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MASTER THESIS

Ontology Supported Recombination of Multi-Models

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Declaration of Authorship

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Ontology Supported Recombination of Multi-Models

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Dresden, March 8, 2013

Eko Nityantoro

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Abstract

One of the objectives of information technology in construction is to control the complexity of a construction project. Complexity increased with the scale of the project, the larger the project means more time, more costs, more participants and more informations. Since every participant might have their own method to construct their information model, what kind of software they use and which format suits them better, diversity might appear. Therefore in project Mefisto a concept of multi-model is introduced to accommodate this diversity. By employing multi-model each participant will be able to collaborate despite having different resources. Information exchange can be accomplished by using multi-model container as transport medium.

This thesis present a method, in which ontology is used as resource to gather and to store the meta-information about the multi-models. As a part of Semantic Web technology, ontology is able to describe the properties of each multi-model, furthermore it creates the possibility of inferring information in to a logical pattern. With this ability, ontology can help participants to obtain the information they need properly and precisely.

Since this thesis is only focusing on how to support the recombination of multi-models, the participants still have to choose, which multi-models they really needed. Therefore, this system is not yet fully automated, it is only a helping tool in order to reduce complexity and to achieve time and cost efficiency.

Beside that the goal of the information sharing and collaboration is also to build trust, avoid misperceptions, and to create synergy and knowledge accumulation among participants. For this, the use of multi-model templates is an effective way to reach the goals.

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List of Codes

List Of Abbreviation

AEC	Architecture, Engineering Construction
API	Application Programming Interface
BIM	Building Information Modelling
BOQ	Bill Of Quantity
DOM	Document Object Model
FM	Facility Managemet
GUI	Graphic User Interface
IFC	Industry Foundation Classes
LOD	Level Of Detail
MMC	Multi-model Container
MMT	Multi-model Template
NS	Name Space
OWL	Web Ontology Language
QTO	Quantity Take Off
RDF	Resource Description Framework
RDFS	Resource Description Framework Schema
IAI	International Alliance for Interoperability
OKBC	Open Knowledge Basic Conectivity
URI	Uniform Resourse Indentifier
URL	Uniform Resource Locator

W3C	World Wide Web Consortium
XML	Extensible Markup Language

1 Introduction

1.1 Information Technology in Construction

As the technology already step forward to the modern and sophisticated era as known as information era, almost every single aspect in our daily life related with computer and automation. The technology in this era, has a huge influence to human activity and behavior. Not just influencing, but its also has a very important role in our life, start from simple thing like coffee machines, vehicles, up to the satellite based communication. Technology cannot be separated from human daily activity.

Information technology also influenced the behavior of construction industry. As one of the main part of life, construction industry has been adapt to utilize the newest technology, like modeling process, graphical representation of building, specific information about the building, and building automation which is also known as smart-building.

The existing technologies such as Internet and e-mail, can be used to share the information about the processes of construction. But not as simple as that, the complexity and the size of information might need a good management and it is important for everyone involved in a project to have the knowledge how to manage and use the information.

The coordination between participants like stakeholders, consultants, project managers plays a very important role in this information sharing. The lack of coordination will bring to some miss information or miss interpretation between participants. Information Technology in construction will not reach its goal to make the whole process efficient, if there is no good coordination between all participants.

1.2 Motivation and Problem Description

The behavior of construction industry has been changed since Information Technology took an important role in the whole lifecycle of construction process. In construction progress, it is very important that all participants who are taking part

in the project can get the correct and actual information about which activity has been done, still in progress, time schedule, additional tasks, specifications, failures and many more. After the construction finished, it is important to maintain the building services ability.

The information can be complex because it includes wide and variant information about the definitions, measurements, time schedules, goals, costs as well as dependencies between one and another, which also can have a large size of data file. With this complexity, it is possible that each participants can have a different interpretations or understanding about the information, therefore the information and the data exchange between participants require more sophisticated way, user friendly (easy to understand and easy to manage). The information in this case are models which contain as many as possible of information which are needed by different parts of a project to access, extract, interpret as well as to maintain. The meaning of each information may cause confusion among participants. Thus, this information needs a classifications method which can carry the description and the role of those information itself. The functions of this information is not just to give the participants some knowledge but also to give some updates and synergies among them.

With the use of workflows, which utilize vertical filter mechanisms compartment of specific models, producing other qualities of models, like lower level of abstraction can be done. Using the existing templates and workflows a system can be developed in to which based on the object space defined by existing multi-models, showing an extended object space which can be achieve by filtering and recombining the existing models to produce new multi-models based on templates.

Hence, complex interrelations become transparent and a dynamic building informations based upon the models can be established. The resulting transparency in combination with the possibility to document and trace previous decisions bases promotes a consolidated level of comprehension among the project participants. As a result, this builds up trust between project participants, avoids misunderstandings and supports synergies and knowledge accumulation between the experts involved.

In order to fulfill the scope of this work, several tasks have to be performed. The first is to investigate existing Ontologies and Reasoners. Which kind of ontology or method can be applied and which reasoners can fulfill the tasks. The second is to develop a resource ontology, which reflects the multi-models and templates through appropriate terms, classes and relations. Developing the interference derivation rules to determine achievable multi-models based on existing models and templates can be the next task to perform. Evaluation of the developed system with existing

multi-models along with the analysis and discussion of the result concludes the list of the tasks.

1.3 Thesis Structure

This thesis consist of following 5 chapters.

Chapter 1 is an introduction chapter, where the problems and motivations as the base of this thesis are described. In this chapter stated the description about which task should be performed in this thesis.

Chapter 2 is the state of the art, more about state of the art of the models and ontology in constructions. In this part examples of models which are used in the construction process are presented a long with ontology in the civil engineering field. Beside that examples from other domains are also given. Since this thesis uses results of the project Mefisto, therefore a brief explanation of the project can be found in this chapter.

Chapter 3 is a chapter where the idea of multi-model recombination will be explained, here describe why it is necessary and what is the main goal. The question why ontology is needed will be answered in this chapter, which editor can be used and also advantages and disadvantages of ontology. Scenarios will be described in this chapter.

Chapter 4 is a how-to chapter, it is explained here how the Multi-model ontology was build, how to accomplish the desired result form this collaboration. The Multi-Model Ontology Information Management is described here, by which programming language its developed and what kind of methods are involved.

Conclusions and the idea about what can be done in the future are described in the **Chapter 5**. Since there is an application and large of codes and data are involved in this thesis, therefore a CD and a download link consist of a digital version of this thesis, application, codes, data, and examples files are attached.

2 Models and Ontologies in Construction - State Of The Art

Models in construction are various, depends on kind of construction and the scale of construction. The use of models are still growing and will grow larger and larger. The question why ontology is needed, advantages and disadvantages of ontology and which editor can be used will be answered in this chapter. There are some subdomain in construction domain using the advantages of ontology. The current and existing usage will be discussed in this chapter.

2.1 Models in Construction

In construction projects, different models are involved, each model has its own domain, purpose and information. These models might be created by different participants, although there are also possibilities that one participants create all the models. The most common models in construction are : building model, cost model, and schedule model.

2.1.1 Building Information Modeling (BIM)

The most recent technology in AEC is Building Information Modeling (BIM). Building Information Modeling is a building design and documentation methodology based on coordinated, reliable, high quality information [Aut]. It enables design and construction teams (participants) to create and manage information about building project consistently and reliably across different scope of projects. BIM consists of many different models which played an important role in construction process and the information stored in a single building model. This ensures that the information is coordinated, consistent, and complete. By adopting BIM (Figure 2.1) all project participants (e.g. architects, engineers, contractors and owner) can easily create a coordinated digital design of information and documentation. BIM can

be represented in IFC (Industry Foundation Classes) file format, IFC itself is a standardize file format for 3D modeling. This format is able to read by mostly BIM software, as well as IFC viewer software.

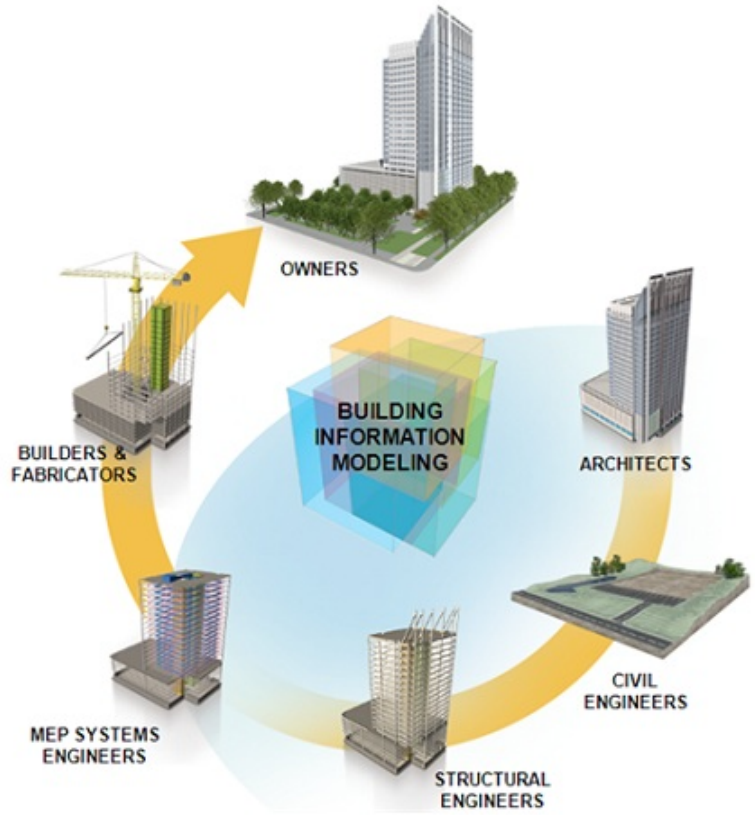

Figure 2.1: Building Information Modeling (AutoDesk Revit Introduction)

2.1.2 Cost Estimation Modeling

Beside BIM, which represents the building itself, there are also model which represent the estimation of cost. Also known as Quantity Takeoff (QTO), these models are generally a mathematical algorithms used to estimate the cost of a project. The models typically function trough the input of the parameters that describe the attributes of the project. It involves counting the number of items associated with the construction project, determining the associated materials and labor cost, as well as formulating or estimating as part of the bidding process (Bill Of Quantity). The participants who create this model are often called cost estimators or cost engineers and also known as quantity surveyors.

These days several software companies like Autodesk have created a software which can read automatically from the drawing design to estimate the cost, as it shown at Figure 2.2.

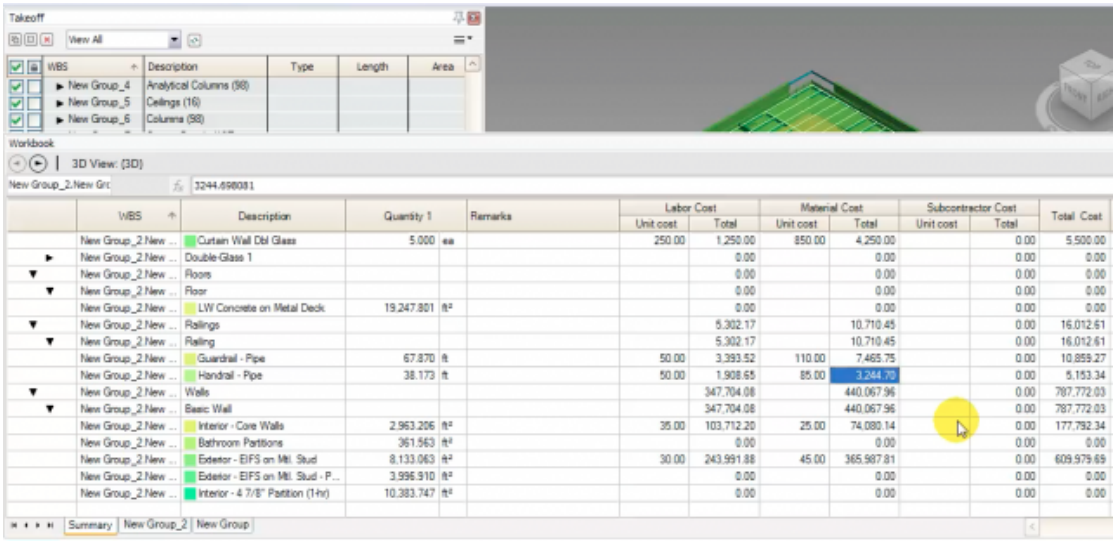

Figure 2.2: Quantity Take Off (Autodesk Quantity takeoff Software)

2.1.3 Schedule Model

As its name, schedule model is helpful in creating the overall schedule for the project [PMK]. By knowing the timing of activities and tasks, the management will be able to make more efficient use of their resources. The schedule model proves to be most effective when used with software programs designed to analyze the schedule network. This analysis is then used by the software to create the finalized schedule.

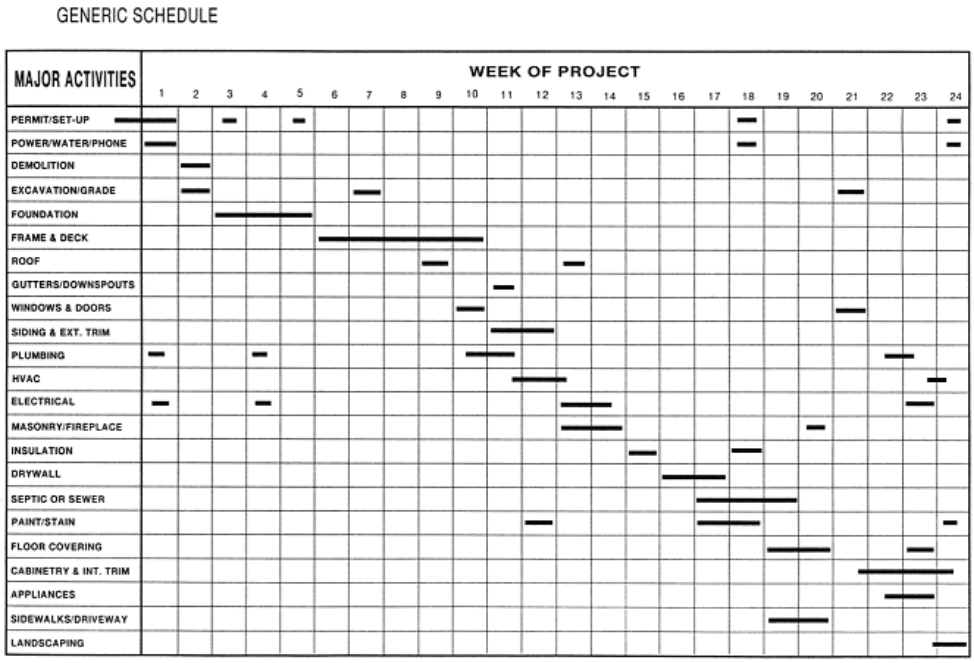

Figure 2.3: Schedule Model (Generic Schedule Model)

2.1.4 Multi-model Approach

With the variety of models in construction, a multi-model approach is a good solution to combine all the difference models. The idea is to get through beyond the borders of disciplines in a construction project. To be able to use as an exchange format, this approach will use a container which defines a superstructure to encapsulate different kinds of models, as a result the multi-model can be applied in any discipline. Ontology will be implemented in the multi-model approach to handle the metadata as well as to describe and classify the multi-model containers and all models within it. More detailed explanation can be found in the Chapter 3.

2.2 Ontology and Reasoning

2.2.1 Ontology

What is ontology? A general one, according to *Merriam-Webster's Dictionary*[1] ontology is "a particular theory about the nature of being or the kinds of things that have existence". From this definition can be understand that ontology deals with the nature and the organization of reality (being or things). Another definition of ontology which is closer to the topic of this thesis can be found at W3C's Web Ontology Language Overview[2]. In context of computer and information science, an ontology defines a set of representational primitives with which to model a domain of knowledge [Gru09]. The representational primitives here are classes, attributes or properties, and relationship between classes. It is also can be said that ontology is an engineering artifact[3] which is purposely designed to enable the modeling of knowledge about some domain, constituted by a specific vocabulary used to describe a certain reality, plus a set of explicit assumptions regarding the intended meaning of the vocabulary. In a domain of interest it formalizes signs to describe things in the world, allowing a mapping from signs to things as exact as possible.

Ontologies came to be of interest to computer scientist in the 1970s as they began to develop the field of artificial intelligence. They realized that if you could create a domain of knowledge and established formal relationship among the items of knowledge in the domain, you could perform certain types of automated reasoning. Tom Gruber, a computer scientist at Stanford University, formally introduced the term ontology to computer science in a 1993 paper [Gru93]. To be understood

[1] *http://www.meriam-webster.com*
[2] *http://www.w3.org/TR/owl-features*
[3] *wikipedia : in connection with software development is largely associated with specific development methods or processes*

by both human and machine, an ontology representation language should provide representation adequacy and efficiency.

The real power of ontology is the possibility to create relationship among classes and instances and to assign properties to those relationships that allows an interferences of them. Ontology will be used as a type of database which is able to describe and classify the information. Ontology has shown to be the right answer to these problems, because ontologies can provide a formal conceptualization of a particular domain which is shared by a group of users [Mae02]. Ontology can describe domain theories for the explicit representation (semantic) of the data. The computer science needs the concept of ontology, why? Ontology is originally from philosophy and its relation to the meaning known from semiotics triangle is introduced in [Mae02]. Based on this concept, ontology has shown an agreement which implies human-human communication, human-machine communication and machine-machine communication.

Ontologies are aimed to provide knowledge about specific domains that are understandable by both developers (human and computers). In particular, ontologies enumerate domain concepts and relationships among the concepts [Zho07]. Generally human uses languages to communicate and to create models of the world. Unfortunately, human languages, or natural languages are not suitable for creating models in computer science, because such languages might be too ambiguous. In order to build a model, computers need a formal language. A mathematics can be considered as a formal language.

Ontology is not just a database, but it is a knowledge database or we can say ontology is a smart database. It is smart because in ontology it is possible to apply a reasoner[4] in order to get the complete information regarding a subject, and even to create the new information. This is what cannot be done in relational database, relational database consist of classes in a table form and more focus on how to relate between one class to another class. Ontology focuses on each instance inside the classes, what kind of attributes it has and how to make a reasoning from the attributes to get more reliable and detailed information about an instance. Each database should be consistent and reliable, creating database can be a long and stressing process, especially when it is a large scale database.

The probability of inserting wrong information to the database is increasing with the scale of the database. With a reasoner, ontology can minimize this possibilities by alerting the database administrator that the ontology is inconsistent, which

[4] a piece of software able to infer logical consequences from a set of asserted facts, http://en.wikipedia.com.

might be caused by doubled information or wrong information.

Based on the natural behavior of ontology, it can be a reliable resource, and like database ontology can be applied in any domain. Ontology uses classes and instances (individuals) to represent knowledge items. It is created with OWL (Web Ontology Language). For semantic languages which are characterized in OWL, we can think of a class set, and the instances of the OWL class (OWLThings), referred collectively as the class extension, as members of that set. OWL also has a universal class, Thing; all individual is a member of Thing, and all classes are subclasses of it. However, in OWL an individual can be an instance of Thing and not an instance of any other class.

The structure of ontology itself will be presented as RDF/XML format. According to definition given by W3C, RDF is a standard model for data interchanges on the web, and like its name, it is a framework for describing resources on the web. RDF has features that facilitate data merging even the underlying schemas differ, and it specifically supports the evolutions of schemas over time without requiring all the data consumers to be changed. RDF extends the linking structure of the web so it can use unique resource identifier (URI) to name the relationship between things as well as the two. By using this simple model, it allows structured and semi-structured data to be mixed, exposed, and shared across different applications.

Ontology is based on RDF format, therefore it can be queried by SPARQL. SPARQL [Apa] is a query language and protocol for accessing RDF which is designed and recommended by the W3C RDF Data Access Working Group. As a query language, SPARQL is "data-oriented" because it only queries the information which held in the models; there is no inference in the query language itself.

Furthermore in this thesis the ontology will be named Multi-Model Ontology, because it is describing the attributes for elementary models of the multi-models.

2.2.2 Ontology Tools

The ontology editor Protege 4.2 is used to build the ontology in this thesis. This part will briefly discuss about the comparison of ontology tools and why Protege is used instead of any other editors.

There are many kinds of ontology editors, each of them has its pluses and minuses. The comparison these editors are mostly based on License, knowledge representation, usability, as well as interoperability with another ontology development tools.

In general there are two different kinds of ontology editors, freeware-open source and commercial. Apollo and Protege are in the list of freeware ontology editors, OntoStudio and TopBraid Composer is among the list of commercial editors.

Generally commercial editors might have more features then the freeware editors.

2.2.2.1 Apollo

Apollo, is user-friendly knowledge modeling application. Apollo allows a user to model ontology with basic primitives, such as classes, instances, functions, relations and so on. Apollo's class system is modeled according to the Open Knowledge Base Connectivity (OKBC) [Apo]. OKBC is a protocol and an API for accessing knowledge in a knowledge representation systems such as ontology repositories and object-relational databases. The knowledge base consists of ontologies that are hierarchically organized. Ontology can inherit other ontologies and then use classes of inherited ontologies as its own. Every ontology inherits at least one ontology – a default ontology, which contains all primitive classes: boolean, integer, float, string, list etc. Class contains slots of two types: non template and template slots. Nevertheless there are two main reasons why it was decided not to use Apollo in this thesis. First, it uses more computer resources, as of decreasing the performance of computer. Second, it does not support RDF/XML which is chosen as the format of the ontology.

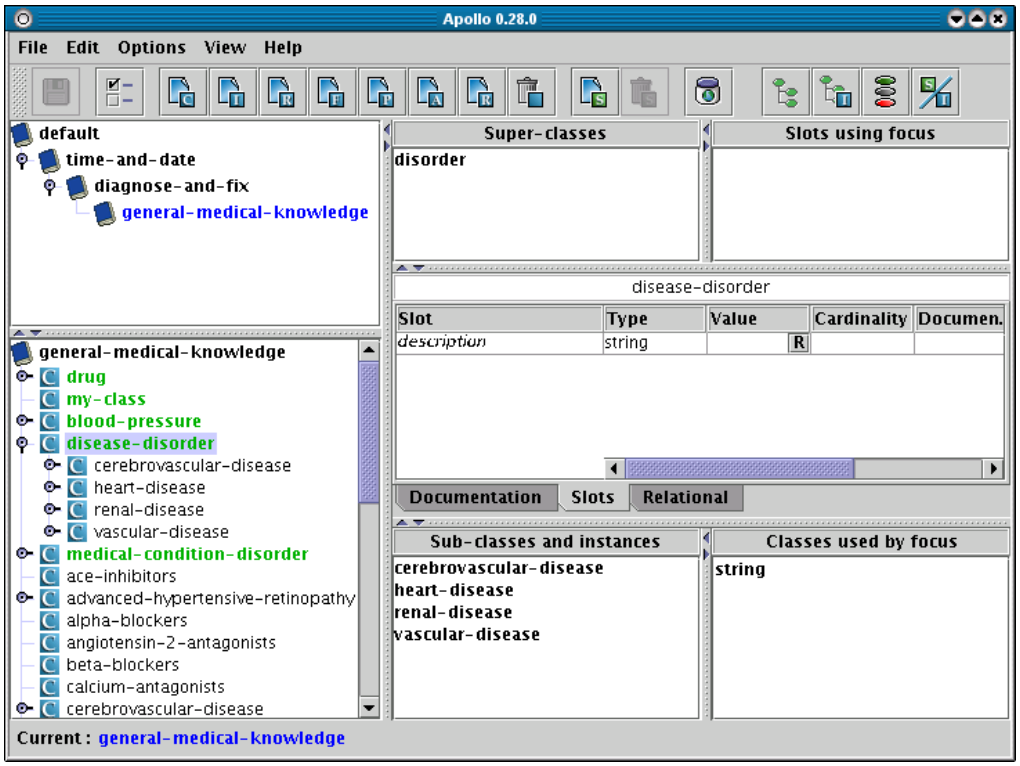

Figure 2.4: Apollo Ontology Editor

2.2.2.2 TopBraid Composer

The TopBraid Composer editor is the one of the frontline software made by TopQudrant [Tbr]. TopBraid Composer is an enterprise-class modeling environment for developing Semantic Web ontologies and building semantic applications. Fully flexible with W3C standards, it offers comprehensive support for developing, managing and testing configurations of knowledge models and their instance knowledge bases. TopBraid Composer is the leading industrial-strength RDF editor and OWL ontology editor, as well as the best SPARQL tool on the market. It comes in three different editions : Maestro Edition, Standard Edition and Free Edition. TopBraid Composer Maestro Edition can be used without any license for 30 days, as well as Standard edition, and the Free edition is totally free. Unfortunately some features are disabled in Free Edition, like graph or diagram view. On the one hand this editor is very advanced, but on the other hand it would not be easy for users especially beginners, because some features are not really convenient.

