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Proceedings of the 36th CIB W78 2019 Conference

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Preface

The CIB – International Council for Research and Innovation in Building Construction – was established in 1953 as an association whose objectives were to stimulate and facilitate international cooperation and information exchange between governmental research institutes in the building and construction sector, with an emphasis on those institutes engaged in technical fields of research. The CIB is organized in working groups, of which the W78 is responsible for IT in construction.

This volume is a collection of papers presented at the 36th Annual Conference of the CIB W78 work group held at Northumbria University in Newcastle, UK in September (18th-20th), 2019. The conference brings together more than 130 scholars from over 30 countries, representing research undertaken all over the world.

The papers embody state-of-the-art in research on digitalisation in built environment and encompass major topics including IoT, Digital Twins, Cyber-Physical Systems, Building Information Modelling. As such this volume serves as a source of reference for researchers in ICT applications in design, construction, operation and maintenance for the Architecture, Engineering, Construction and Operation industries across the world.

Newcastle, UK
September 2019

Prof Bimal Kumar
Dr Farzad Rahimian
Prof David Greenwood
Prof Timo Hartmann

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Part 7. Engineering Design & Collaboration Technologies

Ontology-based modeling for construction site planning: Towards an ifcOWL semantic enrichment

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Abstract

Nowadays, there is an increasing recognition of the value of effective information and knowledge management (KM) in the construction projects. Infact, Knowledge-based Process modelling is used in construction to support various simulation tasks. In this field, ontology-based semantic modelling is seen as an important means of addressing this problem to construct robust knowledge-based systems. In parallel, the advancement of information technology in the AEC industry makes available in a construction project a richness of design information offered by Building Information Modelling (BIM) IFC-based. The development of an ontological version of the IFC schema has been largely promoted and now the *ifcOWL* Ontology is available in the sector. But, in the construction scheduling task, BIM has progressively shown limits in terms of semantic representation and efficiency of supporting scheduling processes and for this reason this study, which is a part of a wider research project, aims to organize and formally represent by using ontologies the construction scheduling knowledge in order to define a complete Knowledge-Base (KB) able to allow the development of computer applications and automated reasoning mechanisms for construction scheduling. It consists of four sub-ontologies, including Construction *Scheduling* Ontology, Construction *Workspaces* Ontology, Construction *Time* Ontology and *Building* Ontology. In this paper the Construction Scheduling Ontology is extensively presented in terms of classes, relationships and axioms. Such an ontology has been converted in a script in OWL language by using *Protégé* that is an open-source platform to construct domain models and knowledge-based applications with ontologies. The developed construction scheduling ontology represents an ifcOWL semantic enrichment which is the first step towards automated knowledge-based scheduling systems integrated with BIM.

Keywords: Construction scheduling, Ontology-based modelling, ifcOWL, BIM

1. Introduction

The effective realization of building construction projects is closely linked to the construction activities scheduling process that should consider many factors such as the workspaces availability in site, according to their dynamic nature. Poor schedules estimate results in congested site areas, wasteful material movements, accidents and decline of productivity. In this context, from 1987 to 2005 few Expert Systems were setted such as *GHOST* (Navinchandra et al., 1988), *Construction Planex* (Zozaya-Gorostiza, 1989), *ConsPlans* (Kano, 1990), *BUILDER* (Cherneff et al., 1991), *FASTRAK-APT* (Lee et al., 1998), *CBRidge Planner* (Tah et al., 1999) and so forth. Their main subjects include coding activities, sequencing activities, representing schedules and levelling resources. They are automatic construction planners based on artificial intelligence techniques, precisely. Among all these, but also in other sectors, it has been proven that ontology-based expert systems are the most effective due to the fact they are based on a formal representation of the knowledge on which rule-based reasonings mechanism can be attached. These formal representations allow a coherent definition of objects, not only by describing their characteristics but also by the relationships that exist between them; so that we can express and share the meanings and structure of the material and immaterial concepts that belong to the construction scheduling domain of knowledge which is the subject of the presented research. What it was missing in those Expert Systems was the availability of a building information so use as input data in a standardized formal representation. In the recent years, with the increasing development of ICT, the AEC industry has available in a construction project a richness of design information offered by Building Information Modelling (BIM) by using the IFC-. The development of an ontological version of the IFC schema has been largely promoted in the sector and now the ifcOWL Ontology is available. But for what concern the construction scheduling task, the IFC data structure and the ifcOWL Ontology is very limited in terms of semantic representation to support construction scheduling processes. On this basis, this article propose a semantic extension of the ifcOWL ontology which allows the integration a knowledge-based able to represent the necessary knowledge to address the scheduling task.

