Duct insulation is a mechanical sub-component with 13 material choices. Remaining mechanical sub-components have one material choice.

FIg.1. Building physical components based on M. Fischer, J. Basbagill, 2013

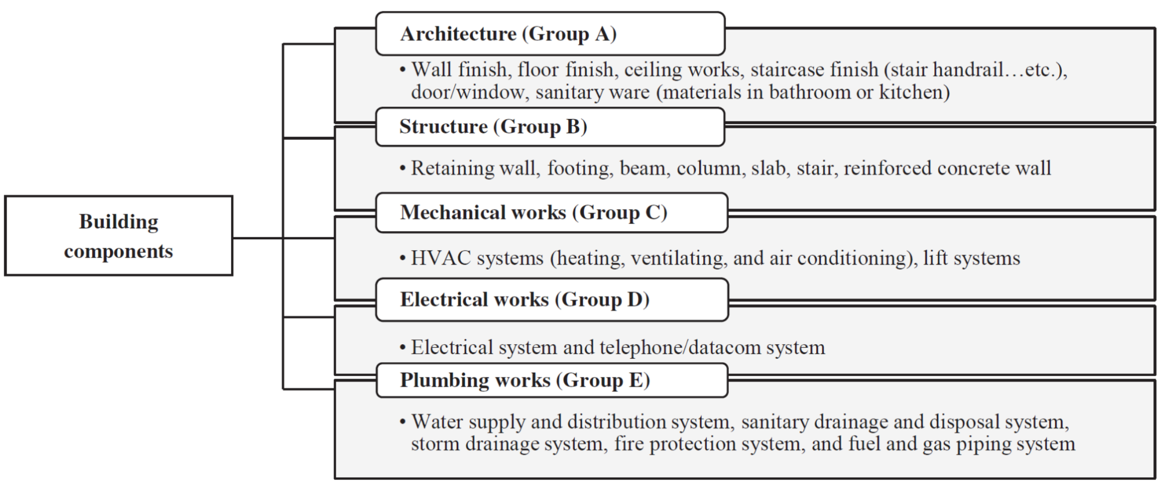

FIg.2. Schematic of building physical components, Vachara Peansupapa, Rothmony Ly, 2015

Based on the results from the mentioned studies, Table.1, represents the physical components within the domain covered by our ontology. Although the primary focus is on building design, combining different elements enables the engineer to establish diverse configurations.

Subclasses	Substructure	Superstructure	Architecture	Services
Components	Foundation	Column	Exterior Walls	Mechanical
	Footings	Beam	Cladding	Electrical
	-	Slab	Ceiling	Plumping
	-	Shear Wall	Flooring	Conveying
	-	Stairs	Opennings	-
	-	-	Partitioning	-

Table.1. Physical components within the ontology domain

2.2. Main Material

In the subsequent step, and in order to specify the main materials used in multi-story buildings I took advantage of the study conducted by Sylvia Marinova, S. Deetman, 2020 on Global construction materials database and stock analysis of residential buildings between 1970-2050. Their findings based on various building functions have been represented in Fig.3 and Fig.4. However, these results are considering all the components of a building, not only the structure which is the focus of this study. Thereby, we only choose the materials which are applicable for the structural integrity.

Given that we are developing the ontology for multi-story buildings focusing on structural integrity, certain materials commonly used in one or two-story buildings, like wood, are not included in our options. Therefore, the key materials for the building structure in this ontology comprise:

- Concrete
- Steel
- Composite; combination of steel frame with core concrete walls

Table 2
Material content assumptions (kg/m2) for the different service sector building types. See SI for details.