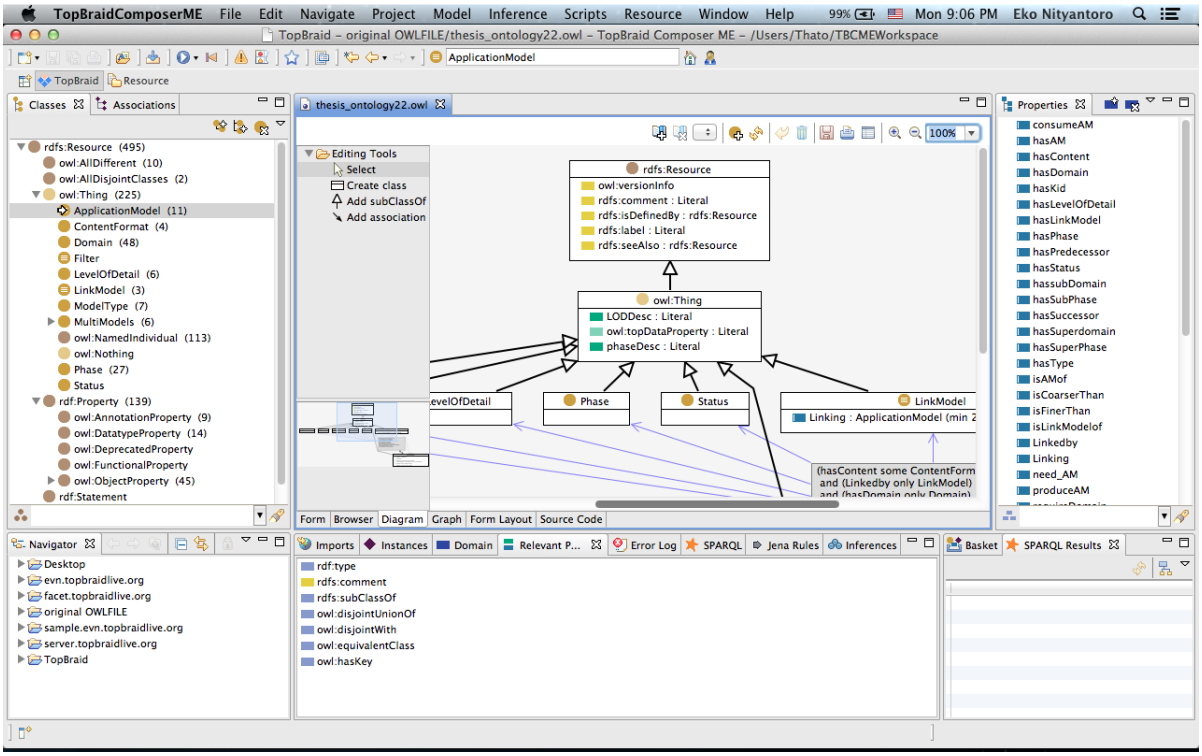

Figure 2.5: TopBraid Composer Screenshot

2.2.2.3 OntoStudio

OntoStudio[5] is based on Eclipse framework. It is not a freeware but it can be used for three months evaluation period. It is an Ontology Engineering Environment which supports ontologies development and maintenance by graphical interface. It supports multilingual development, and the knowledge model is related to frame-based languages. OntoStudio has a user-friendly interface, interactive graphic representations and support ontology mappings. However, it only supports Windows and Linux platforms, therefore it is not as flexible as other three ontology editors which are compared in this thesis.

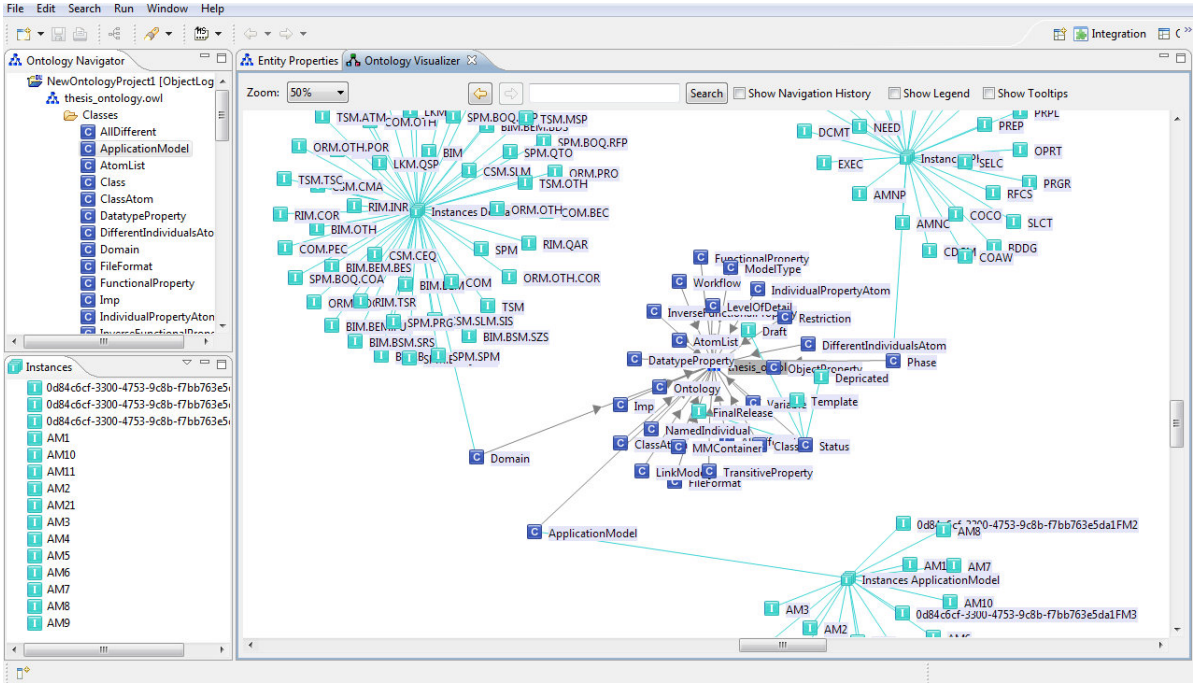

Figure 2.6: OntoStudio Screenshot

2.2.2.4 Protege 4.2

Protege[6] is a free, open-source platform that provides a growing user community with a suite of tools to construct domain models and knowledge-based applications with ontologies. At its core, Protege implements a rich set of knowledge-modeling structures and actions that support the creation, visualization, and manipulation of ontologies in various representation formats. Protege can be customized to provide domain-friendly support for creating knowledge models and entering data. Furthermore, Protege can be extended with a plugin and a Java-based Application

[5]http://www.semafora-systems.com/
[6]http://protege.stanford.edu/

Programming Interface (API) for building knowledge-based tools and applications [Pro]. Since Protege is free and open source, it is possible to find many support and plugins to work with this platform. Protege has been widely used, because it is flexible and there are also possible to work with people all around the world via Protege Ontology Editor & Knowledge Acquisition System, a forum and a support community from the Protege developer. Protege also has a user friendly and convenient GUI (Graphic User Interface).

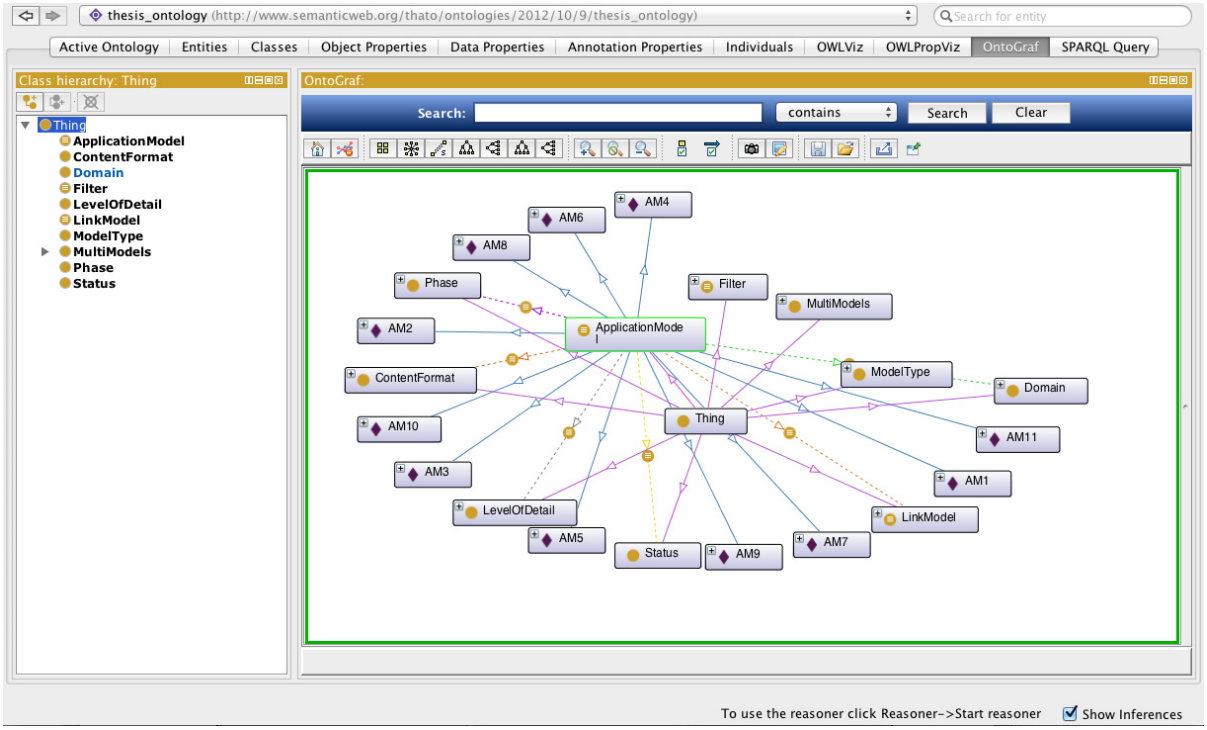

Figure 2.7: Protege Screenshot

After a small research and comparison, as it is shown in the Table 2.1, it was decided to use Protege as the editor and graphical function (Ontology Visualizer) from OntoStudio in this thesis. Protege is free, open source, user friendly, supported by many plugins, relatively stable, support different languages, platforms and file formats. The use of OntoStudio (in virtual machine) is only limited to the graphical representations.

2.2.3 Reasoning

Because the relationships used in ontologies are formally defined, the use of automated reasoner is possible. For example, a reasoner can determine if one class is a subclass of another class. This makes it possible to find the ontology's inferred class hierarchy and determine if a given class has any possible instance.

Features	Apollo	TopBraid Composer	Protege	OntoStudio
License	Freeware	30 Days Trial	Freeware, Open Source	90 Days Trial
Semantic Web Architecture	Standalone	Standalone Eclipse plug-in	Standalone, Client Server and Eclipse plug-in	Eclipse Client / server
Extensibility	Plug-in extensions	Plug-in extensions	Plug-in extensions	Plug-in extensions
Import	Apollo Meta language	RDFa, OWL, RDF(s) ,XHTML, Microdata and RDFa Data sources, SPIN, News Feed, RDF Files into a new TDB, Email and Excel (Maestro Edition)	XML(S), RDF(S), OWL, (RDF,UML, XML)backend, Excel, BioPortal and DataMaster	XML(S), OWL, RDF(S), UML Diagram, database schemas (Oracle,MS-SQL, DB2,MySQL), Outlook, file system Metadata and Remote OntoBroker
Export	OCML and CLOS	Merge / Convert RDF Graphs, RDF(S), OWL	XML(S), RDF(S), OWL, Clips, SWRL-IQ, Instance Selection, MetaAnalysis, OWLDoc, Queries and (RDF,UML, XML)backend	XML(S), OWL, RDF(S),UML and OXML
Inference engine / reasoner	Built-in	OWLIM, Pellet and SPARQL Rules	RACER, FACT, FACT++, F-logic, Pellet, SPARQL Rules, Hermit	OntoBroker
Graphical view	No	Yes (Maestro Edition)	Yes	Yes

Tab. 2.1: Ontology Tools Comparison

After the ontology is ready, the reasoner can be applied. Reasoning is the powerful mechanism to draw conclusions from facts by inferring logical consequences[7] from a set of asserted facts or axioms[8], and as the result it is possible to get new information rather than only inserted information. Protege has a built-in reasoner and other reasoners plugins are easy to get. Protege 4.2 is bundled with FaCT++ reasoner, but unfortunately this reasoner does not consider any rules when reasoning. Therefore another reasoner is required. Pellet[9] and Hermit[10] are two from among reasoners which consider rules in OWL. Hermit and Pellet can be easily used in Protege as plugin. Figure 2.8 and Figure 2.9 show the difference between the ontology without any reasoner applied and the one with reasoner. The yellow highlighted properties are the inferred properties as the result of reasoning.

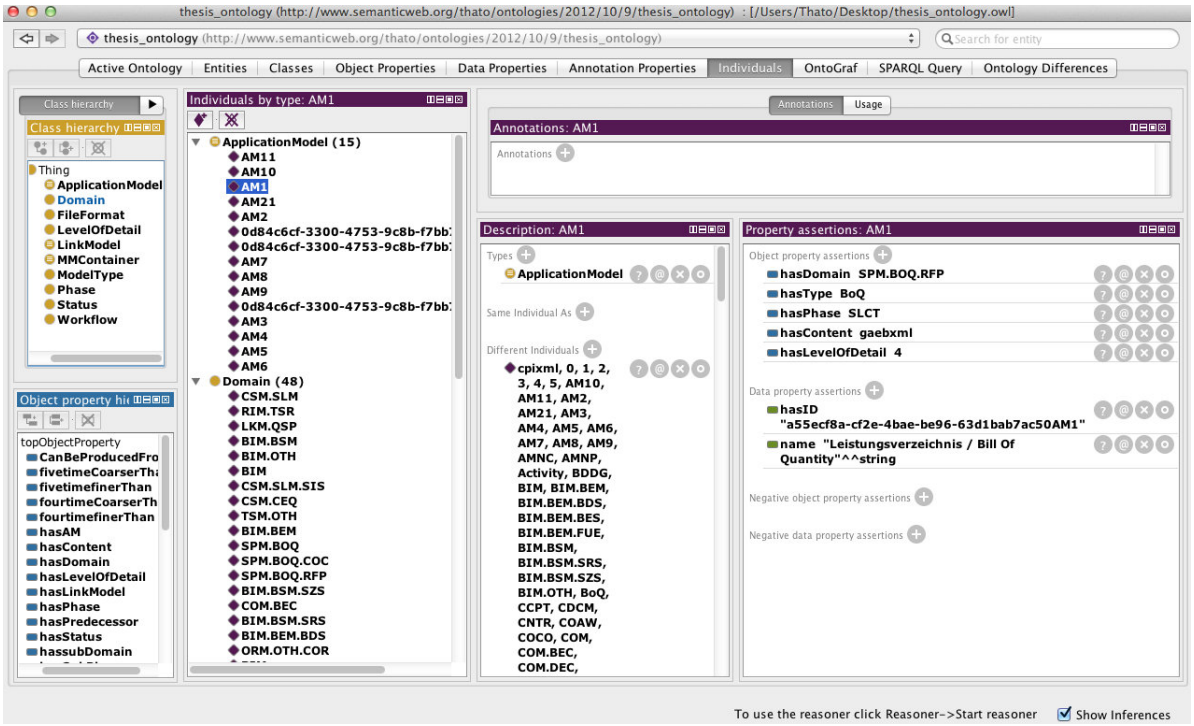

Figure 2.8: Ontology in Protege before reasoning

[7] It is the relationship between statements that holds true when one logically "follows from" one or more others, http://en.wikipedia.org/wiki/Logical_consequence
[8] A premise or starting point of reasoning, http://en.wikipedia.org/wiki/Axioms
[9] http://clarkparsia.com/pellet
[10] http://www.hermit-reasoner.com/

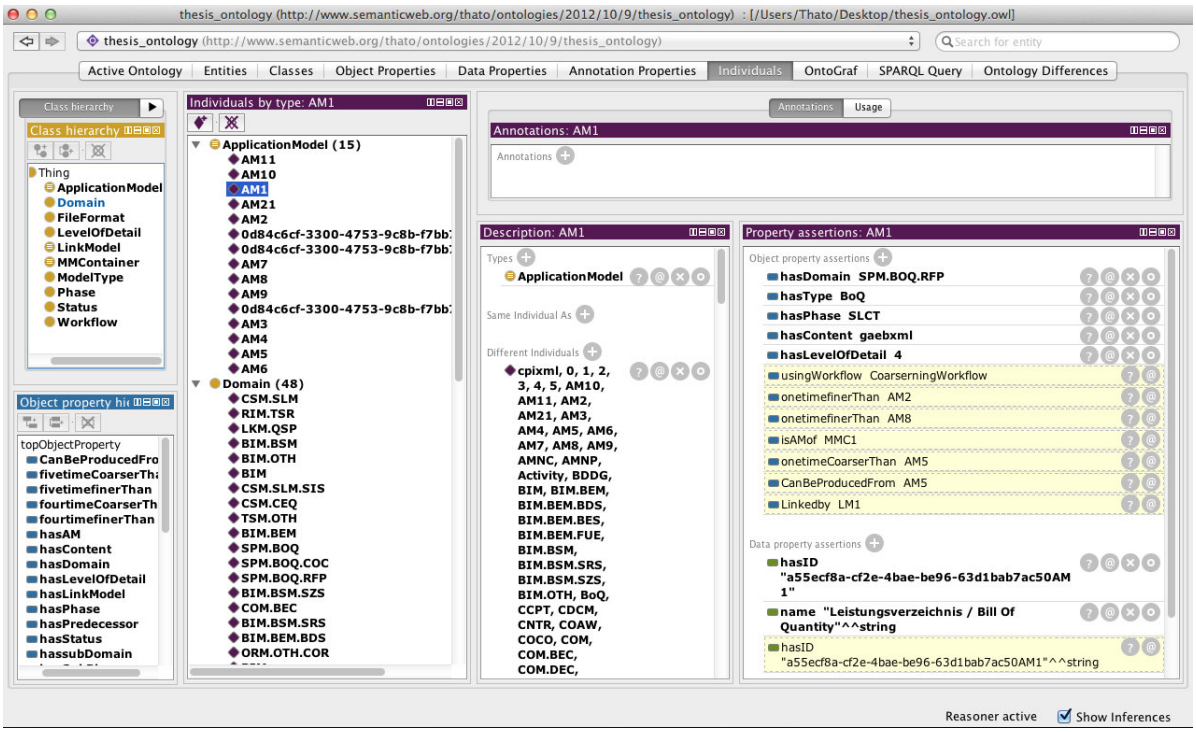

Figure 2.9: Ontology in Protege after reasoning

2.3 Ontology in Civil Engineering

In general, the main applications of ontologies in information sciences are, on the one hand, knowledge sharing and reuse [GN87], and on the other hand, the integration of data. System interoperability is defined as the ability of two or more systems or components to exchange information of various types [Ins90]. Since several years, the research to apply ontology systems in construction and Urban development domain has been done. Both objectives mentioned above are directly relevant. Knowledge sharing and reuse is a critical issue in the view of building a common knowledge or interpretation between participants (experts, stakeholders, and decision-makers).

There is a strong relationship between ontologies and various efforts to standardize models in the building context, such as the IFCs being developed by the International Alliance for Interoperability (IAI). Whereas data exchange standards for a long time are focused on the syntactic level on how information should be presented, the widespread use of XML now encourages standardization efforts to shift to the semantic level of the things about which information should be represented.

The actual use of ontology in Civil Engineering field are mostly for Urban

Development, there are ontologies to improve communication in urban development projects, ontologies for Urban Databases, ontology for Land Development Decision and Plans, City Ontology and many more. In Building Construction Ontologies [vR06], for example Bridge-Building Ontology or Housing Ontology, ontology improves communication between participants. In building construction, there are many terms describe components, materials, connections, equipment and such. Formally defining so many domain-specific terms is not a simple task, but a smart system will be able to enhance the industry's capacity to communicate and co-operate. And since ontology can improve communication in construction, therefore it can be the answer of this problem. Ontology is able to clustering various aspects (e.g. bridges, installation, roofs). Clustering means to separate them by their specific domain, and the clustering should be clear and simple. The resulting clusters are quite big, but the majority of all participants are familiar with these terms. The cluster can be even bigger if it is clustered by ground or water works, buildings, equipments, etc.

In building construction ontology, every cluster will have their own OWL file. For unique identification of the terms in an OWL ontology, OWL uses a mechanism to give every term its own URL. Every OWL ontology should get its own 'base' URI, in this way no ontology can overlap another. The OWL ontology format is built in RDF, the linking mechanism using NS internet. This mechanism is able to link from one item in an ontology to another item in another ontology identified by URI. This make it possible to say that one of the parts of the bridge (in Building-Bridge Ontology) is a foundation (which can be found in Housing Ontology).

Other than Building Construction Ontology, there is also a research about feature ontology which can support construction cost estimating. This research has formalized a vocabulary that classifies three types of features, defines the attributes and functions of each feature type, and represents the relationships between features explicitly. The descriptive semantics of the models are flexible enough to represent estimators varied preferences for naming features, specifying features that result from the component intersections and the similarity of components, as well as grouping features that affect a specific construction domain.

2.4 Ontology in Other Domain

Nowadays the usage of ontology has been developed in many fields. Since ontology is developed by Medical Informatics student in Stanford, therefore one of

the largest usage of ontology is in Medical sciences. One of the most comprehensive, multilingual healthcare terminology in the world is Systematized Nomenclature Of Medicine Clinical Terms (SNOMED-CT). This is a systematically organized computer processable collection of medical terms providing codes, terms, synonyms and definitions covering diseases, findings, procedures, microorganisms, substances, etc. It provides a consistent way to index, store, retrieve, and aggregate clinical data across specialties and sites of care. It also helps in organizing the content of medical records, reducing the variability in the way data is captured, encoded and used for clinical care of patients and research. The primary purpose of SNOMED CT is to support the effective clinical recording of data with the aim of improving patient care [iht].