2. Background: Ontology based modelling in AEC Industry

Modeling plays a significant role in representing the domain of construction process. In the construction industry, process modelling is used more to support simulation. In looking elsewhere, ontologies can provide a powerful modelling approach. As defined by (Gruber 1995), '*ontology is a formal representation of an abstracted view of a domain that describes the objects, concepts and relationships between them that holds in that domain for a stated purpose or concisely an explicit and formal specification of a conceptualization*'.

Nowadays, ontology-based modelling is central to many applications as largely explained in (Motta 2000), such as medical and biological systems, information management and integration systems, electronic commerce and web services and themselves are used within the realm of artificial intelligence to capture knowledge, and create a model of the knowledge Base. It has emerged that in the recent year the development of domain ontologies in the AEC Industry has been identifies as pivotal point to develop knowledge management and integrated workflows (Zhou et al., 2016). An overview is proposed below. (Lima, 2005) implemented the e-COGNOS platform testing the benefits of using semantic systems for adequate search and indexing capabilities. Another example is the ontology DOCK 1.0. It aims to develop a conceptual structure of key terms in the construction domain and their relationships and behaviour (El-Diraby, 2013). (Akinci et al. 2010) envisioned that semantic CAD/GIS web services can provide away to address the lack of interoperability between CAD and GIS platform. (Benevolenskiy et al. 2012) developed a distributed multi-model-based Management Information system for simulation and decision-making on construction project. The major challenge of the system was the management of the information and model logistics as well as the interdependencies among the application models. A domain ontology for construction concepts in urban infrastructure products was developed by (Diraby 2011). (Wang and Boukamp 2011) presented a framework aiming to improve access to a company's JHA knowledge by using ontologies for structuring knowledge about activities, job steps, and hazards. (Zhong et al. 2012) developed an ontology-based semantic modelling approach of regulation constraints based on proposed CQIE ontology and construction process. Recently, (Zhang et al. 2015) investigated a new approach to organize, store and re-use construction safety knowledge. A construction safety ontology is proposed to formalize the safety management knowledge. Finally, in order to understand how other fields, which have high-level scheduling approaches, addressed the problem of scheduling activities and resources, Tab. 1 groups the most important reviewed studies.

Table. 1 Summary of the review of the scheduling ontologies developed in other research fields

Scheduling Ontology Studies	Object	Construction Field	Other fields	Generic	Specific	Integration with other ontologies	Toolkit Integration
Scheduling Task Rajpathak et al. (2000)	Scheduling Cost Control			•		Time	•
OZONE Smith et al. (1997)	Logistic Scheduling		• Transportation logistics				•
Kasis-Sophina Hori et al. (1995)	Generic scheduling		• manufactory				
CommonKADS Gobin and Subramanian (2009)	Scheduling		•	•			
COMIREM Smith, et al. (2005)			Crisis-action logistics planning	•			
Job Assignment Ontology Rajpathak (2001)	Scheduling		•		•		•
Industry Foundation		•			•	Building Structure	

Classes (IFC) BuildingSmart (2004)					
Mephisto **Lambert and Nowak (2009)**		Military and national security domains	•		
OnSITEsimu Proposed in this research	•		•	Time Space Building	•

3. Research objectives and method

The **main goals** of the presented research work are:

1. To formalize construction site planning knowledge; that means to identify relevant concepts and main items, also called entities, in construction site, as well as their attributes and interrelationships. Such an ontology consists of a **Knowledge Base** (KB) to wrap the existing product model in construction, the so-called Industry Foundation Classes (IFC) which doesn't contain such a knowledge representation by now;

2. The ontology should support a fuller semantic representation of construction site activities in terms of: (a) Resources and site workspaces, (b) Planning and Scheduling Constraints;

3. To implement such an ontological structure in a computer interpretable language in order to use it in future work to link information from different knowledge domains, to attach automated reasoning mechanisms and use such a KB as core schema for software applications for construction site planning and scheduling linked to a BIM Model;