	Offices	Retail & Warehouses	Hotels & restaurants	Other
Based on	Average of offices & multi-storey buildings in (Reyna and Chester, 2015; Schebek et al., 2017; Kellenberger et al., 2007; Kashkooli et al., 2014; Kofoworola and Gheewala, 2009; Oka et al., 1993)ʾ.	Average of multiple shop types described in (Reyna and Chester, 2015; Schebek et al., 2017; Gruhler and Deilmannl, 2017) and a hall-type building in (Kellenberger et al., 2007)	Average of a description of multiple hotels in (Reyna and Chester, 2015; Gruhler and Deilmannl, 2017; Rosselló-Batle et al., 2010)	Average of various educational & health care buildings in (Reyna and Chester, 2015; Gruhler and Deilmannl, 2017; Kumanayake et al., 2018; Marcellus-Zamora et al., 2016)
Represents	Offices	Shops, Retail & Warehouses	Hotels, Restaurants	Hospitals, Educational, Institutional, Transport, Public assembly & Others
Steel	115	78.5	84.4	101.9
Concrete	905.1	700.1	724.2	1029.1
Aluminium	4.8	2.4	4.4	5.8
Copper	3.9	2.3	3.5	3.4
Wood	6.7	11.2	18.5	25.5
Glass	6.5	5.9	3.9	14.5

FIg.3. Main materials used in buildings, S. Deetman, Sylvia Marinova, 2020

Table 2
Mean values of the material content by housing type expressed in kg per m² (I_m). In the brackets, the number of data points is presented. They describe the material content in the 56 studies reviewed in our database. Some studies describe material content for multiple houses or case studies, thus leading to more than 56 data points in some cases.

	Steel	Concrete	Wood	Copper	Aluminium	Glass
Detached Houses	35.63 (87)	846.33 (104)	53.07 (121)	1.73 (13)	3.56 (19)	2.68 (43)
Row Houses	32.89 (8)	1208.13 (11)	34.97 (10)	0.01 (4)	0.23 (1)	1.07 (1)
Apartment Buildings	97.36 (53)	955.92 (84)	37.17 (82)	0.31 (22)	1.94 (17)	6.35 (33)
High-rise Buildings	116.98 (30)	910.21 (56)	54.48 (36)	0.01 (1)	2.20 (6)	4.42 (25)

Notes: For region-specific details, please see the SI.

FIg.4. Main materials used in buildings, Sylvia Marinova, S. Deetman, 2020

2.3. Functions

The function of a building significantly influences its configuration. For the purpose of this assignment, I identified the probable functions for our ontology based on insights derived from the 'Classification of Building Types in Germany' study conducted by A. Bandam and E. Busari in 2022, illustrated in Figure 5.

By leveraging the findings from this study, this ontology will categorize and account for these diverse building functions. This not only helps in defining the scope of our ontology but also assists in structuring information concerning each building type's unique characteristics, ensuring that the ontology is comprehensive and applicable to various functional domains within the context of multi-story buildings.

Table 5. Building type classification results for buildings in Germany.

Building Type	Predicted Count
Residential	19,747,802
Attachments	5,583,658
Commercial	3,127,442
Industrial	460,698
Hospital	217,103
Hotel	114,013
Agricultural	105,888
Government	151,98
Event venues	35,935
School	46,452
Religious	33,645
Transport	3117
University	2927
Military	1048
Others	2866

FIg.5. Building type classification in Germany. A. Bandam , E. Busari, 2022

3. Logical Axioms

In this section, an overview of logical axioms implemented on the ontology has been represented in Table 1. These axioms are derived from the decomposition method described in the reading assignment Krötzsch et al.