Ontology is also used in e-Business to capture a common understanding of the terms and their interpretation. Using the concept of business models can help companies understand, communicate and share, change, measure, simulate and learn more about the different aspects of e-business in their firm. The generic e-Business Model Ontology (a rigorous definition of the e-business issues and their interdependencies in a company's business model), the outline is the foundation for the development of various useful tools for e-business management and IS Requirements Engineering. The e-Business Model Ontology is based on an extensive literature review and describes the logic of a "business system" for creating value in the Internet era. It is composed of four main pillars, which are Product Innovation, Infrastructure Management, Customer Relationship and Financial Aspects [OP02].

In general, ontology is divided into two types: *transcendent* ontologies, which are authoritative and defined externally from the applications that use them, and *immanent* ontologies, in which the structure is defined by the domain's knowledge content.

An example of transcendent ontologies [Jep09] is the periodic table of chemistry. This periodic table has never been altered, if we look to this table the noble gases such as helium and neon, the halogens, such as chlorine and fluorine. Any kind of new elements would have to be added to an already existing category, and everyone especially chemist in the world have to agree with that. It can be a new element but it still belongs to the specific category, there is no way we can add a new family of elements.

A simple example of immanent ontology is a structure of a news paper, the structure would change on a daily basis, depends on the news of the day. One day's ontology might include articles on politics, the next day might include a report of stormy weather.

Advantages	Disadvantages
Interoperability	New Concept for many user
Flexibility	Reasoning complexity is high
Consistency and quality checking	Security still questioning
Reasoning	

Tab. 2.2: Ontology advantages and disadvantages

Like any other thing in the world, ontology has advantages and disadvantages. Ontology is still developing, we can expect in the near future, that we will get more advantages of ontology than disadvantages. Basically, these advantages and disadvantages can be variant, depends on the domain where ontologies are used. Table 2.2 shows the advantages and disadvantages of ontology in general.

2.5 Project Mefisto

The main aim of this project was to develop an information management system in a collaboration between participants, construction planning process as well as construction management. This project demonstrate a software solution to collaborate planning and controlling information inside what so called multi-model. Multi-model sustain a transparent representation from a required construction tasks for further comprehensive analysis of a project performance and risk and also for a better management in a collaboration on construction management. This system will empower a real-time visual descriptive simulation based on up-to-date operational data in all abstractive stage [MEF].

The development starting points in Mefisto are the design of the models, engineering and management which is used in construction planning and management. By combining these models this project has done something beyond the boundaries of corporations, AEC/FM disciplines and organizational hierarchy. This enables a flexible integration of a project information to evaluate the current project plans in a better way as well as to simulate and analyze the consequences of designs and management decisions.

Not like in BIM, in Mefisto different applications such as 3D building models, bill of quantities, and time schedules are behold as equal. Moreover, it assumed that in a long term plan the application model will be created separately with certain software and stored locally by the different partners.

To use the project information from specialized model between the same or different domain, project Mefisto developed a multi-model approach. This is an

aggregate of independent domain-specific models (e.g. building models, site plan) that can be linked by a link model targeted for specific applications, domain, or project phases. Such multi-models are defined as templates which are called multi-model template.

The development of Mefisto concentrates in three areas [RIB]:

Multi-models and multi-model containers, multi-models consist of multiple related model which can be compiled and evaluated with a certain software application and able to exchange by using multi-model containers

Mefisto Platform, is a platform which connects the software applications of the project partners with a Web Service interface as a mediator and to coordinates the exchange of the multi-model which is supported by central platform service.

Information logistic, defines a standard business logic for the usage of multi-model to manage collaboration process in order to create and to advanced the elementary models as well as the affiliated access rights.

The topic of this thesis is Information Logistic, therefore the scenarios and samples used in this thesis are based and taken from project Mefisto.

3 Recombination of Multi-models

In this chapter will be explained the Idea of recombination of multi-models, why it is necessary and what is the main goal. The scenarios of how to use the multi-models will be explained in this chapter as well. The task is not to create a new elementary model, but to recombine existing elementary models with new elementary models into a new multi-model container.

3.1 Multi-model Container, Multi-model Template and Elementary Model

Multi-models consist of multiple related models which can be compiled and evaluated with a certain software application and able to exchange by using multi-model containers. Multi-model template is the container which consist the requirement of desired elementary models. The idea of a multi-model is to combine both engineering and management models in a single information resource. The elementary models in the container are bounded with a link model. By the existence of a link model a consistent multi-model that represents a certain status of a project as well as the general information of the project can be achieved [RIB, MEF].

Participants can use software application, such as iTWO (RIB Software AG), GRANID (gibGreiner GmbH) and SolidWorks (SolidWorks GmbH) to create their own multi-model container [RIB].

Elementary model itself can be any kind of either engineering model or management model. Such as IFC, for the exchange of building information models (BIM) or GAEBXML[1] (German Joint Committee for Electronics in Construction), a standard for construction information exchanged during construction bidding, contracting and invoicing as well as during construction execution can be used as the format of elementary model. As shown in Figure 3.1, a multi-model container consists of a 3D building model and calculated quantities deduced from its elements.

[1] http://www.gaeb.de/produkte505.php

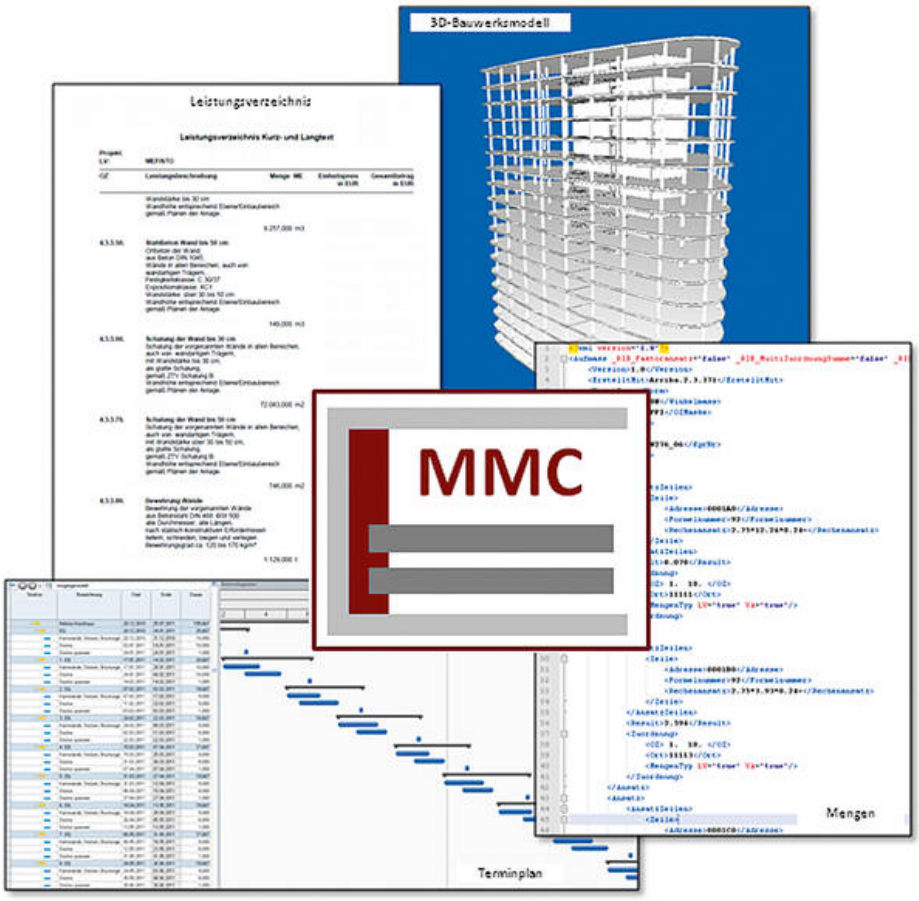

Figure 3.1: multi-model container[RIB]

These can be interlinked with the items in a bill of quantities and a corresponding cost calculation as well as with the activities of a time schedule. With multi-models the different aspects from the needed tasks and the auxiliary measures can be transparently presented.

3.1.1 Multi-model Containers

As mentioned before, communication between participants in Mefisto platform shall use multi-model container (Figure 3.2) as an exchange format. The container defines a structure to bundle different kinds of elementary models. Elementary models are treated as independent information resources with their application domain, data schema and data formalization. In this way multi-models can be applied in any domain [RIB]. Each multi-model container is realized by exchange compressed archive file. The container contains an XML-based description of its contents (Code 2). It provides metadata on the subjects, detailing and data format as well as the creators or contributors for each elementary models. The MMC examples used in

this thesis are taken from the MMC sample file (Leistungsfeststellung 2012-07.mmc) from Mefisto which were presented in Mefisto Congress[2].

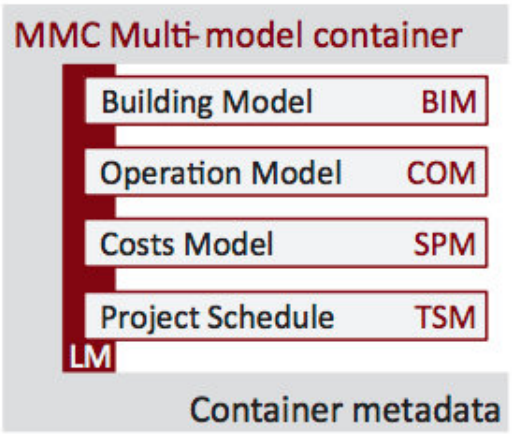

Figure 3.2: Example Structure of MMC [HSA11]

```
<?xml version="1.0"?>
<container guid="0d84c6cf-3300-4753-9c8b-f7bb763e5da1" formatVersion="1.0">
	<meta>
		<origin>
			<created>2012-09-13T09:33:12</created>
			<creatorId>dej</creatorId>
			<appVersion>3.2.134</appVersion>
			<application>iTWO64</application>
		</origin>
		<info>
			<i k="ContainerDescription" t="xs:string" v="MMC-Datenaustausch zur Leistungsfeststellung."/>
			<i k="ContainerFromTemplate" t="xs:string" v="Auftrag_Leistungsfeststellung.mmt"/>
			<i k="ContainerName" t="xs:string" v="Leistungsfeststellung 2012-04"/>
			<i k="ContainerType" t="xs:string" v="MMC Leistungsfeststellung"/>
			<i k="TemplateName" t="xs:string" v="Leistungsfeststellung"/>
		</info>
	</meta>
	<models>
		<model contextId="\Projekte\Mefisto\M04 V2 (AusfÃŒhrung)\Projektvarianten\01" type="BoQ" id="FM1">
			<meta>
				<origin>
					<created>2012-09-13T09:33:12</created>
					<creatorId>dej</creatorId>
					<appVersion>3.2.134</appVersion>
					<application>iTWO64</application>
				</origin>
				<info>
					<i k="ModelName" t="xs:string" v="Leistungsverzeichnis "/>
				</info>
				<phase phaseCode="&#x3e;PRCR&#x3e;BDDG" phaseDesc="Angebotserstellung"/>
				<domain domainDesc="Angebotsabgabe" domainCode="SPM.BOQ.BDP"/>
				<levelOfDetail levelOfDetailDesc="Bauwerkselemente, Objektplanung" levelOfDetailCode="[4]"/>
			</meta>
			<content format="gaebxml" id="1" formatVersion="3.1">
				<contentOptions>
					<i k="description" t="xs:boolean" v="0"/>
					<i k="extension" t="xs:string" v="DA81"/>
					<i k="qtosplit" t="xs:boolean" v="0"/>
					<i k="unitrate" t="xs:boolean" v="1"/>
					<i k="unitrate_breakdown" t="xs:boolean" v="1"/>
				</contentOptions>
				<file namespace="BoQ1">file:///BoQ/1/LV 1.X81</file>
			</content>
		</model>
		<model contextId="\Projekte\Mefisto\M04 V2 (AusfÃŒhrung)\Projektvarianten\01" type="Object" id="FM2">
```

Code 1: MultiModel.xml (Metadata of Leistungsfeststellung 2012-07.mmc from project Mefisto)

[2]http://tu-dresden.de/die_tu_dresden/fakultaeten/fakultaet_bauingenieurwesen/cib/news/mefkong3

```
                        <meta>
                                <origin>
                                        <created>2012-09-13T09:33:12</created>
                                        <creatorId>dej</creatorId>
                                        <appVersion>3.2.134</appVersion>
                                        <application>iTWO64</application>
                                </origin>
                                <info>
                                        <i k="ModelName" t="xs:string" v="GebÃ€udemodell"/>
                                </info>
                                <phase phaseCode="&#x3e;PRCR&#x3e;BDDG" phaseDesc="Angebotserstellung"/>
                                <domain domainDesc="GebÃ€udemodell" domainCode="BIM"/>
                                <levelOfDetail levelOfDetailDesc="Bauwerkselemente, Objektplanung" levelOfDetailCode="[4]"/>
                        </meta>
                        <content format="ifc" id="c1" formatVersion="2x3">
                                <file>file:///Object/c1/BW.ifc</file>
                        </content>
                        <content format="cpixml" id="c2" formatVersion="1.4">
                                <file>file:///Object/c2/BW.cpixml</file>
                                <file>file:///Object/c2/buildingStructure.cpixml</file>
                        </content>
                </model>
                <model contextId="\Projekte\Mefisto\M04 V2 (AusfÃŒhrung)\Projektvarianten\01" type="QTO" id="FM3">
                        <meta>
                                <origin>
                                        <created>2012-09-13T09:33:12</created>
                                        <creatorId>dej</creatorId>
                                        <appVersion>3.2.134</appVersion>
                                        <application>iTWO64</application>
                                </origin>
                                <info>
                                        <i k="ModelName" t="xs:string" v="Teilmengen BoQ-BIM"/>
                                </info>
                                <phase phaseCode="&#x3e;PRCR&#x3e;BDDG" phaseDesc="Angebotserstellung"/>
                                <domain domainDesc="Modellberechnete Mengen" domainCode="SPM.QTO.MCQ"/>
                                <levelOfDetail levelOfDetailDesc="Bauwerkselemente, Objektplanung" levelOfDetailCode="[4]"/>
                        </meta>
                        <subset subsetCode="RE" subsetDesc="RE-Mengen">
                                <subsetFilter application="M2A2">BQ(1)</subsetFilter>
                                <subsetFilter application="iTWO">BQ(1)</subsetFilter>
                        </subset>
                        <content format="xml" id="1" formatVersion="1.1">
                                <file namespace="QTO1">file:///QTO/1/1 LV VA.xml</file>
                                <file namespace="QTO2">file:///QTO/1/1 RE LE.xml</file>
                        </content>
                </model>
        </models>
        <linkModels>
                <linkModel type="QuantitySplit" id="L1">
                        <meta>
                                <origin>
                                        <created>2012-09-13T09:33:12</created>
                                        <creatorId>dej</creatorId>
                                        <appVersion>3.2.134</appVersion>
                                        <application>iTWO64</application>
                                </origin>
                                <info>
                                        <i k="ModelName" t="xs:string" v="Linkmodell"/>
                                </info>
                                <domain domainDesc="Link Model" domainCode="LKM.QSP"/>
                        </meta>
                        <subset>
                                <subsetFilter application="iTWO">NotEmpty[FM3]</subsetFilter>
                        </subset>
                        <models>
                                <model id="FM1"/>
                                <model id="FM2"/>
                                <model id="FM3"/>
                        </models>
                        <file>file:///links/links.xml</file>
                </linkModel>
        </linkModels>
        <context>
                <element type="Other" id="\Projekte">
                        <name>Projekte</name>
                        <element type="Other" id="\Projekte\Mefisto">
                                <name>Mefisto</name>
                                <element type="Project" id="\Projekte\Mefisto\M04 V2 (AusfÃŒhrung)">
                                        <name>M04 V2 (AusfÃŒhrung) Flughafen - Mefistoareal</name>
                                        <element type="Other" id="\Projekte\Mefisto\M04 V2 (AusfÃŒhrung)\Projektvarianten">
                                                <name>Projektvarianten</name>
                                                <element type="Alternative" id="\Projekte\Mefisto\M04 V2 (AusfÃŒhrung)\Projektvarianten\01">
                                                        <name>01 Auftrag vom 20.03.2012</name>
                                                </element>
                                        </element>
                                </element>
                        </element>
                </element>
        </context>
</container>
```

Code 2: MultiModel.xml (continued, metadata of Leistungsfeststellung 2012-07.mmc from project Mefisto)

Metadata consists of an information about the elementary models inside the container. Not just that, metadata can also build a multi-model template that prescribe the requirements regarding which content and formalization of elementary models are needed in a certain project [RIB]. In principal, multi-model containers consist of elementary models from different domains and each model can be independently processed by participants.

Each participant has the opportunity to create or develop their own elementary models and link it with existing models. This opportunity creates a possibility for participants to recombine the multi-models base on what they need as well as based on requirement of the project itself.

3.1.2 Multi-model Templates

Although participants are allowed to construct their own model, by getting the elementary models from the storage, they need to use multi-model template (MMT). Multi-model template is not created by the participants, participants should use one of MMT that has been provided.

MMT is a reference model which consist of partially filled MMC with metadata about the required elementary models [SSK10]. Participants might have different skills and tasks, it is not necessary for them to know all models in technical detail. Therefore MMCs may consist of task depending set of various elementary models, described by MMT.

As described by Hilbert, in the Project Collaboration Ontology [Hil13], the template retrieval starts by selecting suitable registered content for the described situation. Based on the detected content templates can be chosen whose characteristics allow processing in this context. Thereby templates can already contained preset models as basis for subsequent processing.

When a participant accepts a suggested template, the corresponding container with possible preset models is generated. Otherwise on the basis of existing Templates and in conjunction with the entity ontologies, it is also possible to suggest and add new templates. As result we can ensure that the involved collaboration participants retrieve a task- and situation-specific selection of multi-model templates matching the current state of all project entities and the basic idea is to describe the product model instances and templates for better assignments of participants and process [HS12].

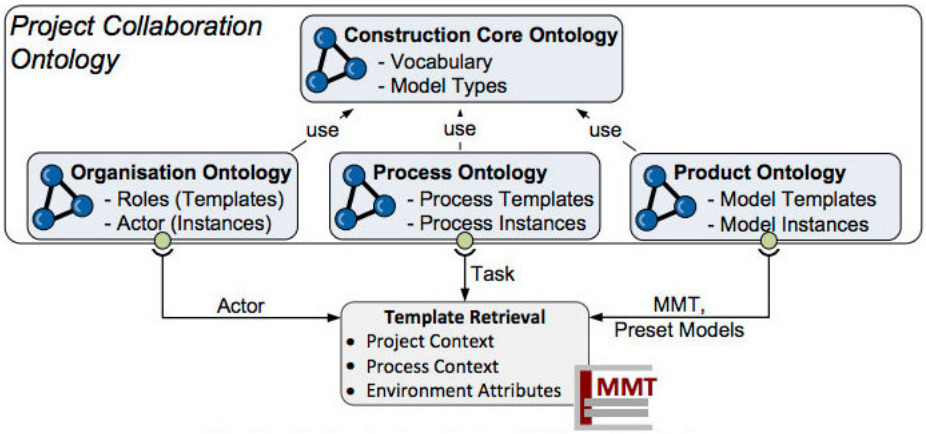

Figure 3.3: MMT Retrieval in Project Collaboration Ontology[Hil13]

3.2 Multi-model Recombination Scenario

Two scenarios will be introduced in this thesis. The first scenario is to register a new elementary model inside multi-model container into the Multi-Model Ontology, and the second scenario is to get the information from Multi-Model Ontology about the existence of required elementary models as shown in Figure 3.4. It is assumed that each participants have the same role to create and to request a meta-information about an elementary model.

Beside creating and requesting, participants also have to store their created elementary models in a particular storage which can be accessed by other participants and provide the information about the storage URL when registering the new elementary model. And to keep in mind, all elementary models are bundled in a multi-model container.

Multi-model Container (MMC) consist of one or more elementary models. As it has been briefly explained in Chapter 2, MMC contains several elementary models such as BIM, Cost-Pricing, as well as Scheduling. Each Elementary Model can be in different file formats such as ifc, cpixml, gaebxml, and xml. These different kinds of file formats have been approved by all participants as the readable format in their systems. A long with the agreement of the format, it is also important to have an agreement regarding the vocabulary, what is included in vocabulary are languages, abbreviations, etc.

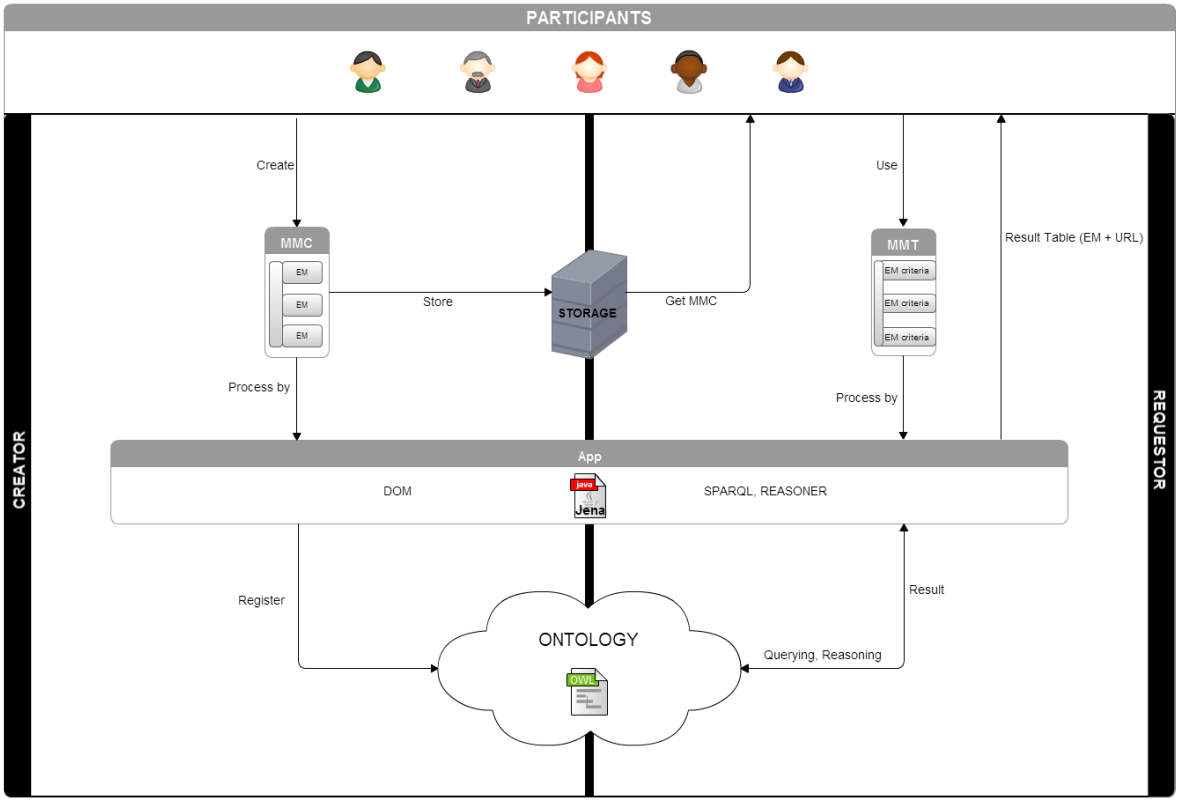

Figure 3.4: General Scenario

3.2.1 Creator Role Scenario

As explained before, in project Mefisto, each participant has an opportunity to construct their own elementary model. There can be many kinds of elementary models, based on the roles and needs of each participant. In the previous section has been explained that all elementary models are bundled in multi-model container. As can be seen in Figure 3.3, after creating the multi-model container, participants have to register their new container which includes their new elementary models. Registration is not to insert the multi-model in certain storage, but only to add information that there are new multi-models with particular elementary models within have been created.