The Knowledge Base was coded by using four sub-ontologies, listed below that have been considered fundamental for representing construction site knowledge:

i) *Construction **Scheduling** Ontology*: this sub-ontology contains all those elements for representing the construction scheduling problems and constraints. It provides a structural foundation for analyzing the information requirements of a construction schedule which should be depend on availability and typology of resources, on space-temporal constraints, on allocation of workspaces.

ii) *Construction **Workspace** Ontology*: it contains the site workspaces representation and the properties Infact, workspaces need to be represented with their basic geometrical and capacity properties and need to be linked to the building objects.

iii) *Construction **Time** Ontology*: it is the ontology of temporal concepts for describing temporal properties of site entities in their evolution across time. It also objects to describe possible relations between time periods in order to define the temporal positions among activities, workspaces and building objects. It plays a pivotal role in developing rule-based reasoning mechanisms for minimize overlapping activities in terms of workspaces.

iv) *Construction* ***Product*** *Ontology*: This sub-ontology represents the domain of Building Information Models (BIMs) and it describes the functional, geometrical and topological information of the building objects –products- that the Knowledge Base needs to get in order to activate reasoning mechanisms in future software applications.

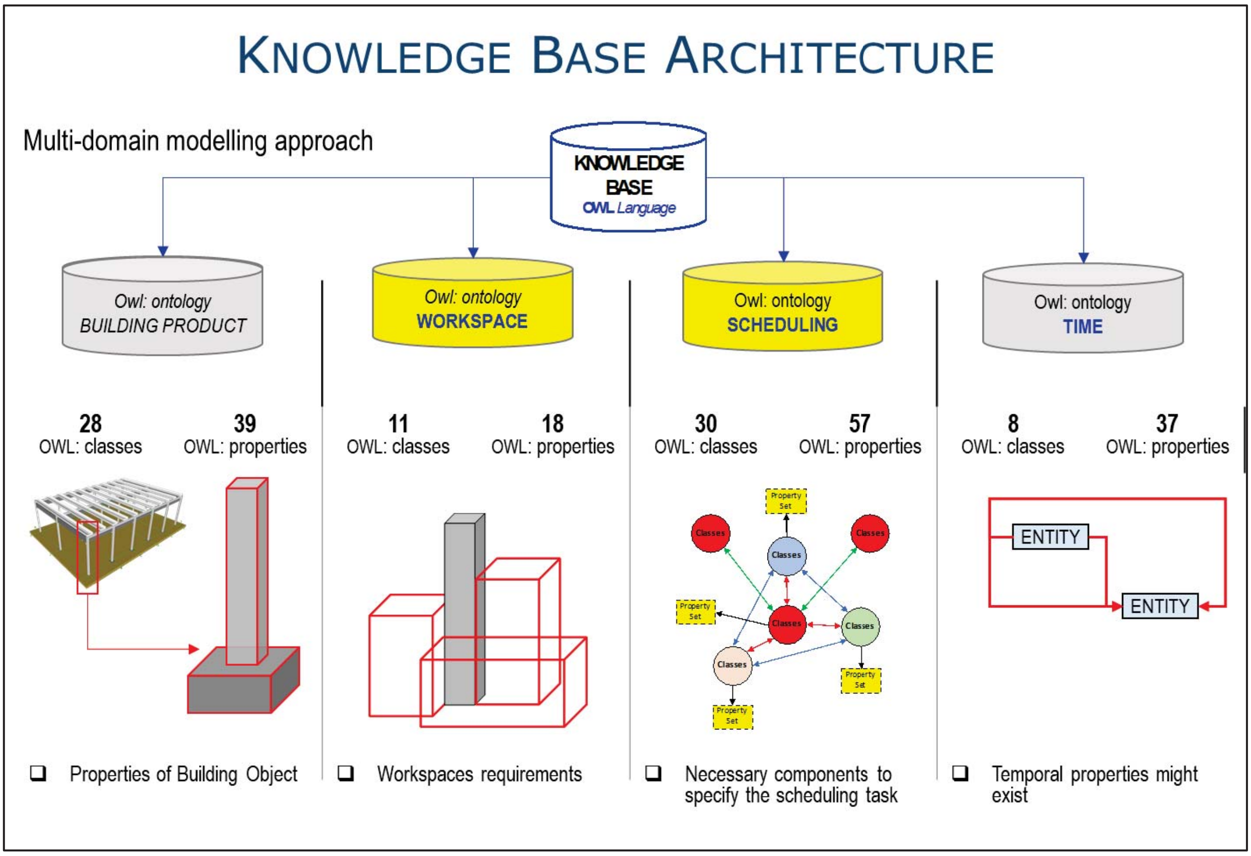


Figure 1: Virtual Reality training protocol application process and data flow

4. Ontology computerization

To make the Knowledge Base machine-interpretable, in this research, we have chosen OWL, the *Web Ontology Language*, to compute the ontologies (Baader et al., 2003). The reasons of this choice are twofold:

a. As before mentioned, BIM systems and models are equipped with a standardized interface for data exchange which is the IFC (Industry Foundation Classes) standard (OpenBIM, 2016). Pilots schemes in academic research have tried to make IFC available as an OWL ontology to allow the usage of semantic web technologies as explained in (Drogemulle and Schevers 2005) and (Beetz (2009). Thanks to these research efforts, it is only a short while since the **ifcOWL ontology**, which is precisely meant to be used to allow extensions towards other structured data sets, is available. This would mean that a practical data-exchange between a given BIM and our KB (ontologies) can be established.