Axiom	Semantics DL	Protégé syntax for axioms implementation
Individuals		Individuals
Atomic concept	A^I	Building
Individual name	a_1^I	BuildingOption1
Individual name	a_2^I	BuildingOption2
Individual name	a_3^I	ConcreteBeam
Individual name	a_4^I	ConcreteColumn
Individual name	a_5^I	Footing
Individual name	a_6^I	Foundation
Individual name	a_7^I	ShearWall
Individual name	a_8^I	Slab
Individual name	a_9^I	SteelBeam
Individual name	a_{10}^I	SteelColumn
Roles		Object Properties
Atomic Role	$R^I{}_1$	hasComponent
Inverse Role	$\{\langle x, y \rangle \mid \langle y, x \rangle \in R^I{}_1\}$	isComponentOf
Atomic Role	$R^I{}_2$	hasSubstructure
Inverse Role	$\{\langle x, y \rangle \mid \langle y, x \rangle \in R^I{}_2\}$	isSubstructureOf
Atomic Role	$R^I{}_3$	hasSuperstructure
Inverse Role	$\{\langle x, y \rangle \mid \langle y, x \rangle \in R^I{}_3\}$	isSuperstructureOf
Atomic Role	$R^I{}_4$	hasArchitecture
Inverse Role	$\{\langle x, y \rangle \mid \langle y, x \rangle \in R^I{}_4\}$	isArchitectureOf
Atomic Role	$R^I{}_5$	hasService
Inverse Role	$\{\langle x, y \rangle \mid \langle y, x \rangle \in R^I{}_5\}$	isServicesOf
Atomic Role	$R^I{}_6$	hasMainMaterial
Inverse Role	$\{\langle x, y \rangle \mid \langle y, x \rangle \in R^I{}_6\}$	isMainMaterialOf
Concepts		Classes
Existential restriction	{x| some $R^I{}_2$-successor of x is in C^I}	hasSubstructure some SubstructureBuilding
Existential restriction	{x| some $R^I{}_3$-successor of x is in C^I}	hasSuperstructure some SuperstructureBuilding
Existential restriction	{x| some $R^I{}_4$-successor of x is in C^I}	hasArchitecture some ArchitectureBuilding
Existential restriction	{x| some $R^I{}_5$-successor of x is in C^I}	hasService some ServocesBuilding
Top concept	Δ^I	Building

Bottom concept	∅	BuildingDomain
Bottom concept	∅	SubstructureBuilding
Bottom concept	∅	SuperstructureBuilding
Bottom concept	∅	BuildingMainMaterial
Bottom concept	∅	BuildingUse
Nominal	$\{a^I\}$	HasColumn value ConcreteColumn
Nominal	$\{a^I\}$	HasBeam value ConcreteBeam
Nominal	$\{a^I\}$	HasShearWall value ConcreteShearWall
Nominal	$\{a^I\}$	HasColumn value SteelColumn
Nominal	$\{a^I\}$	HasColumn value SteelColumn

Table 1. Logical Axioms implemented in the ontology, based on Krötzsch et al, 2013

Based on Krötzsch et al, there are three three kinds of entities in Description Logic (DL) including concepts, roles, and individuals which for this ontology can be seen from the table above. Moreover, a schematic of the system, sub-systems, and components has been illustrated in Fig.6 which is an export from the Protégé software.