In the previous section, has been clearly explained that each multi-model has metadata, this metadata provides the information about what kind of elementary models inside the multi-model and more detail attributes about the multi-models. These metadata are the information which will be registered in the Multi-Model Ontology.

While registering the multi-model, participants should also provide the URL address where they keep the file, this storage can be either in their own server, cloud services or many other possible storage. As long as this storages are accessible to another participants in a particular project.

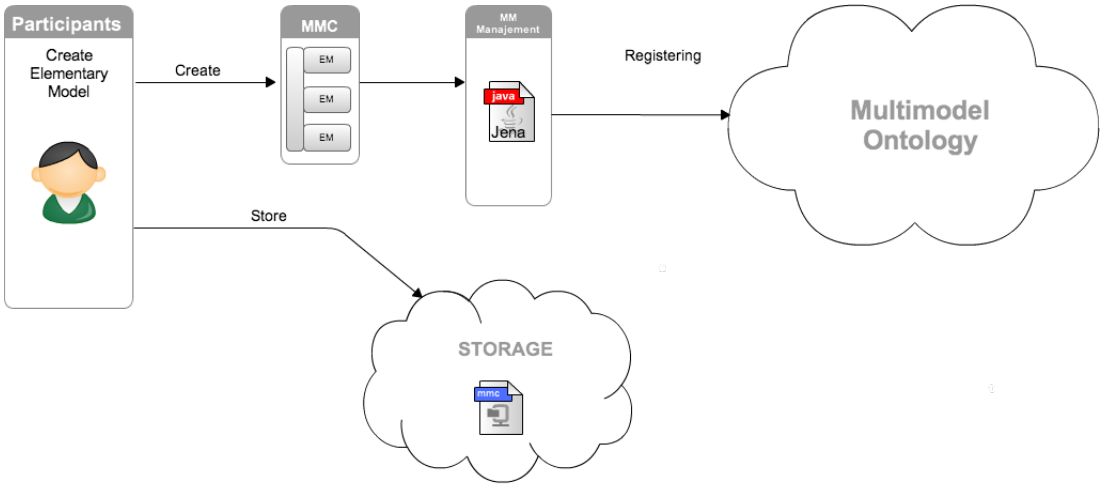

Figure 3.5: Creator Role

3.2.2 Requestor Role Scenario

Not just as a creator, participants also have role as a requestor, which means that participants might need some other elementary models which are made by other participants. The role requestor does not mean that one participant sending request to other participants, but a participant is sending request to the Multi-Model Ontology to get the information whether their required elementary models are already created or not. To create multi-model containers (MMC), participants need to use multi-model template (MMT). This template can be created by the participants them self or they can get it from multi-model template provider. Multi-model template is an empty container, so the participants do not have to create or insert any elementary model. With this MMT participants can sending a request to the Multi-Model Ontology.

After sending a request, participants will get the list of appropriate elementary models. The result might have one or more elementary models, and the participants have to choose which elementary model fits their request. To get the requested multi-model container, the requestor can get it from the URL address provided by the creator. The mechanism of how to get the multi-model from the storage will not be discussed in detail, but as an assumption, the requestor can get the multi-model by having access to the storage, given by the creator.

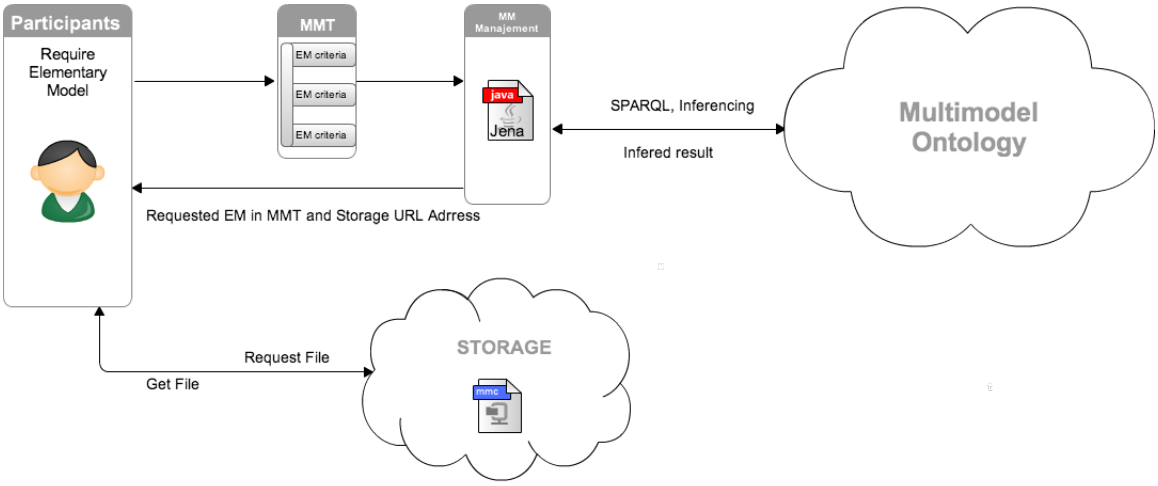

Figure 3.6: Requestor Role

3.2.3 New Combination of Multi-model

As the result of both roles, the new combination of multi-models can be made. It is called new combination because it consists of elementary models which were inside the previous multi-models created by another participants plus the new elementary model.

The new multi-model should have a unique name or ID, otherwise it cannot be registered in the Multi-Model Ontology. Based on of the nature of ontology, it will reject any kind of the same instance names and it can caused inconsistency in the ontology. The elementary models inside the new multi-models might have exactly the same properties with one of the registered elementary model. These elementary models will be registered to ontology as a different instance with different ID because it is bundled in the different multi-model container, and the naming of new elementary model will follow the name of the multi-model container's ID. It means that it is possible that there is an elementary model with two different IDs.

4 Implementation

The how-to will be described in this chapter. How to create and what is inside of the ontology, how to register and to get the information from Multi-models Ontology, what kind of tools are used. Beside that this chapter also explains how the reasoner can help participants to reduce the complexity and to save time and cost.

4.1 Multi-Model Ontology

To create the Multi-Model Ontology, an editor is required, and as already explained before, Protege is chosen to build this ontology. To an build ontology, it is important to define what kind of information needed for the ontology, such as vocabulary used so on. In the project Mefisto, there is information about the domain, phase, level of detail, and also status of each elementary model. Each elementary model will be classified based on this information. With ontology it is possible to create a class and then define which individual will be in the class.

First important things to create are classes, based on the meta data of multi-models, elementary models and also vocabulary library. After studying about the structure of the multi-models and all the attribute it has, there are 10 classes can be created in the Multi-Model Ontology, and there are relations between those classes (Figure 4.1). Those classes are :

1. ApplicationModel (class for elementary model)
2. FileFormat (class for the format attribute of elementary models)
3. Domain (class for domain attribute of the elementary models)
4. Workflow (class for workflow or filter to produce certain elementary models)
5. LevelOfDetail (class for level of detail attribute of elementary models)
6. LinkModel (class for link models connecting elementary models)
7. ModelType (class for type attribute of elementary models)

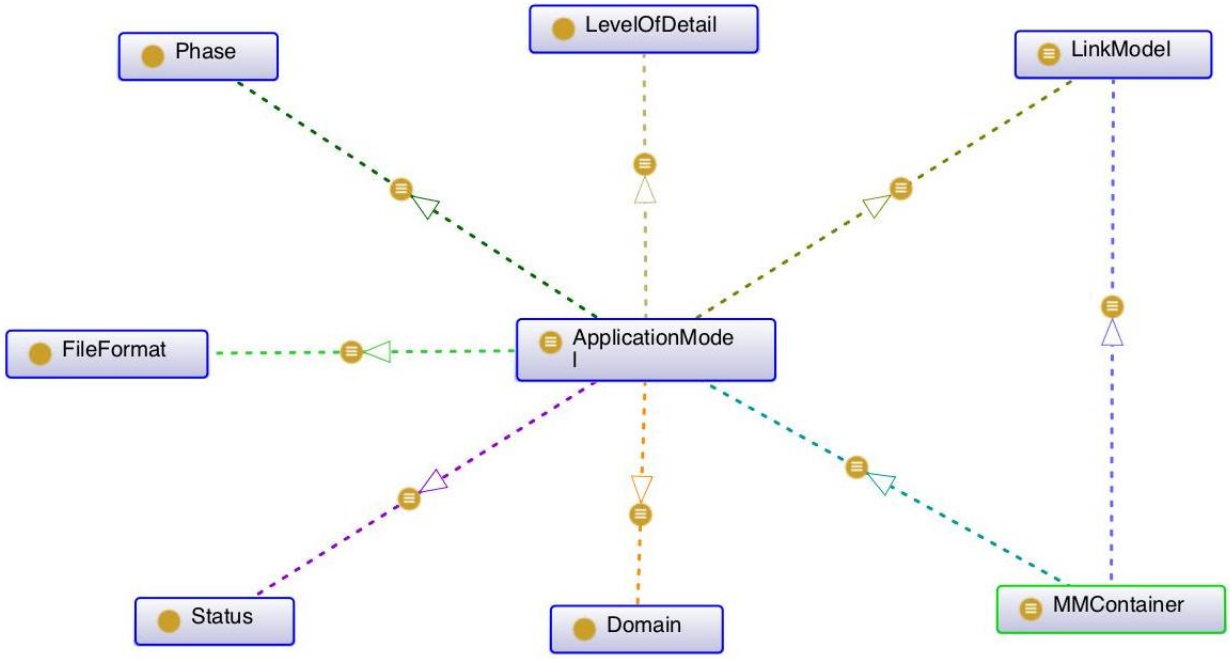

Figure 4.1: Relation between Classes

8. MMContainer (class for multi-model container)
9. Phase (class for phase attribute of elementary models)
10. Status (class for elementary models status attributes)

Classes are disjoints with one and another, has annotation, definition, description, and individuals as the member of the class. For example, class ApplicationModel. This class has annotation that this class also can called elementary model (Fach modell in German). The description can be also the requirement (restriction) of how this class behaves, for example member of ApplicationModel can only have level of detail from class LevelOfDetail and only one level of detail, it is also shown the relation between ApplicationModel class and LevelOfDetail class. It is impossible that an elementary model has a level of detail from class Domain or has more than one level of detail (Figure 4.2).

Protege can provide the relationship between instances in the class. Besides that protege also allowed an individual as a property of another individual, this function called object property. Object properties define the relationships (predicates) between two objects (also called individuals) in an OWL ontology. For example, each elementary model has domain, phase, level of detail then the object property will be 'hasDomain' for domain, 'hasPhase' for phase and 'hasLevelOfDetail' for

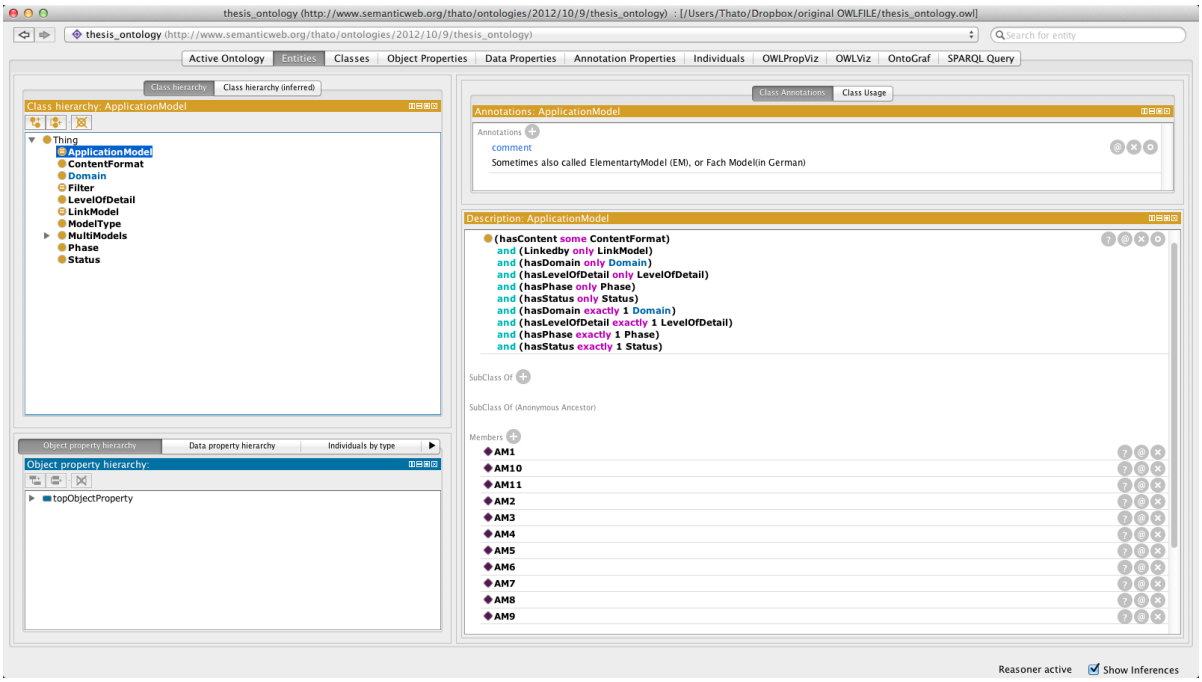

Figure 4.2: Classes and its description in Protege

level of detail. Figure 4.3 shows that the object property 'hasPhase' of individual AM11 is individual BDDG, which is also an individual from class Phase.

Besides object property, there is also datatype property. Datatype property is an attribute of each individuals, which the value is a data literal. In Figure 4.3 can be seen that the Individual AM11 has an id, it shows by datatype property name 'hasID'.

In protege, it is also possible to have a graphical view. It will be easier to understand the structure of the ontology with the graphical view. Figure 4.4 is a graphical representation of individual AM11, the same individual as in the Figure 4.2.

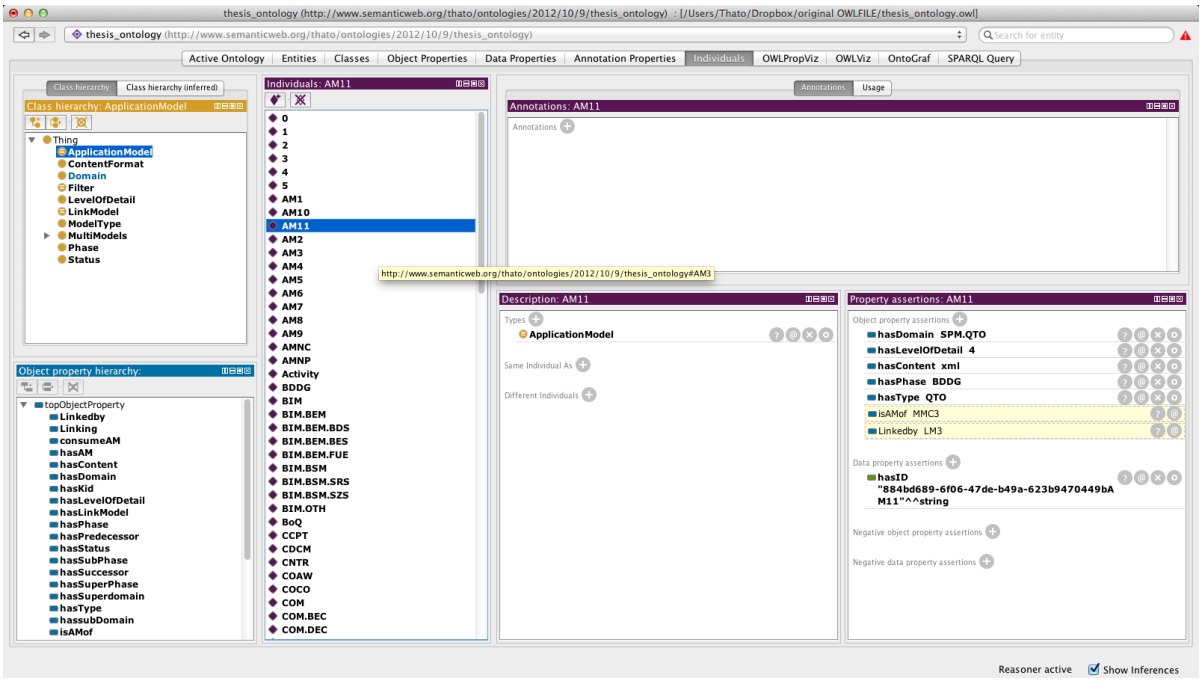

Figure 4.3: Properties of an Individual

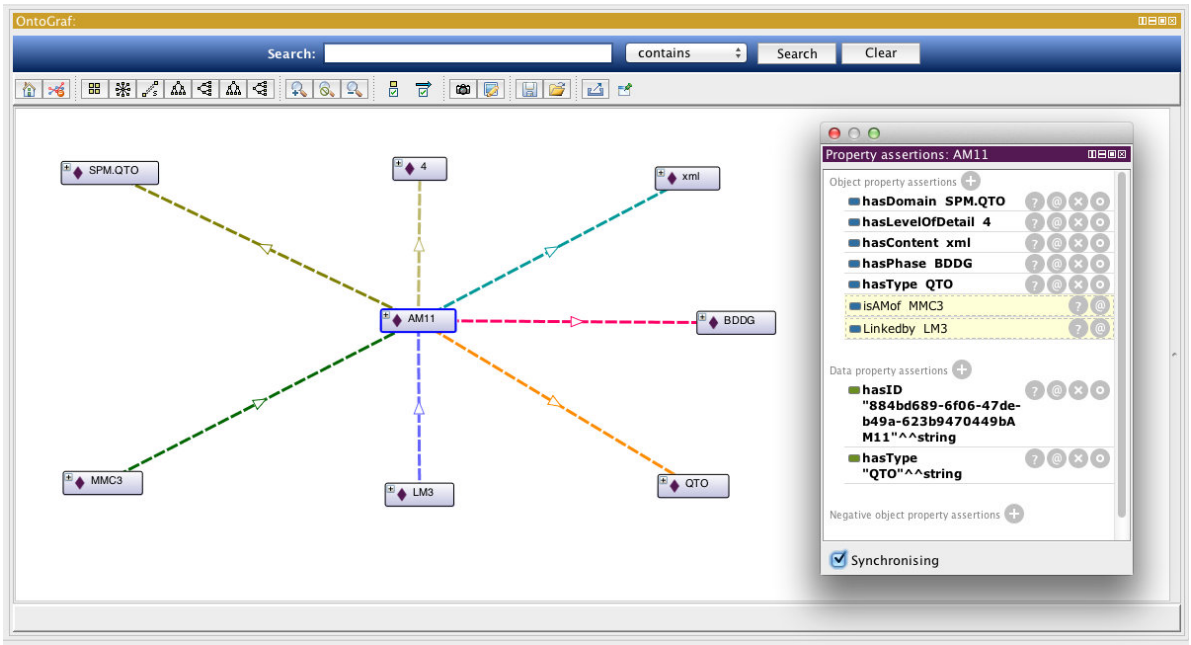

Figure 4.4: Graphical View of Individual AM11

4.1.1 ApplicationModel Class

ApplicationModel Class, is a class where all elementary model will be registered. The elementary models are the individual of this classes. The existing elementary models or the future elementary models will be the part of this class. In Multi-

Model Ontology this class has its own unique resource identifier (URI), which is useful to recognize each class and to distinguish one from another. The structure of this class in web ontology language is shown in Code 3.

```
<owl:Class rdf:ID="ApplicationModel">
    <rdfs:subClassOf rdf:resource="http://www.w3.org/2002/07/owl#Thing"/>
    <owl:equivalentClass>
        <owl:Class>
            <owl:intersectionOf rdf:parseType="Collection">
                <owl:Restriction>
                    <owl:onProperty rdf:resource="#hasContent"/>
                    <owl:someValuesFrom rdf:resource="#ContentFormat"/>
                </owl:Restriction>
                <owl:Restriction>
                    <owl:onProperty rdf:resource="#Linkedby"/>
                    <owl:allValuesFrom rdf:resource="#LinkModel"/>
                </owl:Restriction>
                <owl:Restriction>
                    <owl:onProperty rdf:resource="#hasDomain"/>
                    <owl:allValuesFrom rdf:resource="#Domain"/>
                </owl:Restriction>
                <owl:Restriction>
                    <owl:onProperty rdf:resource="#hasLevelOfDetail"/>
                    <owl:allValuesFrom rdf:resource="#LevelOfDetail"/>
                </owl:Restriction>
                <owl:Restriction>
                    <owl:onProperty rdf:resource="#hasPhase"/>
                    <owl:allValuesFrom rdf:resource="#Phase"/>
                </owl:Restriction>
                <owl:Restriction>
                    <owl:onProperty rdf:resource="#hasStatus"/>
                    <owl:allValuesFrom rdf:resource="#Status"/>
                </owl:Restriction>
                <owl:Restriction>
                    <owl:onProperty rdf:resource="#hasDomain"/>
                    <owl:onClass rdf:resource="#Domain"/>
                    <owl:qualifiedCardinality rdf:datatype="http://www.w3.org/2001/XMLSchema#nonNegativeInteger"
                        >1</owl:qualifiedCardinality>
                </owl:Restriction>
                <owl:Restriction>
                    <owl:onProperty rdf:resource="#hasLevelOfDetail"/>
                    <owl:onClass rdf:resource="#LevelOfDetail"/>
                    <owl:qualifiedCardinality rdf:datatype="http://www.w3.org/2001/XMLSchema#nonNegativeInteger"
                        >1</owl:qualifiedCardinality>
                </owl:Restriction>
                <owl:Restriction>
                    <owl:onProperty rdf:resource="#hasPhase"/>
                    <owl:onClass rdf:resource="#Phase"/>
                    <owl:qualifiedCardinality rdf:datatype="http://www.w3.org/2001/XMLSchema#nonNegativeInteger"
                        >1</owl:qualifiedCardinality>
                </owl:Restriction>
                <owl:Restriction>
                    <owl:onProperty rdf:resource="#hasStatus"/>
                    <owl:onClass rdf:resource="#Status"/>
                    <owl:qualifiedCardinality rdf:datatype="http://www.w3.org/2001/XMLSchema#nonNegativeInteger"
                        >1</owl:qualifiedCardinality>
                </owl:Restriction>
            </owl:intersectionOf>
        </owl:Class>
    </owl:equivalentClass>
    <rdfs:comment>Sometimes also called ElementartyModel (EM), or Fach Model(in German)</rdfs:comment>
</owl:Class>
```

Code 3: OWL Format of ApplicationModel Class

4.1.2 FileFormat Class

This class determines the realization of an elementary model. One elementary model can have different format because it is possible that one of the participants does not have an application which can read certain file. For example, an elementary model with ifc file format can also be stored as cpixml file format.