b. The possibility that the Knowledge Base can be able to rely on the ifcOWL ontology which underpins a BIM, would accomplish higher robustness. That way it would also be possible to link and provide our modelling domain (classes, relationships and properties) with the logical and geometrical relationships between building objects that are contained within the BIM ontology (ifcOWL).

Based on these modelling assumptions, the **Construction Scheduling Ontology**, one of the four ontologies that constitute the KB (Figure 1) is presented. The others three ontologies will be presented in an extended publication.

Building an OWL ontology, the Construction Scheduling Ontology means to consider the formal description of concepts (**OWL classes**) in charge of simulate both construction activities and scheduling problem referred to them. Each concept, within the ontology, is described by using various relationships with other concepts or attributes (**OWL properties**) and restrictions on properties (**OWL restrictions**).

More precisely 'OWL properties' are *binary relations* on classes and there are two main types of properties:

- **Object-properties**. They are relationships between two classes or individuals.
- **Datatype-properties**. They link an individual to a Datatype-value (e.g., real number, decimal number, string, Boolean value, time instance, etc.).

Moreover, OWL allows the meaning of properties to be enriched using *property characteristics* (i.e., *functional* -FU-, *inverse* -IN-, *transitive* -TR-, *symmetric* -SY-, *asymmetric reflexive* -AS-, *irreflexive* -IR-). These textual abbreviations will be used in the ontology specification.

It is evident that classes are the cornerstone of the ontology. In this regard, the ontology visualization can help by assisting in the development, exploration and verification of themselves. Although several computerizations for ontologies have been developed in the last couple of years.

In this research *Protégé* was used as open-source platform to construct knowledge-based applications with ontologies. The Visual Notation for OWL Ontologies –VOWL- has been chosen to represent ontologies in this research (Lohmann et al., 2014). The representations are based on graphical primitives and colour scheme; a selection is shown in the Figure below.

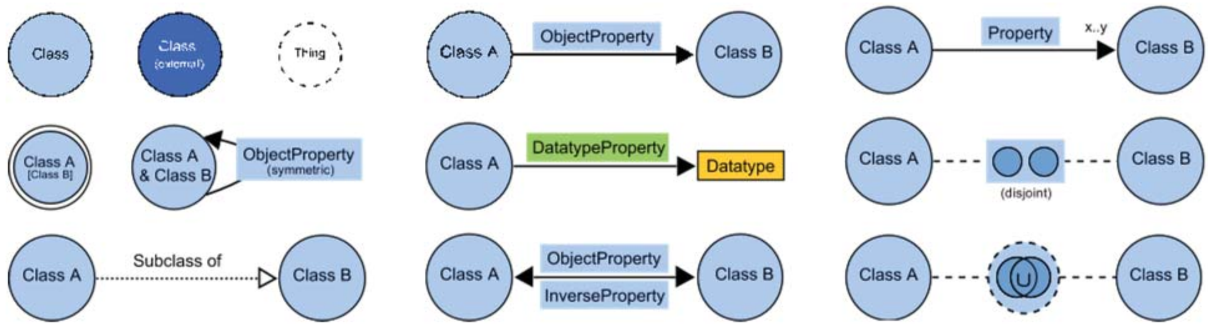


Figure 2: Selection of visual notions to represent ontologies after developing a specific script in OWL language (Lohmann, 2014)