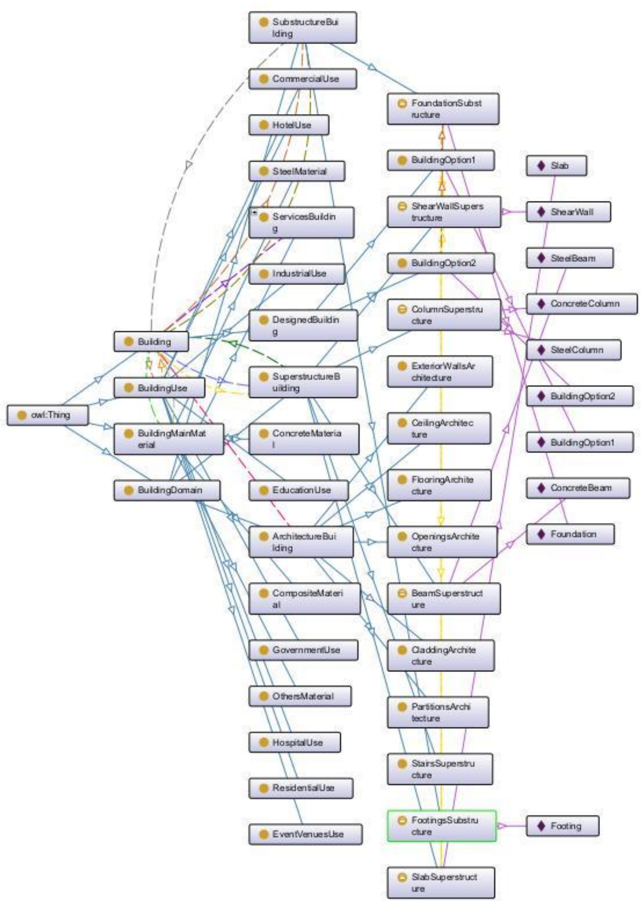

Fig 6. System overall graph represented by Protégé software

4. Engineering Examples

4.1. Functional shuffling

Scenario:

In this scenario, there is a 5-story building within a university campus that requires expansion due to a rise in student numbers and an immediate need for additional spaces. As part of this expansion, the decision has been made to add another story to the existing building. Additionally, after the expansion project, the roof is going to be used as an open area theater and cafeteria. However, implementing this plan mandates a meticulous assessment of the current structure to ensure its ability to withstand the increased load from the new story, particularly the educational activities it will accommodate.

Use Case:

Engineers can use this ontology to gain a deep understanding of the building's various subsystems and their relationships, particularly the structure. More importantly, they can understand different structural methodology to increase the building's bearing capacity together with various materials. For instance, to add another story to a building with concrete structure, there are two options of implementing that with use of concrete frame or steel frame. Depending on the current situation, engineers can gain the details from the ontology and make the best decision.

4.2. Functional change

Scenario:

Within this scenario an old abandoned industrial building has been decided to change to a modern hotel , aligning with the city's efforts to develop its tourism industry. To facilitate this transformation, the existing structure will undergo significant modifications including interior and cladding redesign and the addition of amenities such as restaurants and recreational spaces. Therefore, engineers have to make sure that the old structure can withstand new loads, otherwise the structure needs reinforcement. Furthermore,

Use Case:

Engineers and architects involved in the project can take advantage of this ontology to comprehensively understand the building's current state and its potential for adaptation. By examining the ontology, they can analyze various aspects, such as the building's layout, utility connections, and load-bearing capacity. This information is crucial for planning the functional changes required for the conversion, whether it involves reconfiguring internal spaces, reinforcing structural elements, or integrating new utilities to meet the demands of a modern hotel. Engineers can leverage the ontology to explore different design possibilities and make informed decisions about the best strategies for repurposing the building.

4.3. Design of a multi-purpose building

Scenario:

A multi-purpose 15-story building is going to be constructed in the city town, with residential, commercial, offices, and event venues functioning. Ensuring structural integrity, exploring various materials, and selecting appropriate structural methodologies are key considerations in this project.

Use Case:

By utilizing the ontology, engineers can make informed decisions about the most suitable materials and structural methodologies to ensure the building's structural integrity. The ontology provides a comprehensive documentation of the building's possible structural system, and the potential use of different materials such as concrete, steel, and composite. The representation of these crucial elements within the ontology can be a valuable resource for optimizing the design for structural integrity, and ultimately contributing to a successful design and construction of the multi-purpose building project.

5. Conclusion

In conclusion, the developed ontology for multi-story buildings, focusing structural integrity, offers practical advantages both in real-world projects and scientific research. In projects, it streamlines decision-making processes, fostering collaboration among stakeholders and experts involved in the project for reaching optimized designs and efficient construction. Additionally, in scientific research, the ontology provides a foundational resource for investigating the impacts of design choices and materials on building performance, contributing to advancements in structural engineering and sustainable construction practices. Overall, the ontology serves as a transformative and guiding tool with both practical and research-oriented significance in the field of multi-story building construction.

1. References

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