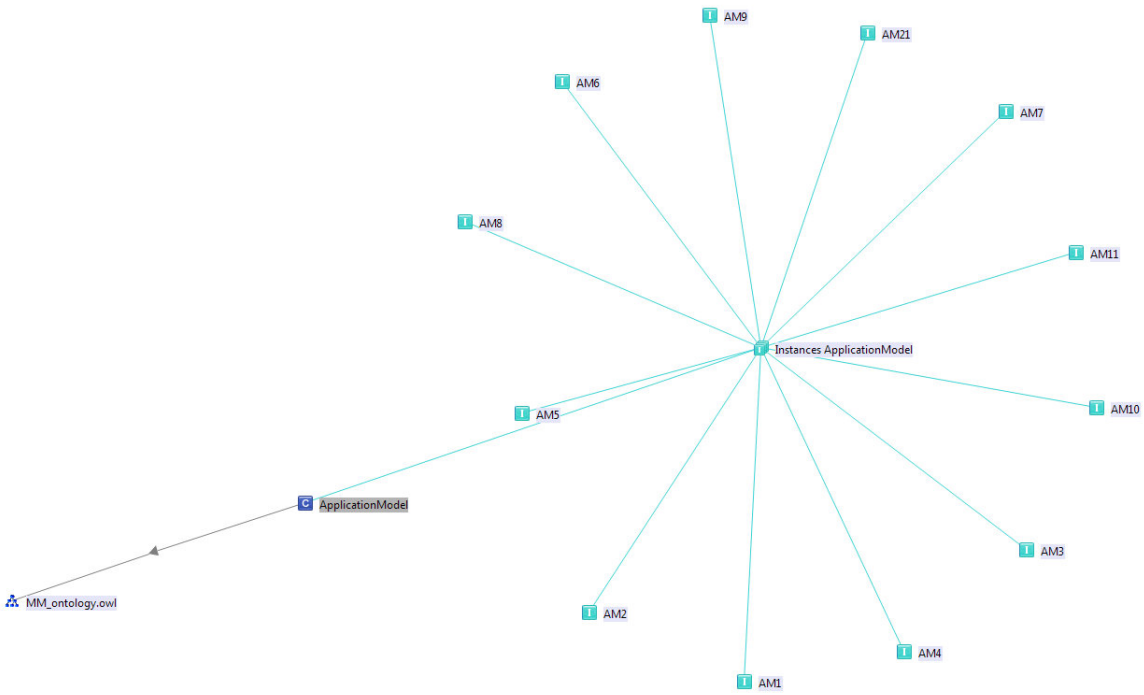

Figure 4.5: ApplicationModell Class

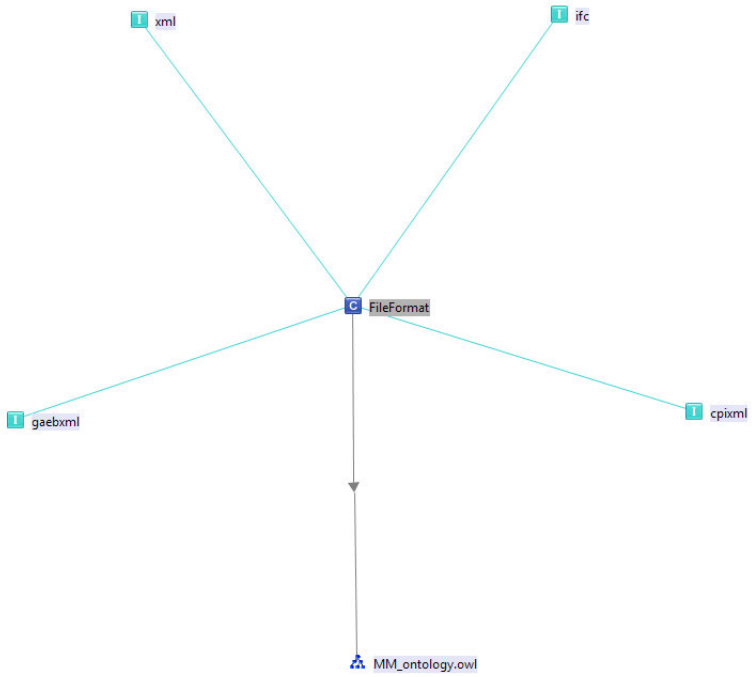

Figure 4.6: FileFormat Class

4.1.3 Domain Class

Each elementary model has its own Domain which is the individual of Domain class (Figure 4.7), this domain is important to determine from which participants or from which field is an elementary model. Domain has sub domain, and sub domain also has sub sub domain. In Multi-Model Ontology the individual name is an abbreviation of the domain. For example, when the elementary model is an IFC file, then this elementary model has domain building information modeling with individual name BIM. Domain BIM has sub and sub sub domain, so it is also a super domain of its subdomain. The description of this domain is the augmentation of its individual name, so in Multi-Model Ontology domain BIM has description Building Information Modeling(Figure 4.8). The reason why in Multi-model ontology usies the abbreviation is to create the same vocabulary from project Mefisto. In project Mefisto the dot (.) are used to describe the sub domain. For example CSM.SLM.SIS it means that domain SIS (Site Infrastructure System) is a sub domain of SLM (Site Layout Models) and SLM is a sub domain of CSM (Construction Site Models).

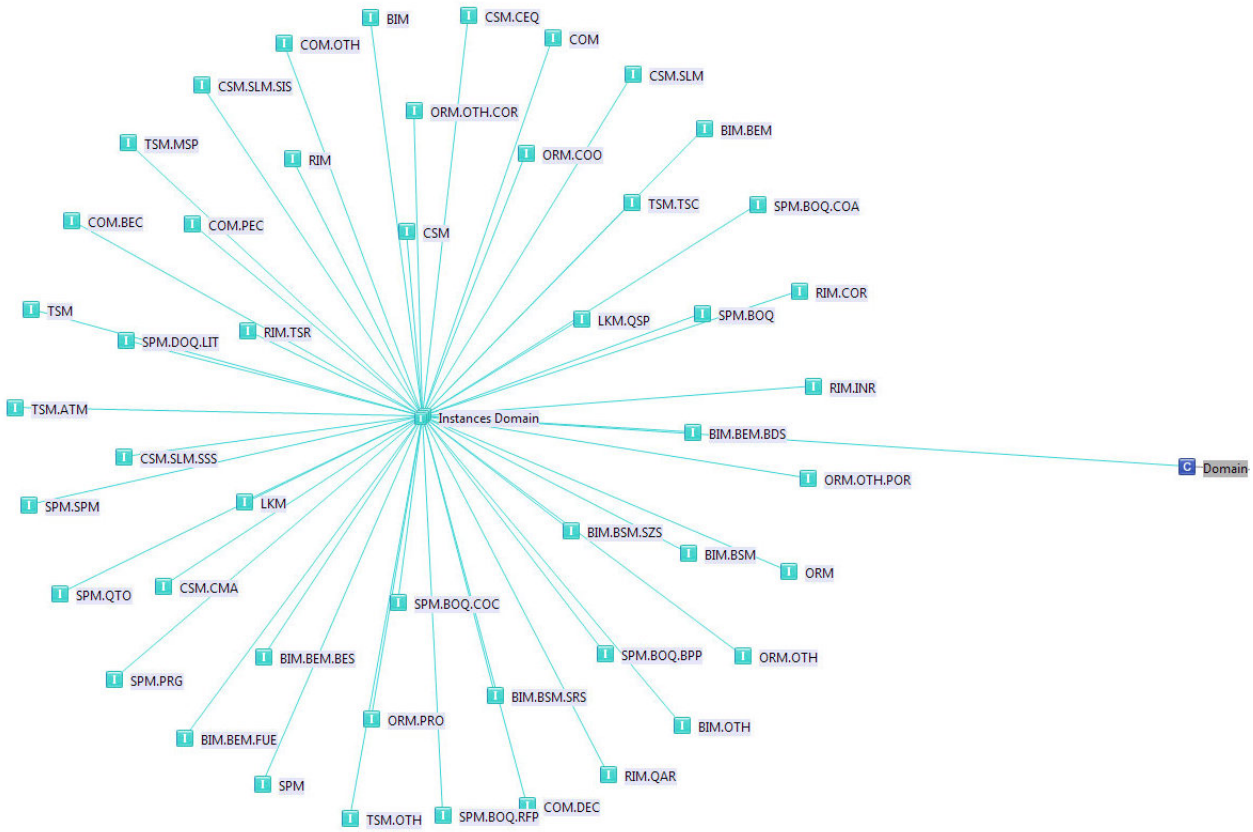

Figure 4.7: Domain Class

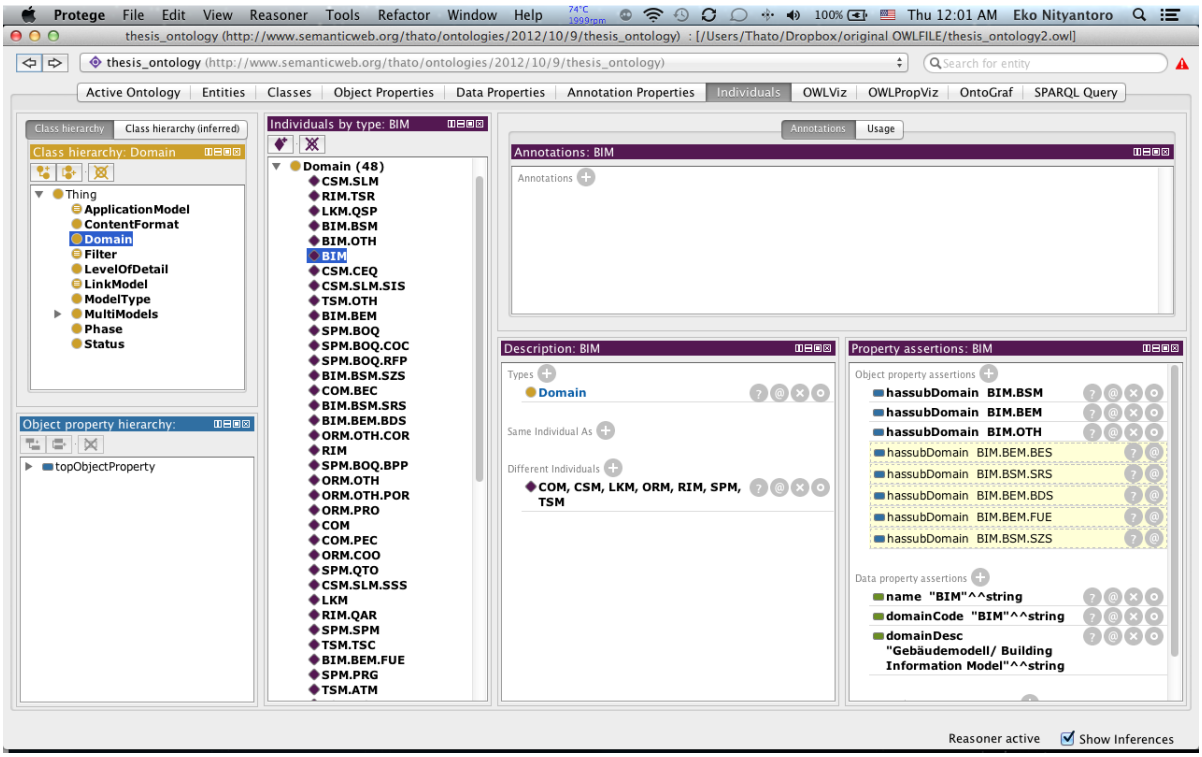

Figure 4.8: Domain BIM

4.1.4 Workflow Class

There are workflows to create the elementary model. With workflow it is possible to reduce complexity of the whole process. Participants can get what they need by using workflows. For example, a participant needs an elementary model with domain BIM, phase SLCT and level of detail 4, the exact same model does not exist in the Multi-Model Ontology, but there is a model with both the same domain and phase but with level of detail 5. In this case, the reasoner will give an advice to participants to use one of the filter which has function to reduce the amount of level of detail instead of asking the other participant who created the elementary model to create another one. There might be a question what if the participants want to get the higher level of detail or the finer model. In this case, the workflow will not work that way. It is possible to reduce the level of detail of a model via workflow, but it is not possible to add detail on a model via workflow. This thesis will not discuss how the workflows work, only to show that reasoner can consider the usage of a workflow, and only two example workflows are registered in the Multi-Model Ontology.

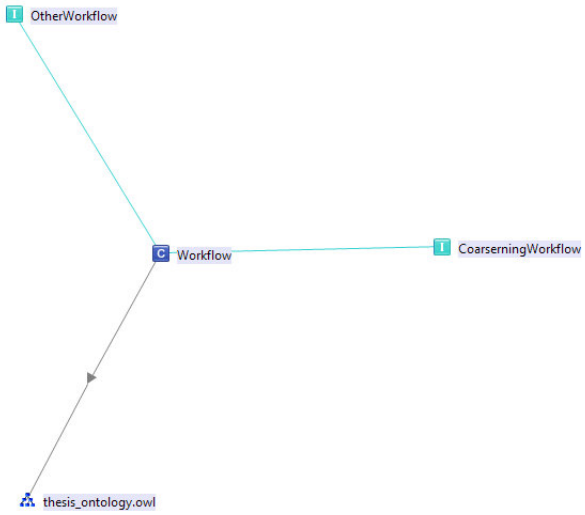

Figure 4.9: Workflow Class

4.1.5 LevelOfDetail Class

Like its name, this class contains the level of detail for each elementary model. There are six level of details from 0 to 5. Level of detail itself is the level of complexity, accuracy and how definitive the model is, commonly used in 3D modeling which is mostly applied to geometry detail. Its also measures how much information provided. In this thesis, the LoD is illustrated in a simple way. In reality every domain has its own descriptions of LoD. Those six LoDs that use here are :

- LoD 0 ; The lowest or the most coarser level of detail, Regional Landscape.
- LoD 1 ; City Region.
- LoD 2 ; City Districts or Project.
- LoD 3 ; Building Section, exterior.
- LoD 4 ; Building Elements.
- LoD 5 ; The highest detail or the most finer level of detail, Components of building elements.

In the section about Workflow Class, it is stated how participants can get the different level of LoD by using workflow. Important to keep in mind that, it is only

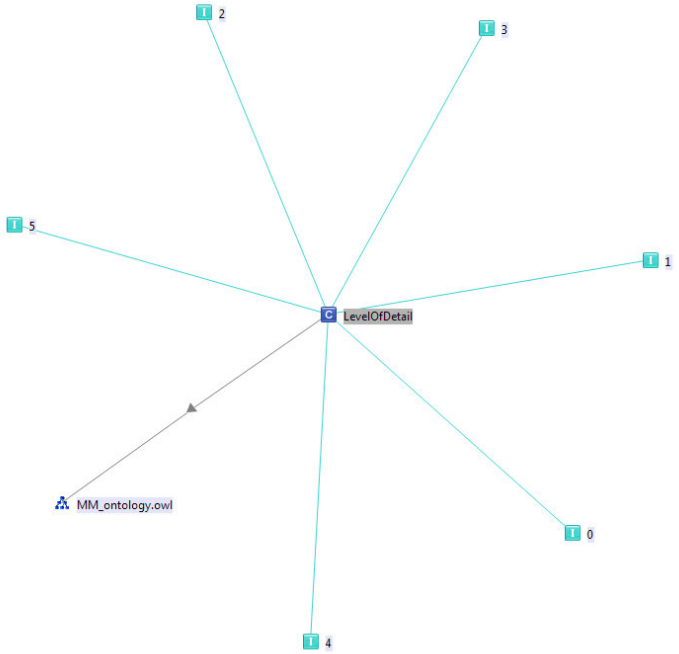

Figure 4.10: LevelOf Detail Class

possible to get the lower level of LoD from the workflow. Because the highest level of detail (LoD 5), has included all the other LoD in it, therefore it is possible to reduce some elements from the model to reduce the level of detail.

4.1.6 LinkModel

Link model class is a class of models which play the role of the connector between elementary models. Link-models explicitly specify the interdependencies among the models[RIB].

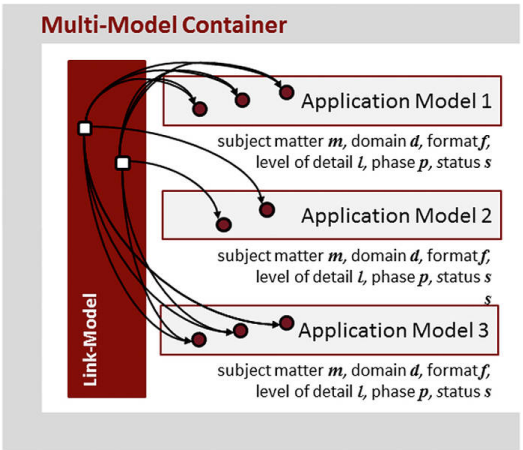

Figure 4.11: Link Model in Mefisto project[RIB]

4.1.7 MMContainer Class

This is a class where the individuals are the MMCs (Figure 4.12) . Each MMC has its own ID. Later on this ID will be use to give the name of each individuals. Each MMC has a restriction or a standard what should be inside and what should not be inside. For example, an MMC can only have one ID and it should have at least one elementary model.

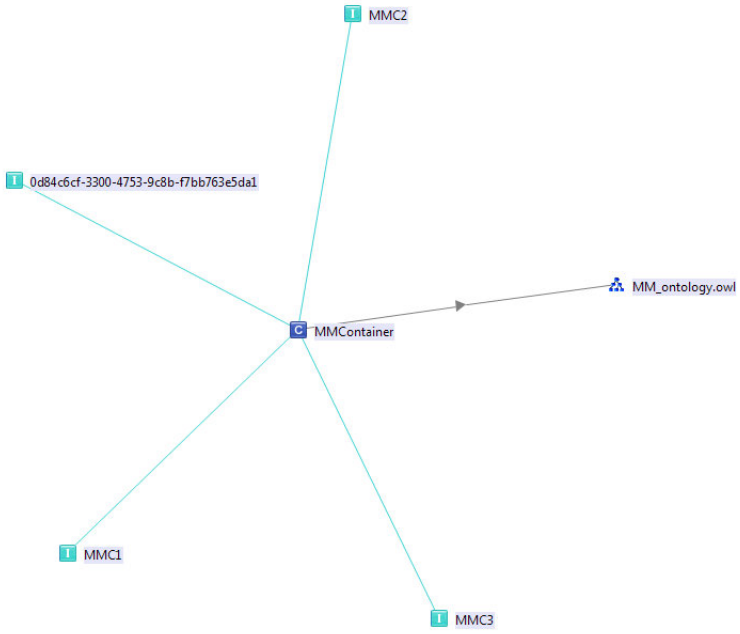

Figure 4.12: MMContainer Class

4.1.8 ModelType Class

ModelType class (Figure 4.13) is a class for the types of elementary models. There are different kinds of models type in construction, for example, the models which describes the general plan of the construction project, models which describe an Activity and also model about quantity and budget. The different types of models has been explained in Section 2.1.

4.1.9 Phase Class

In the construction process there is a phase, construction phase itself is a specific period, provided in a contract (beginning from the date stated in the notice to proceed) during which the contractor must complete the construction, subject to the condition of the contract. Each elementary model has its own phase, each phase has sub phase and also has predecessor and successor. The structure of a phase in

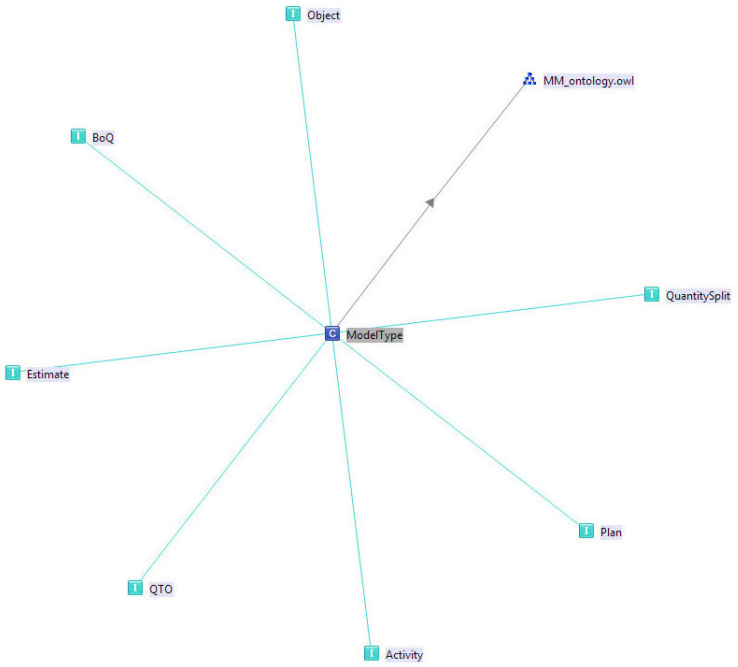

Figure 4.13: ModelType Class

Mefisto project can be seen in the Figure 4.15 . The 'greater than' sign (>) is use to describe sub phase. In Multi-model ontology, the 'greater than' sign (>) can not be used, because the naming of individual in ontology is not allowed to use such character. Therefore, Multi-Model Ontology only uses the name (abbreviation) of the phase and if it has sub phase will be described in the datatype property of each phase as shown in Figure 4.14.

This is contradict to the rule or statement that everything should use the same vocabulary. Different vocabulary might lead to the failure when register or reading meta-data from multi-models. Later in the section 4.2.1, how to fill the gap of this vocabulary shall be explained.

In the Figure 4.14, Phase EXEC is highlighted, in the right corner it can be seen that EXEC is an execution phase. Here one can also see the sub-phases, predecessor and the successor of EXEC.