5. Overall framework of the Scheduling Ontology

In the proposed scheduling framework, the ontology can be formally represented as a mapping from a *twelve-dimensional* space (classes). Such an input parameter provide the necessary components to specify the scheduling task.

1. **Construction Method**, (CM) = $\{cm_1, ..., cm_n\}$. This class is an abstract entity which describes the construction work execution. This entity drives the ontology. The construction schedule, linked to a given Building Information Model, should have Construction Methods as much as the number of Object types.

2. **Work Description**, (WD) = $\{wd_1...., wd_n\}$. It describes the construction execution referred to a given Construction Method, its spaces and resources on site by using generic terms.

3. **Demand**, (De) = $\{de_1, ..., de_n\}$. This class contains both construction procedures and safety rules that are formally and graphically simulated by using the 'workspace ontology'.

4. **Construction Product**, (CP) = $\{cp_1, ..., cp_n\}$. This class comprises all the building objects that are primarily part of the construction of the building itself. Its categorization comes directly from the IFC-schema as later described in *Chapter 7*. Hence, the *ifcBuildingObjects*, contained in a given BIM, are converted in individuals that are referred to as being instances of the class 'Construction Product'.

5. **Condition**, (Cn) = $\{co_1, ..., co_n\}$. This abstract entity describes condition that must be achieved at the beginning (pre-condition) or ending (post-condition) of a Construction Method. A Condition can be expressed in terms of activities or milestone in a time period.

6. **Resource**, (Re) = $\{re_1, ..., re_n\}$. To define a Construction Method, it is necessary to choose specific Resources with a specific proposed-set. Semantics and properties of those resources vary according to the type of Resource and define their available capacity across time. A number of resources have

been proposed which should be cover those required by a construction process.

7. **Constraint**, (Cs) = {co_1, ..., co_n}. Getting the Expert System to work on the solution to the given scheduling problem, constraints determination and satisfaction is essential. Generally, a constraint restricts the set of values that can be assigned to a given variable according to (Smith et al. 2005). Our scheduling domain provides the means to model three types of constraints that restrict the assignment of Start and End-Times and the physical allocation in site of Resources and Workspaces related to each construction activity:

   a) **Resource-depended**. It designates the condition under which a Resource (e.g., scaffolding, labor crew, etcetera) can be assigned to a given construction activity or restrict the physical capabilities of resources to handle more activities simultaneously;

   b) **Time-depended**. It defines the possible relations between objects within the construction process (e.g., *before*, *meets*, *overlaps*, *during*, *equals*, etc.) and their time periods;

   c) **Space-depended**. It consists in a family of three sub-constraints which are strictly connected to the workspace simulation (e.g., equipment space, labor crew space, hazard space, etc.) and all those constraints which can be automatically extracted by the IFC Building Structure (e.g., if workspaces of two activities overlap, they can't run simultaneously in construction site).

   Moreover, a further classification of constraints has been introduced:

   d) **User-setted**. They derive directly from the user specifications depending on his experience who directly could add constraints;

   e) **System-setted**. Those ones that are automatically generated by the ontological structure due to properties assigned to the relationships;

   f) **Building-setted**. They derive directly from the BIM by using transformation rules (e.g., a beam should be constructed after connected columns);

   g) Simulation-setted. Those ones that derive from the 'workspaces conflicts checking process'.

8. **Phase**, (Ph) = {ph_1, ..., ph_n}. A group of strongly-related construction processes defines a Phase which ends with a Milestone.

9. **Process**, (Pr) = {pr_1, ..., pr_n}. A process represents the most abstract class that groups various activities.