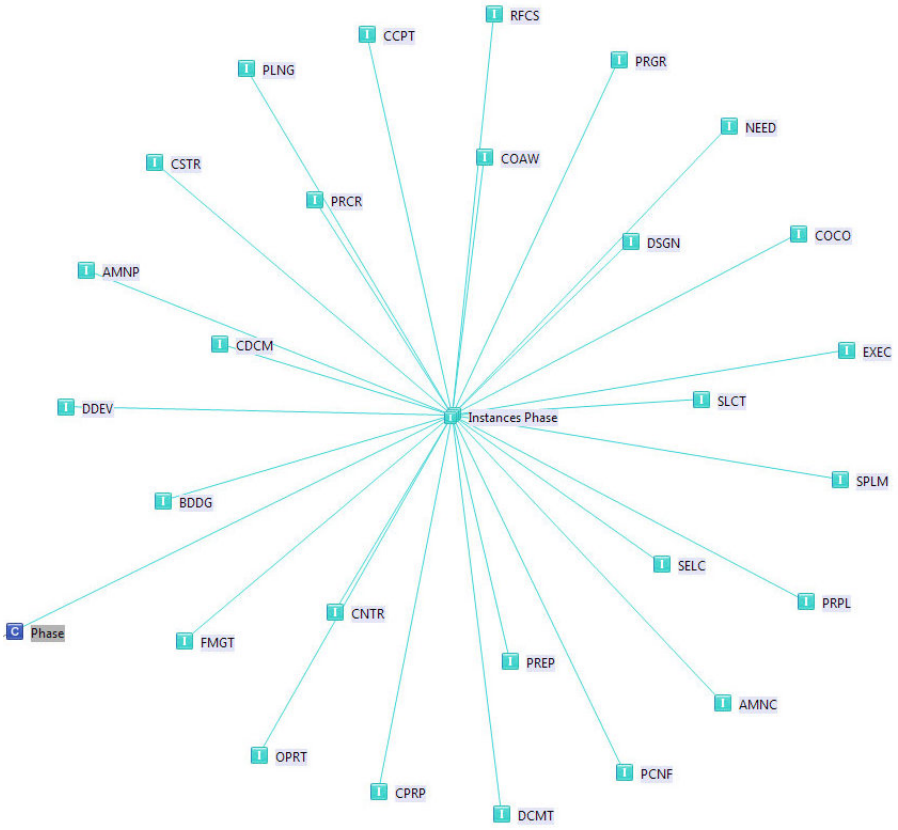

Figure 4.15: Phase Class

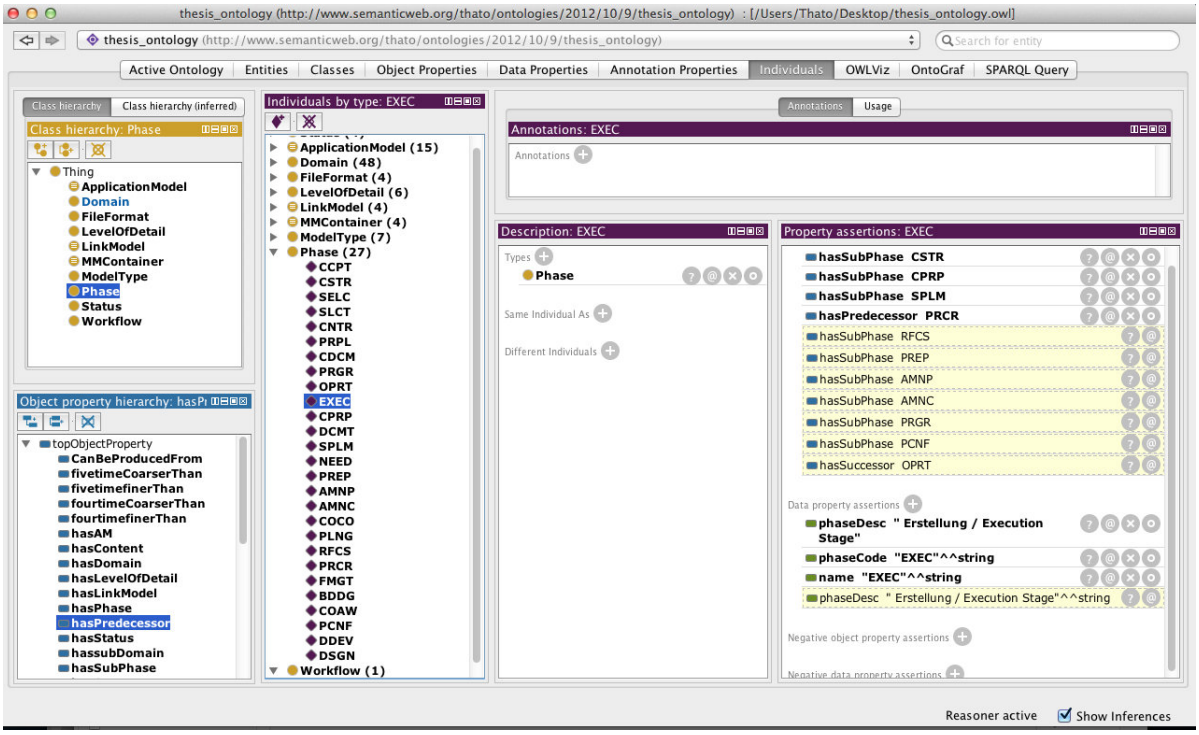

Figure 4.14: Phase Class EXEC

4.1.10 Status Class

Status shows the current editing status of an elementary model. It describes whether an elementary model is a final version or still can be changed. A simple ordinal scale is used as vocabulary to describes this class[SKS11]. As shown in Figure 4.16, Status class consists of :

$\alpha(alpha)$, describes that the elementary model is a model request or templates.

$\beta(beta)$, an elementary model is a draft.

$\gamma(gamma)$, shows that this elementary model has been accepted as the final release.

$\epsilon(epsilon)$, status given if the elementary model is deprecated and rejected.

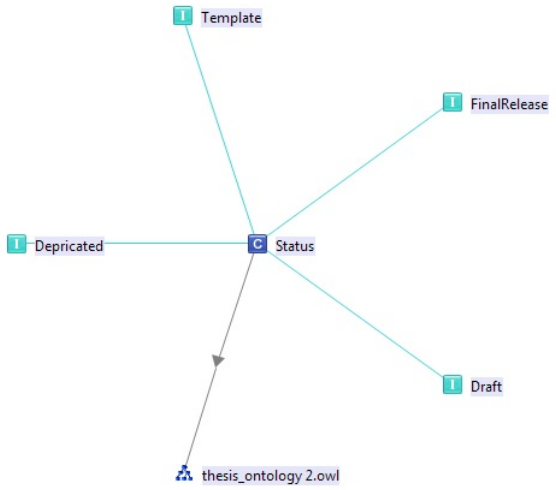

Figure 4.16: Status Class

4.2 Registration and Recombination

Mefisto allows every project participants to create their own elementary model and bundle it in Multi-model container. This container has to be registered in the Multi-Model Ontology. To register a multi model, as part of the task in this thesis a simple application has been has been developed. This application is called The Multi-Model Ontology Information Management (MeMOIREN). With this application we can register or add the information as well as to get information from multi-model Ontology. Multi-Model Ontology Information Manager is developed under java programming base, using DOM library as XML parser, and Jena API

to handle the ontology and developed with Eclipse[1] (Figure 4.17). This application can be a standalone application which is distributed among the participants and connected to the server. But in the future it is possible to make this application as an online or web service application.

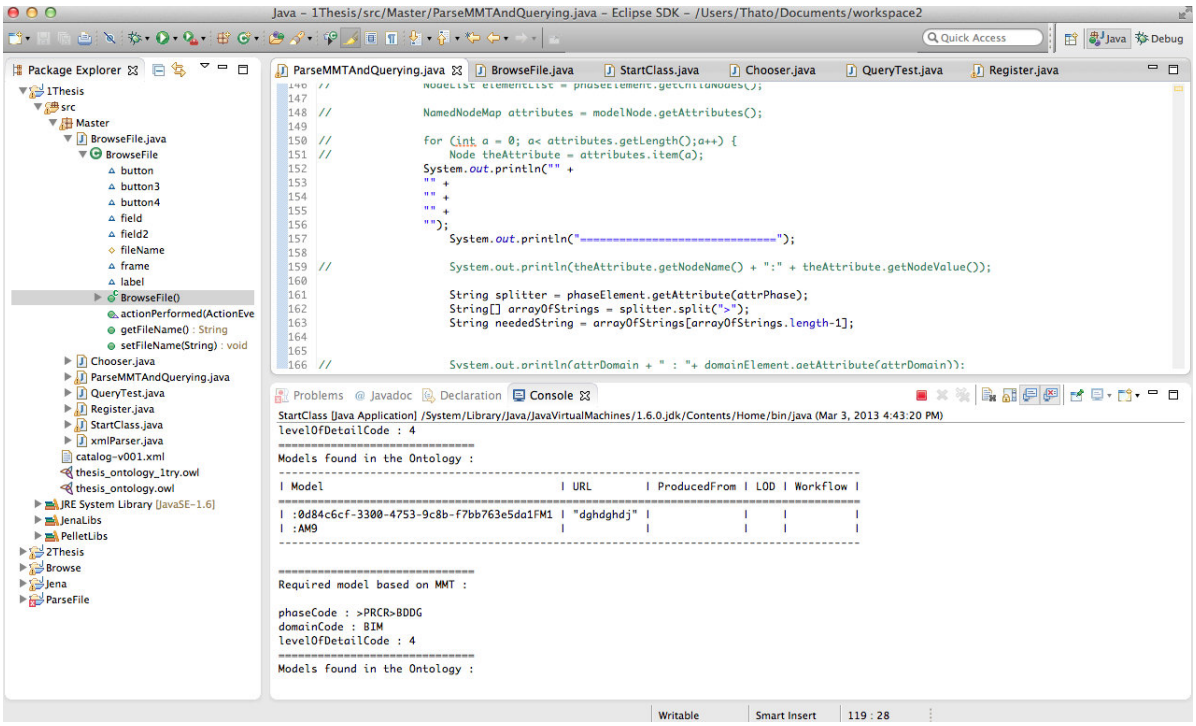

Figure 4.17: MeMOIREN in Eclipse Console Screenshot

4.2.1 Register a Multi-model Container

The registration process started with extracting and parsing the information in the metadata form from Multi-model container. After creating a Multi-model container, participants can use MeMOIREN application to register their new MMC. MMC is a file with .mmc extension, MeMOIREN can not read this kind of file, this file is only readable by certain softwares. MeMOIREN only need the metadata of MMC, therefore, participants need to change the extension into .zip (compressed file) and then decompress it. After decompressing the file, participants will get the file name Multimodel.xml. Multimodel.xml is the file that will be read by the application. This file consists of metadata.

Participants should enter the path where they have the Multimodel.xml file and they also have to insert the URL address of the storage where they keep the file so other participant can access it. There are two option buttons. One is to search

[1] a multi-language software development environment consist of a base workspace and can be extended and customized with plug-in. http://wikipedia.org/wiki/eclipse(software)

whether there are desired elementary models in Multi-Model Ontology and the other one is to register the new Multi-model. Then it is clear that in this step participant should press Register MMC button(Figure 4.18).

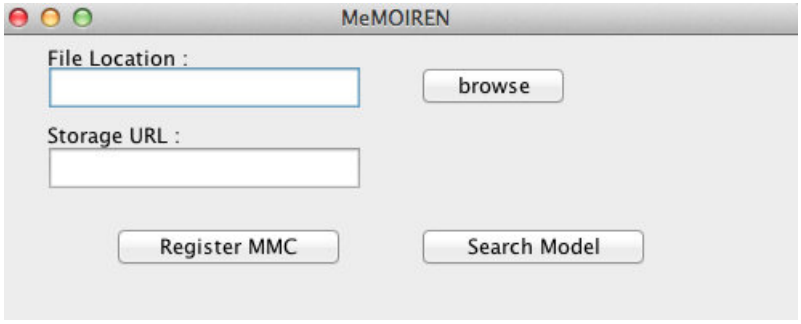

Figure 4.18: Multi-Model Ontology Information Manager (MeMOIREN)

To make sure that the new Multi-model containers are registered, MeMORIEN will create a confirmation file in participants desktop folder, this file will be named addedMMC.txt. This confirmation file will show the MMC ID, link model, the number of elementary models exist in MMC, elementary models name, and elementary models type, domain, phase and level of detail as shown in Figure 4.19.

It has been explained before in the section 4.1.9, that the vocabulary for phase in project Mefisto using 'greater than' sign (>), and this sign is not allowed to be the name of individual in ontology. Therefore, when creating MeMOIREN using java programming language, it is necessary to split the phase code based on 'greater than' sign (>) as a compensation of this difference. In java programming this can be done with split method (Code4).

```
String splitter = phaseElement.getAttribute(attrPhase);
String[] arrayOfStrings = splitter.split(">");
String neededString = arrayOfStrings[arrayOfStrings.length−1];
```

Code 4: Split method in Java

After the new Multi-model Container has been registered in the Multi-Model Ontology, automatically the new MMC and all models inside as well as their properties are added in Multi-Model Ontology. In ontology editor, the difference between before and after registration can be clearly seen (Figure 4.20 and Figure 4.21). To be noticed that in this thesis the same MMC example is used, therefore all have the same MMC ID.

```
MMC ID: 0d84c6cf-3300-4753-9c8b-f7bb763e5da1
Number of Models in MMC : 3
Number of Link Models in MMC : 1
================================================


# New Elemetary Model id : 0d84c6cf-3300-4753-9c8b-f7bb763e5da1FM1
# New Link Model id : 0d84c6cf-3300-4753-9c8b-f7bb763e5da1L1
================================================
type :BoQ
phaseCode : BDDG
domainCode : SPM.BOQ.BPP
levelOfDetailCode : 4
================================================


# New Elemetary Model id : 0d84c6cf-3300-4753-9c8b-f7bb763e5da1FM2
# New Link Model id : 0d84c6cf-3300-4753-9c8b-f7bb763e5da1L1
================================================
type :Object
phaseCode : BDDG
domainCode : BIM
levelOfDetailCode : 4
================================================


# New Elemetary Model id : 0d84c6cf-3300-4753-9c8b-f7bb763e5da1FM3
# New Link Model id : 0d84c6cf-3300-4753-9c8b-f7bb763e5da1L1
================================================
type :QTO
phaseCode : BDDG
domainCode : SPM.QTO
levelOfDetailCode : 4
================================================
Done
```

Figure 4.19: addedMMC.txt Confirmation File

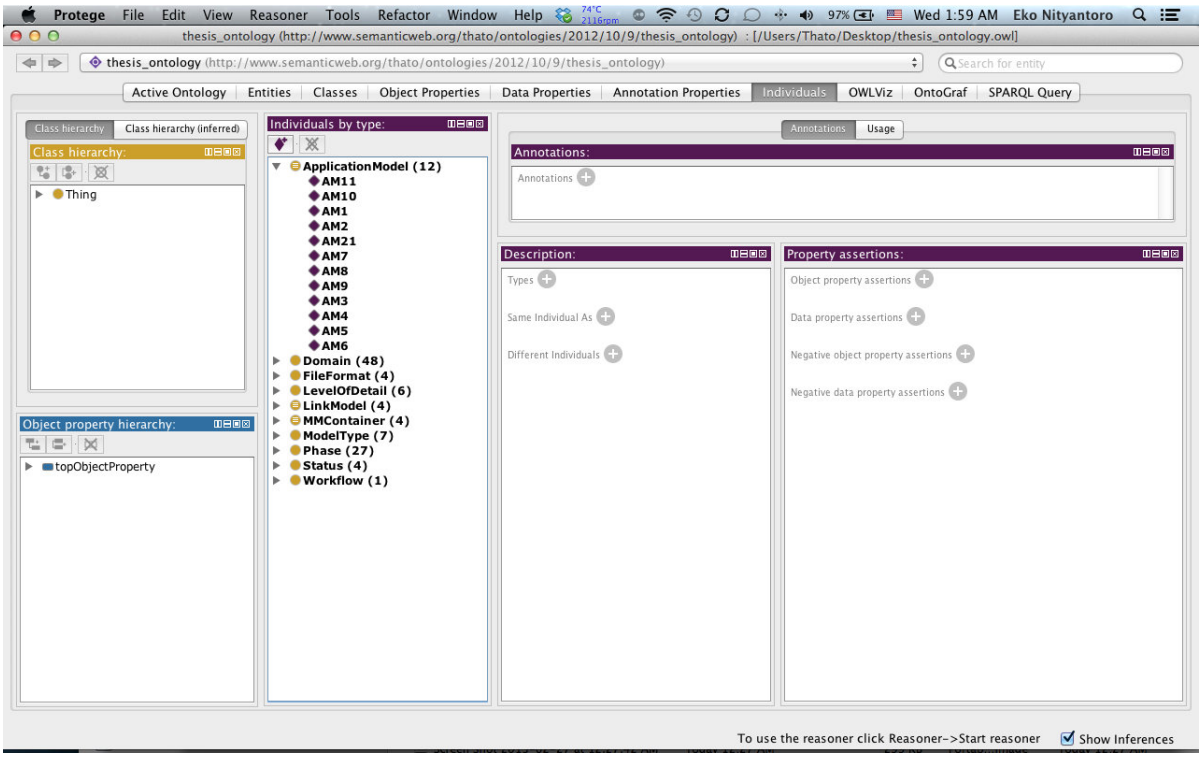

Figure 4.20: Before registration.

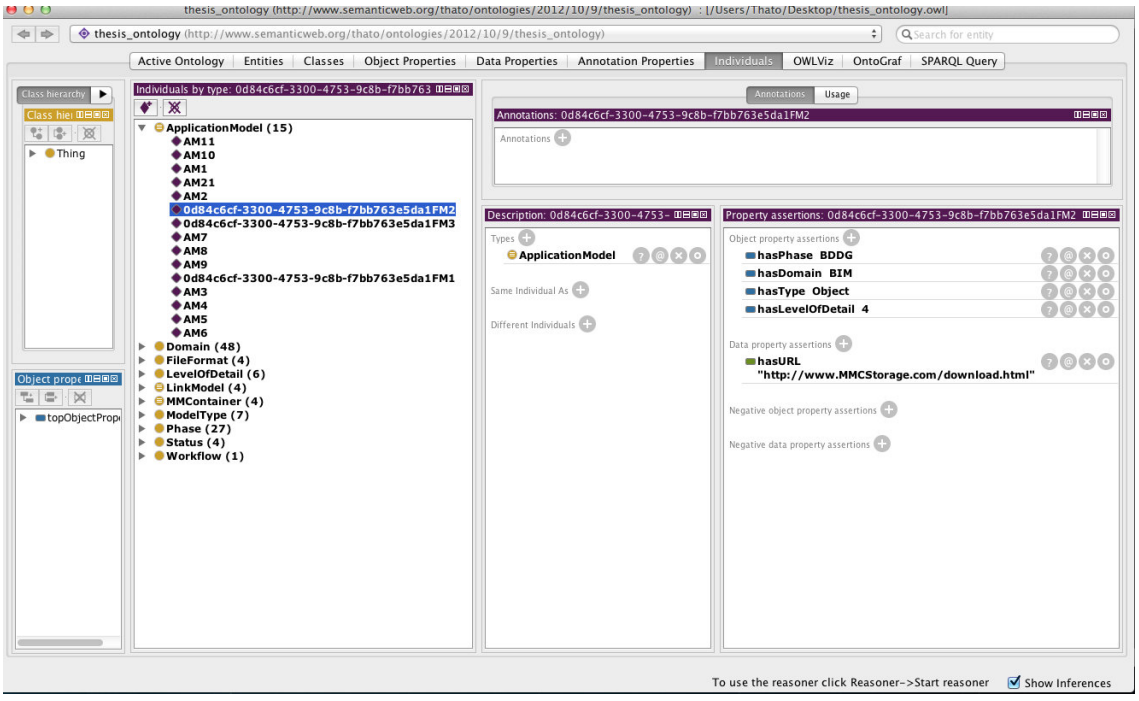

Figure 4.21: After Registration

4.2.2 Requesting an Elementary Model (Recombination)

The second role is a requestor. Participant may request one or more elementary model based on what they need and their role. The first step is to get the Multi-model Template. After participants received a MMT, participants can use MTT by using MeMOIREN. It works nearly the same with how to use MeMOIREN for registering, but in this step it is not necessary to change the file extension because MeMOIREN can read .mmt extension file. This file is no other than an xml file, contains no elementary models, only the metadata for desired elementary models. After inserting the file location, participant can directly press the Search Model button without the need to insert the URL storage address field (Figure 4.18).

Instead of adding information to Multi-Model Ontology, this step is searching the required elementary model trough the Multi-Model Ontology. MeMOIREN create a SPARQL query to search trough the ontology.

```
String queryString =
"prefix : <http://www.semanticweb.org/thato/ontologies/2012/10/9/thesis_ontology#> "
+
"prefix rdfs: <" + RDFS.getURI() + "> " +
"prefix owl: <" + OWL.getURI() + "> " +
"prefix rdf: <" + RDF.getURI() + "> " +
"select ?Model ?URL ?ProducedFrom ?LOD ?Workflow " +
"where {{ " +
"?Model rdf:type :ApplicationModel. " +
"?Model :hasDomain ?domain. " +
"?domain :domainCode ?domaincode. " +
"FILTER (?domaincode =" + "'"+ domainElement.getAttribute(attrDomain) + "'"+ ")"
+
"?Model :hasPhase ?phase." +
"?phase :name ?phasecode. " +
"FILTER (?phasecode = "+ "'"+ neededString +"'"+")" +
"?Model :hasLevelOfDetail ?lod." +
"?lod :name ?lodcode." +
"FILTER (?lodcode = "+ lodElement.getAttribute(attrLOD)+ ")" +
"OPTIONAL{?Model :hasURL ?URL.}" +
"}"
```

Code 5: Part of SPARQL Query used in MeMOIREN

The query result will be in the participants desktop folder. Simple text file named output.txt, will be created as the result file. The result will shows whether the requested elementary models are available or not and give the URL address where participants can get the file if it exist.

The result is not just showing the desired elementary models from MMT, if SPARQL cannot find any elementary models with the same properties as required in MMT the reasoner will play its role recommending another way to get the desired elementary model by using a workflow, with condition there are certain categories of properties to be fulfilled.

4.3 Reasoning

One of the most important process inside the MeMOIREN is reasoning. It is a logical description and by implementing reasoner in ontology it makes ontology not just a knowledge management but also a knowledge acquisition by learning. With reasoning we can get a new and useful information which is not asserted before. Multi-Model Ontology and MeMOIREN using a pellet reasoner for reasoning process and to handle rules. MeMOIREN use both OWL-Full, an OWL version that provide compatibility with RDF schema, and SWRL (Semantic Web Rule Language). By using both methods, the possibility to get the inferred result by the minimum asserted increases. More information can be achieved by inserting a minimum information. It is important during the development of ontology to think about what kind of logic rules can be applied to get the desired information.

In the section 2.2.3, it has been described that to accommodate the usage of rules it is possible to use either Pellet or Hermit reasoner. Unfortunately Hermit reasoner cannot be used together with Jena and does not support OWL-Full. Therefore Pellet is used as a reasoner, although when using external reasoner in Jena it might have a performance (especially memory use) and time consuming issues.