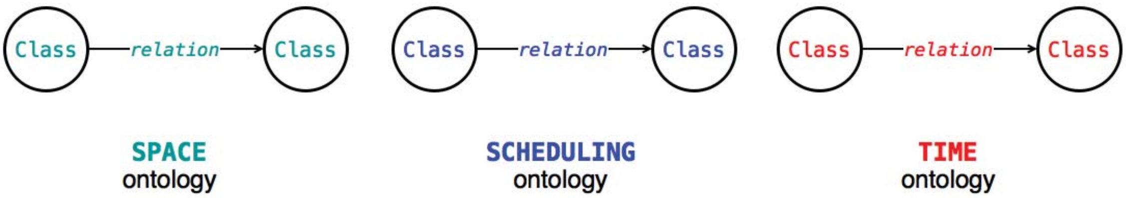
10. **Activity**, (Ac) = {ac_1, ..., ac_n}. In the proposed architecture, a schedule is represented as a network of Activities that will produce a number of Construction Products by using workspaces. To schedule an Activity, it is necessary to choose Resources that produce the time intervals to assign to

each activity depending on their capacity level.

11. **Milestone**, (Mi) = {mi_1, ..., mi_n}. A Milestone represents a Phase finalization connected to a given Time Instant.

6. Topological structure

Here, it is depicted the framework models of the scheduling ontology in terms of the main classes, properties and relations diagrams. To enhance a better explication, in body of the text that follows, a different font has been used for ontological objects and the font color is used to distinguish the belonging to one ontology that composes the Knowledge Base (Figure below).



Core class of this ontology is ConstructionMethod. This is due to the fact that other classes depend on it. Infact by using relationships and properties, listed below, each construction method is described in terms of required resources, activities and workspaces. All these classes are inextricably linked in an intelligent framework.

Therefore, a ConstrucitonMethod *produces* or *consumes* a number of Construction Products. The class ConstructionProduct contains a list of individuals which represent the building elements and their information requirements, such as columns, beams, slabs and walls, and provide the main interface for connecting the scheduling problem to the given BIM. It follows the structure of the IFC schema and mainly includes sub-types of *IfcBuildingElement*. This building elements include major functional parts of a building.

The binary relationship between Construction Methods and Construction Products is chosen by the user. A Construction Method presumes some Condition could be existing before (*precondition*) or after (*postcondition*) the given Construction Method runs within the construction site. A Construction Method *isDescribedBy* a WorkDescription which specifies the construction execution describing allocation of spaces and required resources by using generic terms. A WorkDescription is regulated by a procedural guideline which is specified in the class Demand by using a set of principles or conditions which can define a procedure or a SafetyRule. This means that if the user links two workspaces to a construction method the system automatically classifies this relation as a procedure of the Construction Method or as a safety rule if a safety or hazard space is included. Each procedure or safety rule contained in a Demand *requires* a number of Resource.

The class Resource is also central to the definition of our scheduling ontology. It represents an entity which is assigned to a Construction Method for its execution. Each Resource can *handle* one or more activities simultaneously and is provided by a specific property set. These properties are all those which effect its availability and utilization in function of its specific Capacity (e.g., *hasCapacityLevel*). Making efficient use of Resources, in supporting activities, becomes the one crux of the scheduling problem which is managed by the rule-engine. A resources class hierarchy has been proposed which models each sub-class in terms of its dynamically changing amount of *CapacityLevel*. The class hierarchy is explained in Figure 4 and the main class restrictions which are modelled are depicted in Figure 5.

Going on, an Activity *isFollowedBy* an interrelated set of sub-activities. To define a schedule, each Activity requires MicroLevelWorkspaces (entities of the Workspaces Ontology) to being performed in site. A Process is modelled as an abstract entity which *isComposedOf* a number of Activities. More Processes make up a Phase which ends with a Milestone and requires MacroLevelWorkspaces (entities of the Workspaces Ontology) to being performed within the construction site. Finally, a Milestone involves one or more ConstructionProduct.