To show the role of reasoner an example of MMT, named Request.mmt (see Appendix) is used. In this MMT there are four difference meta informations of elementary models. Some of this meta-informations are the same as the metadata from elementary models which were registered in the previous section. But, there are also meta-information which does not yet exist in the Multi-Model Ontology. Figure 4.22 shows which registered elementary models fulfill the MMT requirements, and also the recommendation which elementary models can be used to get the desired elementary model using workflows. It shows that, in MMT there is an pre-description of an elementary model with Phase SLCT, Domain QTO and LoD 4. Without a proper reasoner, (left figure, inside the red box) SPARQL could not find any elementary model registered in Multi-Model Ontology. Therefore, reasoner recommends (right figure, inside the red box) that it is possible to get the required elementary model from elementary model AM3 which has the same

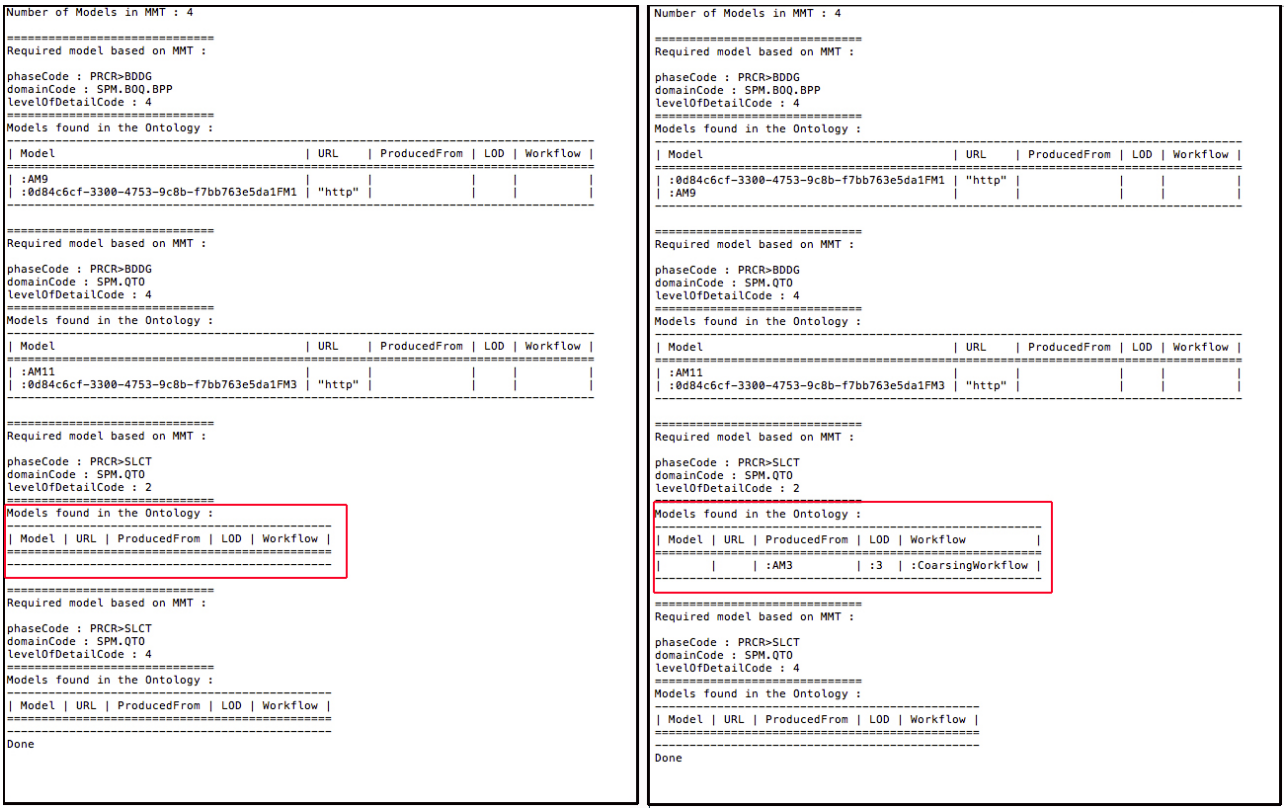

Figure 4.22: Without Reasoner (left) and with Reasoner (right)

Phase and Domain, but has one level lower of LoD by using a workflow called "Coarsening Workflow".

4.4 Jena API

Ontology editor is not addressed to participants but more for project managers or database administrators to manage the ontology itself. For the purpose of participants, other application can be made to support the whole process. For example, participants need to add or to get information based on what they have. Participants should not add information to Multi-model ontology directly by using editor, otherwise the security and consistency of database could be on the thread. Participants can only work with application which is supported by Jena API without any direct access to Ontology.

Since the structure of metadata is in XML format, a parser is necessary to use in order to read and get information from the data. Document Object Model (DOM) is a platform- and language-neutral interface that will allow programs and scripts to dynamically access and update the content, structure and style of documents[2].

[2]http://www.w3.org/

It can parse an xml file which will be use to read the MMC and MMT, and the information will be forwarded to Jena API for further processes.

Jena[3] is a framework which is able to read, processing and write ontology, the using of this API is to register the new instance in ontology and its properties as well as to send queries to ontology. Jena also support rule-based inference engine for reasoning with RDF and OWL data sources, stores to allow large numbers of RDF triples to be efficiently stored on disk and query engine compliant with the latest SPARQL specification.

There are some reasons why it has been decided to use Jena API instead of OWL API. Jena API is most flexible, it covers all of RDF and therefore can be used to create OWL constructs, axioms and run inferences. The OWL API bypasses RDF to provide services based on OWL. It is not RDF-friendly and it will not be applying SPARQL queries any time soon. The APIs will also provide features to create file serializations from the internal data storage.

[3]http://jena.apache.org/

5 Conclusion and Future Works

The technologies of information systems have been progressing in a rapid pace. Information systems are now being called upon to support knowledge management, not just to process data or information. The key to providing a useful support for knowledge management lies in how a meaning is embedded in information models as defined in ontologies.

In this thesis, it has been explicitly mentioned and shown that the use of ontology can be an effective and useful support for a project collaboration management. As the participants in project Mefisto will get not only the desired results but they will also get a recommendation on how to get the desired result by using a proper reasoner.

The new recombination of multi-model can be supported by implementing reasoner in ontology. Supported means that ontology does not directly create the new multi-model, however it helps the participants by giving a recommendation and direction how to get or create the desired multi-model which is not yet exist.

In the beginning of ontology implementation, some obstacles might occurs. It was not an easy task to understand the terms, to describe an object, distinguished them into different classes and then represent them in ontology. Nevertheless we can get a satisfying result afterwards.

In the Chapter 3 subsection 3.2.3, it has been mentioned that the elementary models inside the new multi-models might have exactly the same properties with one of the registered elementary model. These elementary models will be registered to ontology as a different instance with different ID because it is bundled in the different multi-model container, and the naming of new elementary model will follow the name of the multi-model container's ID. It means that it is possible that there is an elementary model with two different IDs. In the future this problem can be avoided by formulating a better rule or method. So when there is an elementary model in the new multi-model which has exactly the same properties with one of the registered elementary model, it will no longer registered as the same elementary model with different ID but it will be referred to the registered elementary model. This will prevent a double information in Multi-Model Ontology.

Many other aspects and possible results are not included in this thesis, but it can be accomplished in the future. More research can be done as the extension of this thesis. In the future Multi-Model Ontology can be the part of an interactive web collaboration manager. Within the merging of virtual organization concept, the further result can be an interactive, flexible, reliable and secure.

By Interactive means, that all participants might get a notification when something is changed in the ontology, these changes can be a vocabulary updates, new registered multi-models and many other aspects. More Information such as the creator and file format can be added in Multi-Model Ontology in order to enhance the search for more relevant and detailed results.

Flexible means that the service is available everywhere at anytime. Of course this can be a long term project research and implementation, it is possible that this collaboration can have the main role in the construction project. Since nowadays people are getting more mobilized, therefore the idea of developing a mobile application for this collaboration is necessary.

Since the security aspect plays one of the most important role, it is important to convince all participants that all data and resources are not just user friendly but also reliable and secure. In case of Multi-Model Ontology, the ontology itself should not be handled by many people. Only a certain person who can have access directly to the ontology, for example the database administrator or the project manager who knows how to work with the ontology. This is to make sure that there is no information pollution, to keep the information accurate and consistent. In the participant side, they can only add or retrieve information from the database, and get a secure access to the storage.

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A CD Contents and Download Link

1. Master_Thesis_Eko.pdf ; The digital version of Master Thesis.
2. Readme.txt ; A short instruction manual.
3. MeMOIREN Folder, contains :

- MeMOIREN.jar ; The Multi-Model Ontology Information Management application.
- Multi_model_ontology.owl ; Ontology file.
- Request.mmt ; example of Multi-model template.
- Multimodel.xml ; example file contains metadata of the new MMC which will be registered.

All CD contents can be downloaded from :
https://www.dropbox.com/s/6fhg6a962msq5il/Master_Thesis.zip?m

B Multi-Model Ontology.owl

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  <owl:DatatypeProperty rdf:about="http://www.semanticweb.org/thato/ontologies/2012/10/9/thesis_ontology#hasURL"/>
  <owl:DatatypeProperty rdf:about="http://www.semanticweb.org/thato/ontologies/2012/10/9/thesis_ontology#isDerivedby">
    <rdfs:comment>For AM either derived by Workflows or Filters</rdfs:comment>
  </owl:DatatypeProperty>
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  <owl:DatatypeProperty rdf:about="http://www.semanticweb.org/thato/ontologies/2012/10/9/thesis_ontology#domainDesc">
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  </owl:DatatypeProperty>
  <owl:DatatypeProperty rdf:about="http://www.semanticweb.org/thato/ontologies/2012/10/9/thesis_ontology#domainCode"/>
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  <owl:TransitiveProperty rdf:about="http://www.semanticweb.org/thato/ontologies/2012/10/9/thesis_ontology#hasSuperdomain">
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  <owl:TransitiveProperty rdf:about="http://www.semanticweb.org/thato/ontologies/2012/10/9/thesis_ontology#hasSuperPhase">
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    </owl:inverseOf>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#ObjectProperty"/>
  </owl:TransitiveProperty>
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    <owl:inverseOf>
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    </owl:inverseOf>
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  <owl:inverseOf rdf:resource="http://www.semanticweb.org/thato/ontologies/2012/10/9/thesis_ontology#hasSuperdomain"/>
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              <domainCode rdf:datatype="http://www.w3.org/2001/XMLSchema#string"
              >COM.PEC</domainCode>
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              >DEC</name>
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          >COM</name>
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        <name rdf:datatype="http://www.w3.org/2001/XMLSchema#string"
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    >Ausscreibung / Solicitation</phaseDesc>
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      <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#NamedIndividual"/>
    </Domain>
  </hassubDomain>
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  >Time Schedule Model</domainDesc>
  <name rdf:datatype="http://www.w3.org/2001/XMLSchema#string"
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      >TSM</domainCode>
      <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#NamedIndividual"/>
    </Domain>
  </owl:distinctMembers>
</owl:AllDifferent>
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  <owl:distinctMembers rdf:parseType="Collection">
    <Domain rdf:about="http://www.semanticweb.org/thato/ontologies/2012/10/9/thesis_ontology#SPM.BOQ"/>
    <Domain rdf:about="http://www.semanticweb.org/thato/ontologies/2012/10/9/thesis_ontology#SPM.PRG"/>
    <Domain rdf:about="http://www.semanticweb.org/thato/ontologies/2012/10/9/thesis_ontology#SPM.QTO"/>
    <Domain rdf:about="http://www.semanticweb.org/thato/ontologies/2012/10/9/thesis_ontology#SPM.SPM"/>
  </owl:distinctMembers>
</owl:AllDifferent>
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  <owl:distinctMembers rdf:parseType="Collection">
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    <Domain rdf:about="http://www.semanticweb.org/thato/ontologies/2012/10/9/thesis_ontology#TSM.MSP"/>
    <Domain rdf:about="http://www.semanticweb.org/thato/ontologies/2012/10/9/thesis_ontology#TSM.OTH"/>
    <Domain rdf:about="http://www.semanticweb.org/thato/ontologies/2012/10/9/thesis_ontology#TSM.TSC"/>
  </owl:distinctMembers>
</owl:AllDifferent>
<Domain rdf:about="http://www.semanticweb.org/thato/ontologies/2012/10/9/thesis_ontology#RIM.QAR">
  <hasSuperdomain rdf:resource="http://www.semanticweb.org/thato/ontologies/2012/10/9/thesis_ontology#RIM"/>
  <name>QAR</name>
  <domainCode rdf:datatype="http://www.w3.org/2001/XMLSchema#string"
  >RIM.QAR</domainCode>
  <domainDesc rdf:datatype="http://www.w3.org/2001/XMLSchema#string"
  >Quantity Risk</domainDesc>
  <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#NamedIndividual"/>
</Domain>
<Domain rdf:about="http://www.semanticweb.org/thato/ontologies/2012/10/9/thesis_ontology#ORM.OTH">
  <hassubDomain>
    <Domain rdf:about="http://www.semanticweb.org/thato/ontologies/2012/10/9/thesis_ontology#ORM.OTH.POR">
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      >other Project Organisation Model</domainCode>
      <domainCode rdf:datatype="http://www.w3.org/2001/XMLSchema#string"
      >ORM.OTH.POR</domainCode>
      <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#NamedIndividual"/>
    </Domain>
  </hassubDomain>
  <hassubDomain>
    <Domain rdf:about="http://www.semanticweb.org/thato/ontologies/2012/10/9/thesis_ontology#ORM.OTH.COR">
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      >Other Project Corporate Organisation</domainDesc>
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      <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#NamedIndividual"/>
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  </hassubDomain>
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  >Other Organization Model</domainDesc>
  <domainCode rdf:datatype="http://www.w3.org/2001/XMLSchema#string"
  >ORM.OTH</domainCode>
  <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#NamedIndividual"/>
</Domain>
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  >Workflow2</name>
  <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#NamedIndividual"/>
</Workflow>
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  <name>Plan</name>
  <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#NamedIndividual"/>
</ModelType>
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  <statusDesc rdf:datatype="http://www.w3.org/2001/XMLSchema#string"
  >beta</statusDesc>
  <statusDesc rdf:datatype="http://www.w3.org/2001/XMLSchema#string"
  >Draft / Entwurf</statusDesc>
  <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#NamedIndividual"/>
</Status>
<swrl:Imp>
  <swrl:head>
    <swrl:AtomList>
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        <swrl:argument2>
          <swrl:Variable rdf:about="urn:swrl#A"/>
        </swrl:argument2>
        <swrl:propertyPredicate rdf:resource="http://www.semanticweb.org/thato/ontologies/2012/10/9/thesis_ontology#onetimefinerThan"/>
      </swrl:IndividualPropertyAtom>
    </rdf:first>
    <rdf:rest rdf:resource="http://www.w3.org/1999/02/22−rdf−syntax−ns#nil"/>
  </swrl:AtomList>
</swrl:head>
<swrl:body>
  <swrl:AtomList>
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      <swrl:ClassAtom>
        <swrl:argument1 rdf:resource="urn:swrl#A"/>
        <swrl:classPredicate rdf:resource="http://www.semanticweb.org/thato/ontologies/2012/10/9/thesis_ontology#ApplicationModel"/>
      </swrl:ClassAtom>
    </rdf:first>
    <rdf:rest>
      <swrl:AtomList>
        <rdf:rest>
          <swrl:AtomList>
            <rdf:first>
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                <swrl:propertyPredicate rdf:resource="http://www.semanticweb.org/thato/ontologies/2012/10/9/thesis_ontology#hasLevelOfDetail"/>
                <swrl:argument2>
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                      <LevelOfDetail rdf:about="http://www.semanticweb.org/thato/ontologies/2012/10/9/thesis_ontology#1">
                        <isCoarserThan>
                          <LevelOfDetail rdf:about="http://www.semanticweb.org/thato/ontologies/2012/10/9/thesis_ontology#2">
                            <isCoarserThan>
                              <LevelOfDetail rdf:about="http://www.semanticweb.org/thato/ontologies/2012/10/9/thesis_ontology#3">
                                <isCoarserThan>
                                  <LevelOfDetail rdf:about="http://www.semanticweb.org/thato/ontologies/2012/10/9/thesis_ontology#4">
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                                      <LevelOfDetail rdf:about="http://www.semanticweb.org/thato/ontologies/2012/10/9/thesis_ontology#5">
                                        <isFinerThan rdf:resource="http://www.semanticweb.org/thato/ontologies/2012/10/9/thesis_ontology#4"/>
                                        <LODCode rdf:datatype=
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                                        >[5]</LODCode>
                                        <LODDesc rdf:datatype=
                                        "http://www.w3.org/2001/XMLSchema#string"
                                        >Component of building element</LODDesc>
                                        <name rdf:datatype=
                                        "http://www.w3.org/2001/XMLSchema#int"
                                        >5</name>
                                        <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#NamedIndividual"/>
                                      </LevelOfDetail>
                                    </isCoarserThan>
                                    <isFinerThan rdf:resource="http://www.semanticweb.org/thato/ontologies/2012/10/9/thesis_ontology#3"/>
                                    <LODCode rdf:datatype=
                                    "http://www.w3.org/2001/XMLSchema#string"
                                    >[4]</LODCode>
                                    <LODDesc rdf:datatype=
                                    "http://www.w3.org/2001/XMLSchema#string"
                                    >Building Element , Building Elements; Interior</LODDesc>
                                    <name rdf:datatype="http://www.w3.org/2001/XMLSchema#int"
                                    >4</name>
                                    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#NamedIndividual"/>
                                  </LevelOfDetail>
                                </isCoarserThan>
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                                <rdfs:comment>Building Section; Exterior</rdfs:comment>
                                <LODCode rdf:datatype="http://www.w3.org/2001/XMLSchema#string"
                                >[3]</LODCode>
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                                >Building Section, Building Exterior; </LODDesc>
                                <name rdf:datatype="http://www.w3.org/2001/XMLSchema#int"
                                >3</name>
                                <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#NamedIndividual"/>
                              </LevelOfDetail>
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                    </isCoarserThan>
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                    >[2]</LODCode>
                    <LODDesc rdf:datatype="http://www.w3.org/2001/XMLSchema#string"
                    >City District, Projects</LODDesc>
                    <name rdf:datatype="http://www.w3.org/2001/XMLSchema#int"
                    >2</name>
                    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#NamedIndividual"/>
                  </LevelOfDetail>
                </isCoarserThan>
                <isFinerThan rdf:resource="http://www.semanticweb.org/thato/ontologies/2012/10/9/thesis_ontology#0"/>
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                >[1]</LODCode>
                <LODDesc rdf:datatype="http://www.w3.org/2001/XMLSchema#string"
                >City, Region</LODDesc>
                <name rdf:datatype="http://www.w3.org/2001/XMLSchema#int"
                >1</name>
                <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#NamedIndividual"/>
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            </isCoarserThan>
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            >[0]</LODCode>
            <LODDesc rdf:datatype="http://www.w3.org/2001/XMLSchema#string"
            >Regional , Landscape</LODDesc>
            <name rdf:datatype="http://www.w3.org/2001/XMLSchema#int"
            >0</name>
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      </swrl:IndividualPropertyAtom>
    </rdf:first>
    <rdf:rest>
      <swrl:AtomList>
        <rdf:rest>
          <swrl:AtomList>
            <rdf:first>
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                <swrl:argument1 rdf:resource="urn:swrl#B"/>
                <swrl:argument2 rdf:resource="urn:swrl#A"/>
              </swrl:DifferentIndividualsAtom>
            </rdf:first>
            <rdf:rest rdf:resource="http://www.w3.org/1999/02/22-rdf-syntax-ns#nil"/>
          </swrl:AtomList>
        </rdf:rest>
        <rdf:first>
          <swrl:IndividualPropertyAtom>
            <swrl:argument1 rdf:resource="urn:swrl#B"/>
            <swrl:propertyPredicate rdf:resource="http://www.semanticweb.org/thato/ontologies/2012/10/9/thesis_ontology#hasLevelOfDetail"/>
            <swrl:argument2 rdf:resource="http://www.semanticweb.org/thato/ontologies/2012/10/9/thesis_ontology#1"/>
          </swrl:IndividualPropertyAtom>
        </rdf:first>
      </swrl:AtomList>
    </rdf:rest>
  </swrl:AtomList>
</rdf:rest>
<rdf:first>
  <swrl:ClassAtom>
    <swrl:argument1 rdf:resource="urn:swrl#B"/>
    <swrl:classPredicate rdf:resource="http://www.semanticweb.org/thato/ontologies/2012/10/9/thesis_ontology#ApplicationModel"/>
  </swrl:ClassAtom>
</rdf:first>
</swrl:AtomList>
</rdf:rest>
</swrl:AtomList>
</swrl:body>
</swrl:Imp>
<ApplicationModel rdf:about="http://www.semanticweb.org/thato/ontologies/2012/10/9/thesis_ontology#AM21">
<hasContent>
<FileFormat rdf:about="http://www.semanticweb.org/thato/ontologies/2012/10/9/thesis_ontology#ifc">
<ontologies:hasVersion rdf:datatype="http://www.w3.org/2001/XMLSchema#string"
>2x3</ontologies:hasVersion>
<rdf:type rdf:resource="http://www.w3.org/2002/07/owl#NamedIndividual"/>
</FileFormat>
</hasContent>
<hasPhase rdf:resource="http://www.semanticweb.org/thato/ontologies/2012/10/9/thesis_ontology#SLCT"/>
<hasType>
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    <ModelType rdf:about="http://www.semanticweb.org/thato/ontologies/2012/10/9/thesis_ontology#Object">
      <name>Object</name>
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    </ModelType>
  </hasType>
  <hasDomain rdf:resource="http://www.semanticweb.org/thato/ontologies/2012/10/9/thesis_ontology#BIM.BEM"/>
  <hasLevelOfDetail rdf:resource="http://www.semanticweb.org/thato/ontologies/2012/10/9/thesis_ontology#2"/>
  <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#NamedIndividual"/>
</ApplicationModel>
<swrl:Imp>
  <swrl:head>
    <swrl:AtomList>
      <rdf:first>
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          <swrl:argument1 rdf:resource="urn:swrl#B"/>
          <swrl:argument2 rdf:resource="urn:swrl#A"/>
          <swrl:propertyPredicate rdf:resource="http://www.semanticweb.org/thato/ontologies/2012/10/9/thesis_ontology#onetimefinerThan"/>
        </swrl:IndividualPropertyAtom>
      </rdf:first>
      <rdf:rest rdf:resource="http://www.w3.org/1999/02/22−rdf−syntax−ns#nil"/>
    </swrl:AtomList>
  </swrl:head>
  <swrl:body>
    <swrl:AtomList>
      <rdf:rest>
        <swrl:AtomList>
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              <swrl:classPredicate rdf:resource="http://www.semanticweb.org/thato/ontologies/2012/10/9/thesis_ontology#ApplicationModel"/>
            </swrl:ClassAtom>
          </rdf:first>
          <rdf:rest>
            <swrl:AtomList>
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                        <swrl:DifferentIndividualsAtom>
                          <swrl:argument1 rdf:resource="urn:swrl#B"/>
                          <swrl:argument2 rdf:resource="urn:swrl#A"/>
                        </swrl:DifferentIndividualsAtom>
                      </rdf:first>
                      <rdf:rest rdf:resource="http://www.w3.org/1999/02/22−rdf−syntax−ns#nil"/>
                    </swrl:AtomList>
                  </rdf:rest>
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                      <swrl:argument2 rdf:resource="http://www.semanticweb.org/thato/ontologies/2012/10/9/thesis_ontology#4"/>
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              </rdf:rest>
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                  <swrl:argument1 rdf:resource="urn:swrl#A"/>
                  <swrl:propertyPredicate rdf:resource="http://www.semanticweb.org/thato/ontologies/2012/10/9/thesis_ontology#hasLevelOfDetail"/>
                  <swrl:argument2 rdf:resource="http://www.semanticweb.org/thato/ontologies/2012/10/9/thesis_ontology#3"/>
                </swrl:IndividualPropertyAtom>
              </rdf:first>
            </swrl:AtomList>
          </rdf:rest>
        </swrl:AtomList>
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      <rdf:first>
        <swrl:ClassAtom>
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          <swrl:classPredicate rdf:resource="http://www.semanticweb.org/thato/ontologies/2012/10/9/thesis_ontology#ApplicationModel"/>
        </swrl:ClassAtom>
      </rdf:first>
    </swrl:AtomList>
  </swrl:body>
</swrl:Imp>
<owl:AllDifferent>
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    >a55ecf8a-cf2e-4bae-be96-63d1bab7ac50</hasID>
    <hasAM>
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        <hasContent>
          <FileFormat rdf:about="http://www.semanticweb.org/thato/ontologies/2012/10/9/thesis_ontology#xml">
            <ontologies:hasVersion rdf:datatype="http://www.w3.org/2001/XMLSchema#string"
            >1.0</ontologies:hasVersion>
            <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#NamedIndividual"/>
          </FileFormat>
        </hasContent>
        <hasDomain rdf:resource="http://www.semanticweb.org/thato/ontologies/2012/10/9/thesis_ontology#SPM.QTO"/>
        <hasPhase rdf:resource="http://www.semanticweb.org/thato/ontologies/2012/10/9/thesis_ontology#SLCT"/>
        <hasType>
          <ModelType rdf:about="http://www.semanticweb.org/thato/ontologies/2012/10/9/thesis_ontology#QTO">
            <name>QTo</name>
            <rdfs:comment>Quantity Takeoff</rdfs:comment>
            <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#NamedIndividual"/>
          </ModelType>
        </hasType>
        <hasLevelOfDetail rdf:resource="http://www.semanticweb.org/thato/ontologies/2012/10/9/thesis_ontology#3"/>
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        >a55ecf8a-cf2e-4bae-be96-63d1bab7ac50AM3</hasID>
        <name rdf:datatype="http://www.w3.org/2001/XMLSchema#string"
        >Teilmengen / Subset</name>
        <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#NamedIndividual"/>
      </ApplicationModel>
    </hasAM>
    <hasAM>
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        <hasContent>
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            <ontologies:hasVersion rdf:datatype="http://www.w3.org/2001/XMLSchema#string"
            >3.1</ontologies:hasVersion>
            <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#NamedIndividual"/>
          </FileFormat>
        </hasContent>
        <hasDomain rdf:resource="http://www.semanticweb.org/thato/ontologies/2012/10/9/thesis_ontology#SPM.BOQ.RFP"/>
        <hasPhase rdf:resource="http://www.semanticweb.org/thato/ontologies/2012/10/9/thesis_ontology#SLCT"/>
        <hasType>
          <ModelType rdf:about="http://www.semanticweb.org/thato/ontologies/2012/10/9/thesis_ontology#BoQ">
            <name>BOQ</name>
            <rdfs:comment>Bill of Quantity</rdfs:comment>
            <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#NamedIndividual"/>
          </ModelType>
        </hasType>
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        >Leistungsverzeichnis / Bill Of Quantity</name>
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      </ApplicationModel>
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    <hasAM>
      <ApplicationModel rdf:about="http://www.semanticweb.org/thato/ontologies/2012/10/9/thesis_ontology#AM4">
        <hasContent rdf:resource="http://www.semanticweb.org/thato/ontologies/2012/10/9/thesis_ontology#xml"/>
        <hasDomain rdf:resource="http://www.semanticweb.org/thato/ontologies/2012/10/9/thesis_ontology#TSM.TSC"/>
        <hasPhase rdf:resource="http://www.semanticweb.org/thato/ontologies/2012/10/9/thesis_ontology#SLCT"/>
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            <name>Activity</name>
            <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#NamedIndividual"/>
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        </hasType>
        <hasLevelOfDetail rdf:resource="http://www.semanticweb.org/thato/ontologies/2012/10/9/thesis_ontology#1"/>
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        >a55ecf8a-cf2e-4bae-be96-63d1bab7ac50AM4
</hasID> <name rdf:datatype="http://www.w3.org/2001/XMLSchema#string"
        >Rahmenterminplan / Scheduling</name>
        <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#NamedIndividual"/>
      </ApplicationModel>
    </hasAM>
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    >Ausschreibung 06.12.2012</name>
    <templateName rdf:datatype="http://www.w3.org/2001/XMLSchema#string"
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  >Angebotsanfrage</templateName>
  <hasAM>
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      <hasPhase rdf:resource="http://www.semanticweb.org/thato/ontologies/2012/10/9/thesis_ontology#SLCT"/>
      <hasType rdf:resource="http://www.semanticweb.org/thato/ontologies/2012/10/9/thesis_ontology#Object"/>
      <hasDomain rdf:resource="http://www.semanticweb.org/thato/ontologies/2012/10/9/thesis_ontology#BIM.BEM"/>
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              <swrl:classPredicate rdf:resource="http://www.semanticweb.org/thato/ontologies/2012/10/9/thesis_ontology#ApplicationModel"/>
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      </rdf:rest>
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      </rdf:first>
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</swrl:Imp>
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  >gamma</statusCode>
  <statusDesc rdf:datatype="http://www.w3.org/2001/XMLSchema#string"
  >Final Release / Final und Freigegeben</statusDesc>
  <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#NamedIndividual"/>
</Status>
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  <hasAM>
    <ApplicationModel rdf:about="http://www.semanticweb.org/thato/ontologies/2012/10/9/thesis_ontology#0d84c6cf-3300-4753-9c8b-f7bb763e5da1FM3">
      <hasURL>http</hasURL>
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      <hasPhase rdf:resource="http://www.semanticweb.org/thato/ontologies/2012/10/9/thesis_ontology#BDDG"/>
      <hasDomain rdf:resource="http://www.semanticweb.org/thato/ontologies/2012/10/9/thesis_ontology#SPM.QTO"/>
    </ApplicationModel>
  </hasAM>
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      <Linking rdf:resource="http://www.semanticweb.org/thato/ontologies/2012/10/9/thesis_ontology#0d84c6cf-3300-4753-9c8b-f7bb763e5da1FM3"/>
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  </hasLinkModel>
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  <hasAM rdf:resource="http://www.semanticweb.org/thato/ontologies/2012/10/9/thesis_ontology#0d84c6cf-3300-4753-9c8b-f7bb763e5da1FM2"/>
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          <rdf:rest>
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                    </swrl:DifferentIndividualsAtom>
                  </rdf:first>
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              <rdf:first>
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    <LevelOfDetail rdf:about="http://www.semanticweb.org/thato/ontologies/2012/10/9/thesis_ontology#3"/>
    <LevelOfDetail rdf:about="http://www.semanticweb.org/thato/ontologies/2012/10/9/thesis_ontology#4"/>
    <LevelOfDetail rdf:about="http://www.semanticweb.org/thato/ontologies/2012/10/9/thesis_ontology#5"/>
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</owl:AllDifferent>
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                  <swrl:argument2 rdf:resource="http://www.semanticweb.org/thato/ontologies/2012/10/9/thesis_ontology#2"/>
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    >Depricated / Verworfen</statusDesc>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#NamedIndividual"/>
  </Status>
  <Phase rdf:about="http://www.semanticweb.org/thato/ontologies/2012/10/9/thesis_ontology#NEED">
    <hasSuccessor>
      <Phase rdf:about="http://www.semanticweb.org/thato/ontologies/2012/10/9/thesis_ontology#PRPL">
        <hasPredecessor rdf:resource="http://www.semanticweb.org/thato/ontologies/2012/10/9/thesis_ontology#NEED"/>
        <hasSuperPhase>
          <Phase rdf:about="http://www.semanticweb.org/thato/ontologies/2012/10/9/thesis_ontology#CCPT">
            <hasSubPhase rdf:resource="http://www.semanticweb.org/thato/ontologies/2012/10/9/thesis_ontology#PRPL"/>
            <hasSuccessor rdf:resource="http://www.semanticweb.org/thato/ontologies/2012/10/9/thesis_ontology#PLNG"/>
            <hasSubPhase rdf:resource="http://www.semanticweb.org/thato/ontologies/2012/10/9/thesis_ontology#NEED"/>
            <phaseDesc rdf:datatype="http://www.w3.org/2001/XMLSchema#string"
            >Konzept / Conception</phaseDesc>
            <phaseCode rdf:datatype="http://www.w3.org/2001/XMLSchema#string"
            >CCPT</phaseCode>
            <name rdf:datatype="http://www.w3.org/2001/XMLSchema#string"
            >CCPT</name>
            <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#NamedIndividual"/>
          </Phase>
        </hasSuperPhase>
        <phaseDesc rdf:datatype="http://www.w3.org/2001/XMLSchema#string"
        >Vorplanung / Pre-Planning
</phaseDesc>
        <name rdf:datatype="http://www.w3.org/2001/XMLSchema#string"
        >PRPL</name>
        <phaseCode rdf:datatype="http://www.w3.org/2001/XMLSchema#string"
        >CCPT.PRPL</phaseCode>
        <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#NamedIndividual"/>
      </Phase>
    </hasSuccessor>
    <hasSuperPhase rdf:resource="http://www.semanticweb.org/thato/ontologies/2012/10/9/thesis_ontology#CCPT"/>
    <name rdf:datatype="http://www.w3.org/2001/XMLSchema#string"
    >NEED</name>
    <phaseDesc rdf:datatype="http://www.w3.org/2001/XMLSchema#string"
    >Grundlagenermittlung / Needs Identification</phaseDesc>
    <phaseCode rdf:datatype="http://www.w3.org/2001/XMLSchema#string"
    >CCPT.NEED</phaseCode>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#NamedIndividual"/>
  </Phase>
  <Phase rdf:about="http://www.semanticweb.org/thato/ontologies/2012/10/9/thesis_ontology#FMGT">
    <hasSuperPhase>
      <Phase rdf:about="http://www.semanticweb.org/thato/ontologies/2012/10/9/thesis_ontology#OPRT">
        <hasSubPhase rdf:resource="http://www.semanticweb.org/thato/ontologies/2012/10/9/thesis_ontology#FMGT"/>
        <hasPredecessor rdf:resource="http://www.semanticweb.org/thato/ontologies/2012/10/9/thesis_ontology#EXEC"/>
        <hasSubPhase>
          <Phase rdf:about="http://www.semanticweb.org/thato/ontologies/2012/10/9/thesis_ontology#DCMT">
            <phaseCode rdf:datatype="http://www.w3.org/2001/XMLSchema#string"
            >OPRT.DCMT</phaseCode>
            <phaseDesc rdf:datatype="http://www.w3.org/2001/XMLSchema#string"
            >Dokumentation / Documentation</phaseDesc>
            <name rdf:datatype="http://www.w3.org/2001/XMLSchema#string"
            >DCMT</name>
            <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#NamedIndividual"/>
          </Phase>
        </hasSubPhase>
        <name rdf:datatype="http://www.w3.org/2001/XMLSchema#string"
        >OPRT</name>
        <phaseCode rdf:datatype="http://www.w3.org/2001/XMLSchema#string"
        >OPRT</phaseCode>
        <phaseDesc rdf:datatype="http://www.w3.org/2001/XMLSchema#string"
        >Nutzung / Operation</phaseDesc>
```