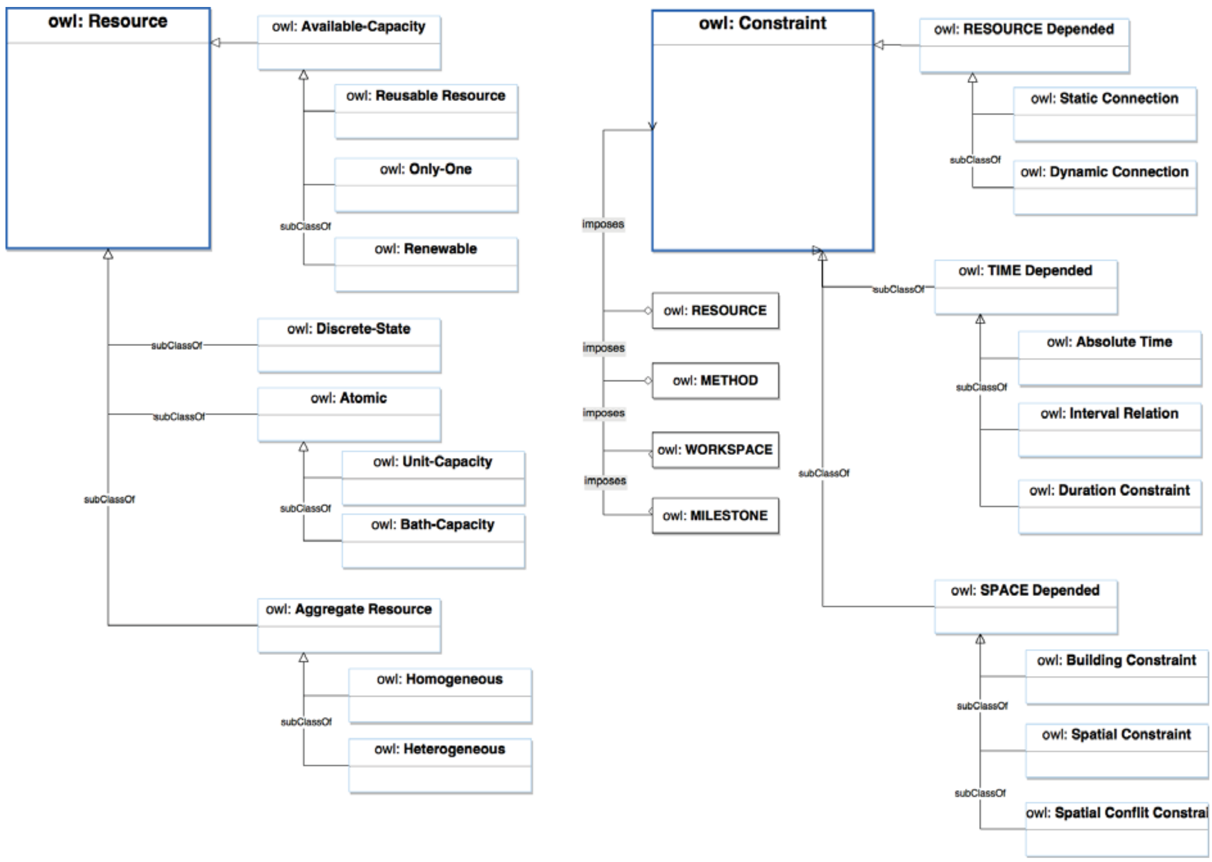


Figure 4: Class hierarchy in the construction scheduling ontology: resources types on the left side and constraints types on the right side

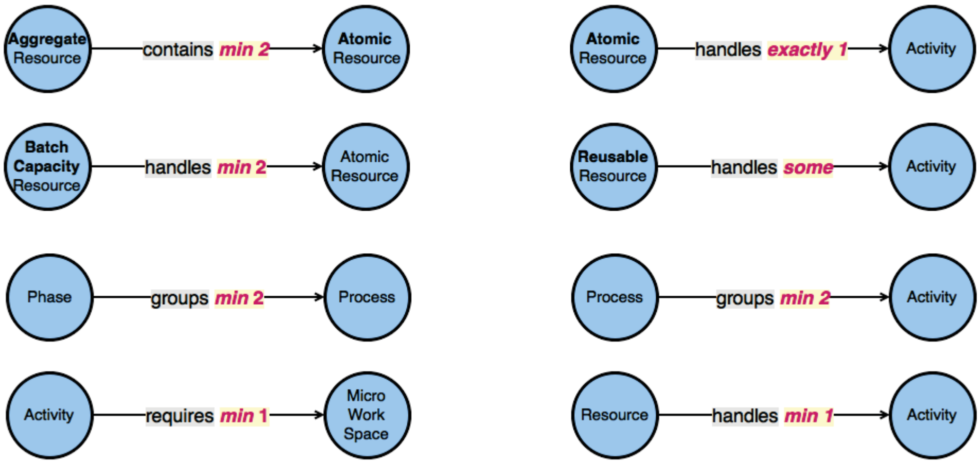


Figure 5: OWL classes restrictions as regard the scheduling ontology

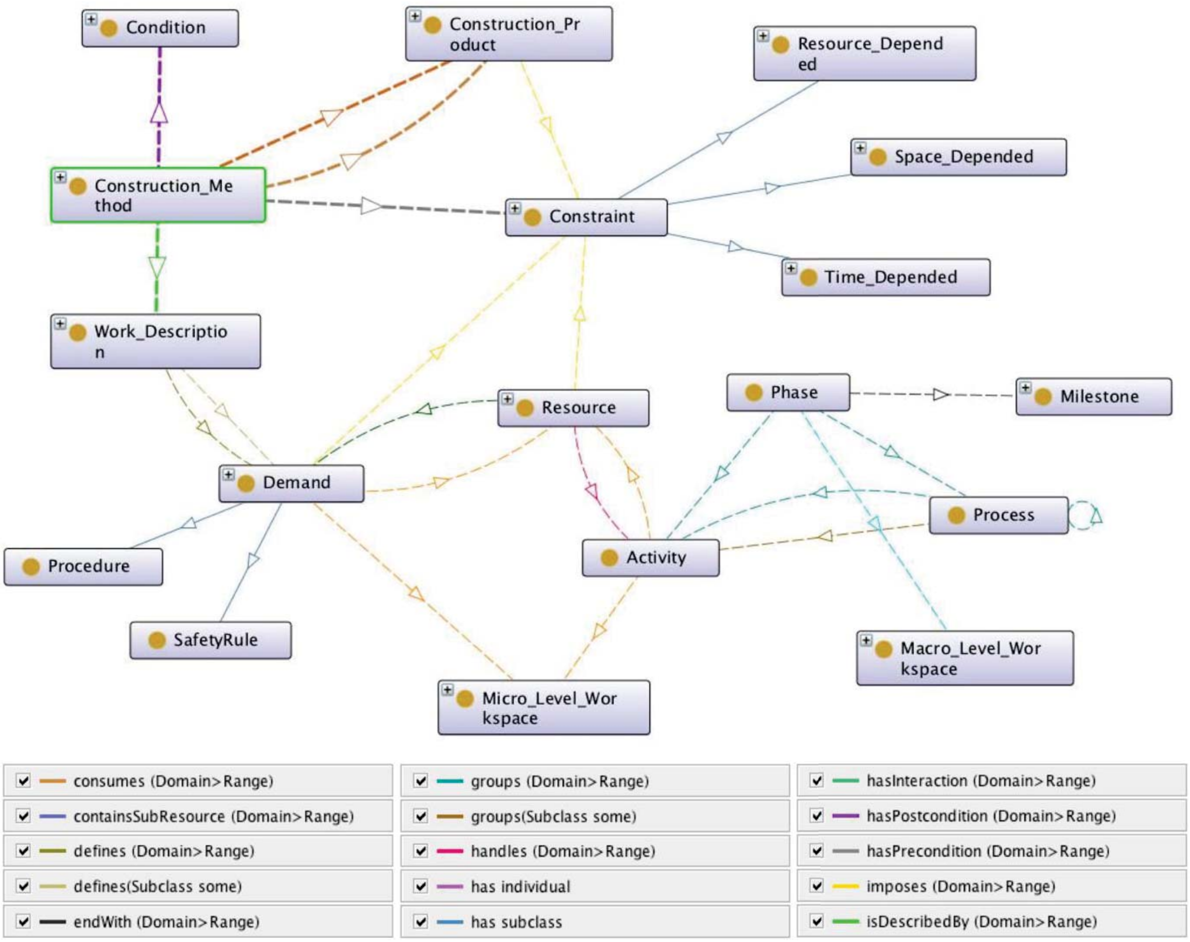


Figure 6. Visualization of the dynamic graph representing classes and relations of the Construction Scheduling Ontology. It derived automatically from the script in OWL and visualized in Protégé.

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