```
      <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#NamedIndividual"/>
    </Phase>
  </hasSuperPhase>
  <phaseCode rdf:datatype="http://www.w3.org/2001/XMLSchema#string"
  >OPRT.FMGT</phaseCode>
  <phaseDesc rdf:datatype="http://www.w3.org/2001/XMLSchema#string"
  >Facility Management / Facility Management</phaseDesc>
  <name rdf:datatype="http://www.w3.org/2001/XMLSchema#string"
  >FMGT</name>
  <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#NamedIndividual"/>
 </Phase>
</rdf:RDF>
```

C Register.java

```
package Master;

//Registering new Elementary Model, by parsing MMT created by user

import java.io.FileOutputStream;
import java.io.IOException;
import java.io.InputStream;
import java.io.PrintStream;

import org.xml.sax.*;
import org.mindswap.pellet.PelletOptions;
import org.mindswap.pellet.jena.PelletReasonerFactory;
import org.w3c.dom.*;

import com.hp.hpl.jena.ontology.DatatypeProperty;
import com.hp.hpl.jena.ontology.Individual;
import com.hp.hpl.jena.ontology.ObjectProperty;
import com.hp.hpl.jena.ontology.OntClass;
import com.hp.hpl.jena.ontology.OntModel;
import com.hp.hpl.jena.ontology.OntModelSpec;
import com.hp.hpl.jena.rdf.model.ModelFactory;
import com.hp.hpl.jena.util.FileManager;

import javax.swing.JFrame;
import javax.swing.JOptionPane;
import javax.xml.parsers.*;
import javax.xml.xpath.XPath;
import javax.xml.xpath.XPathConstants;
import javax.xml.xpath.XPathExpressionException;
import javax.xml.xpath.XPathFactory;




public class Register {



public void doEkosMasterThesisWork(String filepath, String url) throws XPathExpressionException, IOException {

        Document xmlDoc = getDocument(filepath);

        PrintStream out = new PrintStream(new FileOutputStream((System.getProperty("user.home")+"/Desktop/addedMMC.txt")));

        System.setOut(out);


        System.out.println("MMC␣ID:␣"+
                xmlDoc.getDocumentElement().getAttribute("guid"));


        XPath xp = XPathFactory.newInstance().newXPath();

        Object num = xp.evaluate("(//model[@type])", xmlDoc, XPathConstants.NODESET);
        NodeList mode = (NodeList) num;

        NodeList link = xmlDoc.getElementsByTagName("linkModel");


        System.out.println("Number␣of␣Models␣in␣MMC␣:␣" + mode.getLength());
```

```
    System.out.println("Number of Link Models in MMC : " + link.getLength());

    System.out.println("============================================================");

    String URL = url;
String elementPhase = "phase";
    String elementDomain = "domain";
    String elementLOD = "levelOfDetail";
    String attrPhase = "phaseCode";
    String attrDomain = "domainCode";
    String attrLOD = "levelOfDetailCode";

    getElementAndAttrib(mode, link, xmlDoc, elementPhase, elementDomain, elementLOD, attrPhase, attrDomain, attrLOD, URL);
    }



    private static Document getDocument(String docString) {

            try {

                    DocumentBuilderFactory factory = DocumentBuilderFactory.newInstance();

                    factory.setIgnoringComments(true);
                    factory.setIgnoringElementContentWhitespace(true);
                    DocumentBuilder builder = factory.newDocumentBuilder();
                    return builder.parse(new InputSource(docString));

            }

            catch(Exception ex) {

                    System.out.println(ex.getMessage());

            }


            return null;
    }

    private static void getElementAndAttrib(NodeList mode, NodeList link, Document xmlDoc,
            String elementPhase, String elementDomain, String elementLOD,
            String attrPhase, String attrDomain, String attrLOD, String URL) throws IOException {


            try {

            for(int i=0; i <= mode.getLength() ; i++){

            Node modelNode = mode.item(i);


                    Element modelElement = (Element)modelNode;
                    NodeList phaseList = modelElement.getElementsByTagName(elementPhase);
                    NodeList domainList = modelElement.getElementsByTagName(elementDomain);
                    NodeList lodList = modelElement.getElementsByTagName(elementLOD);
                    Element phaseElement = (Element)phaseList.item(0);
                    Element domainElement = (Element)domainList.item(0);
                    Element lodElement = (Element)lodList.item(0);

                    NamedNodeMap attributes = modelNode.getAttributes();

                            for (int a = 0; a< link.getLength() ; a++) {
                            Node LinkNode = link.item(a);
                    NamedNodeMap linkattr = LinkNode.getAttributes();

                            Node theAttribute = attributes.getNamedItem("id");
                            Node theAttrType = attributes.getNamedItem("type");

                            Node linkattrid = linkattr.getNamedItem("id");

       String splitter = phaseElement.getAttribute(attrPhase);
       String[] arrayOfStrings = splitter.split(">");
       String neededString = arrayOfStrings[arrayOfStrings.length-1];
```

```
System.out.println("                                                                    ");
System.out.println("                                                                    ");
System.out.println("# New Elemetary Model id " + "  "+ ":" +" " +
xmlDoc.getDocumentElement().getAttribute("guid")+theAttribute.getNodeValue());
System.out.println("# New Link Model id " + "  "+ ":" +" " +
xmlDoc.getDocumentElement().getAttribute("guid")+
linkattrid.getNodeValue());
System.out.println("===================================================================");

System.out.println("type :" + theAttrType.getNodeValue());
System.out.println(attrPhase + " : "+ neededString);
System.out.println(attrDomain + " : "+ domainElement.getAttribute(attrDomain));
System.out.println(attrLOD + " : "+ lodElement.getAttribute(attrLOD));
System.out.println("===================================================================");

InputStream in = FileManager.get().open((System.getProperty("user.home")+"/Desktop/thesis_ontology.owl"));
OntModel model = ModelFactory.createOntologyModel(PelletReasonerFactory.THE_SPEC, null);
PelletOptions.FREEZE_BUILTIN_NAMESPACES = false;

String NS = "http://www.semanticweb.org/thato/ontologies/2012/10/9/thesis_ontology#";
model.read(in, null);
in.close();

OntClass ApplicationModel = model.getOntClass(NS + "ApplicationModel");
OntClass LinkModel = model.getOntClass(NS + "LinkModel");
OntClass MMContainer = model.getOntClass(NS + "MMContainer");

Individual MMC = model.createIndividual(NS + xmlDoc.getDocumentElement().getAttribute("guid"), MMContainer);
Individual AM20 = model.createIndividual(NS + xmlDoc.getDocumentElement().getAttribute("guid")+
theAttribute.getNodeValue(), ApplicationModel);
Individual LM = model.createIndividual(NS + xmlDoc.getDocumentElement().getAttribute("guid") +
linkattrid.getNodeValue(), LinkModel);

Individual mmc = model.getIndividual(NS + xmlDoc.getDocumentElement().getAttribute("guid")+
linkattrid.getNodeValue());

Individual dom = model.getIndividual(NS + domainElement.getAttribute(attrDomain));
Individual pha = model.getIndividual(NS + neededString.trim());
Individual lev = model.getIndividual(NS + lodElement.getAttribute(attrLOD));
Individual typ = model.getIndividual(NS + theAttrType.getNodeValue());

Individual lnk = model.getIndividual(NS + xmlDoc.getDocumentElement().getAttribute("guid")+
theAttribute.getNodeValue());
//   Property urlAdd = model.createDatatypeProperty(NS + URL);---with this you create annotation

        // Create Object Property

        ObjectProperty container = model.createObjectProperty(NS + "hasAM");
        ObjectProperty mmlink = model.createObjectProperty(NS + "hasLinkModel");
        ObjectProperty links = model.createObjectProperty(NS + "Linking");
        ObjectProperty domain = model.createObjectProperty(NS +"hasDomain");
        ObjectProperty fase = model.createObjectProperty(NS +"hasPhase");
        ObjectProperty lod = model.createObjectProperty(NS +"hasLevelOfDetail");
        ObjectProperty type = model.createObjectProperty(NS +"hasType");

        model.add(AM20, domain, dom);
        model.add(AM20, fase, pha);
        model.add(AM20, lod, lev);
        model.add(AM20, type, typ);
        model.add(LM, links, lnk);
        model.add(MMC, container, lnk);
        model.add(MMC, mmlink, mmc);

        // Create Data Property
        DatatypeProperty url = model.createDatatypeProperty(NS + "hasURL");

        model.add(AM20, url, URL);

            PrintStream p = new PrintStream((System.getProperty("user.home")+"/Desktop/thesis_ontology.owl"));

        model.write(p, "RDF/XML-ABBREV", null);
        p.close();

        }
    }
    }
```

```
                catch(Exception ex) {

//   System.out.println(ex.getMessage());
                        System.out.println("Done");
                }
                 // Create Confirmation Dialog Box
            JFrame parent = new JFrame();
            String multiLineMsg[]={"Done, the new Model has been registered in the Database!"};
            JOptionPane.showMessageDialog(parent, multiLineMsg);
            System.exit(0);
        }


}
```

D Querying.java

```
package Master;

//this is to parse MMT(required model not new EM) and then apply query in the database (to search Model)

import java.io.File;
import java.io.FileInputStream;
import java.io.FileOutputStream;
import java.io.IOException;
import java.io.InputStream;
import java.io.PrintStream;

import org.xml.sax.*;
import org.w3c.dom.*;

import com.hp.hpl.jena.ontology.OntModelSpec;
import com.hp.hpl.jena.query.Query;
import com.hp.hpl.jena.query.QueryExecution;
import com.hp.hpl.jena.query.QueryExecutionFactory;
import com.hp.hpl.jena.query.QueryFactory;
import com.hp.hpl.jena.query.ResultSet;
import com.hp.hpl.jena.query.ResultSetFormatter;
import com.hp.hpl.jena.rdf.model.Model;
import com.hp.hpl.jena.rdf.model.ModelFactory;
import com.hp.hpl.jena.vocabulary.OWL;
import com.hp.hpl.jena.vocabulary.RDF;
import com.hp.hpl.jena.vocabulary.RDFS;

import javax.swing.JFrame;
import javax.swing.JOptionPane;
import javax.xml.parsers.*;
import javax.xml.xpath.XPath;
import javax.xml.xpath.XPathConstants;
import javax.xml.xpath.XPathExpressionException;
import javax.xml.xpath.XPathFactory;

import org.mindswap.pellet.PelletOptions;
import org.mindswap.pellet.jena.PelletReasonerFactory;




public class ParseMMTAndQuerying {


        public void doParceMMTAndQuerying(String fileName) throws XPathExpressionException, IOException {


                Document xmlDoc = getDocument(fileName);


                System.out.println("Root:␣"+
                                xmlDoc.getDocumentElement().getNodeName());


                NodeList mode = xmlDoc.getElementsByTagName("model");

                String elementPhase = "phase";
                String elementDomain = "domain";
```

```
        String elementLOD = "levelOfDetail";
        String attrPhase = "phaseCode";
        String attrDomain = "domainCode";
        String attrLOD = "levelOfDetailCode";


        getElementAndAttrib(mode, elementPhase, elementDomain, elementLOD, attrPhase, attrDomain, attrLOD);
}

private static Document getDocument(String docString) {



        try {

                DocumentBuilderFactory factory = DocumentBuilderFactory.newInstance();

                factory.setIgnoringComments(true);
                factory.setIgnoringElementContentWhitespace(true);

                DocumentBuilder builder = factory.newDocumentBuilder();

                return builder.parse(new InputSource(docString));

        }

        catch(Exception ex) {

                System.out.println(ex.getMessage());

        }


        return null;
}

private static void getElementAndAttrib(NodeList mode,
                String elementPhase, String elementDomain, String elementLOD,
                String attrPhase, String attrDomain, String attrLOD) throws IOException {

        System.out.println("Number␣of␣Models␣in␣MMT␣:␣" +
                        mode.getLength());


        try {


                for(int i=0; i < mode.getLength() ; i++){

                        Node modelNode = mode.item(i);

                        Element modelElement = (Element)modelNode;

                        NodeList phaseList = modelElement.getElementsByTagName(elementPhase);

                        NodeList domainList = modelElement.getElementsByTagName(elementDomain);

                        NodeList lodList = modelElement.getElementsByTagName(elementLOD);

                        Element phaseElement = (Element)phaseList.item(0);

                        Element domainElement = (Element)domainList.item(0);

                        Element lodElement = (Element)lodList.item(0);


                        System.out.println("" +
                ""  +
                ""  +
                ""  +
                "");
                                System.out.println("================================");

                                String splitter = phaseElement.getAttribute(attrPhase);
                                    String[] arrayOfStrings = splitter.split(">");
                                    String neededString = arrayOfStrings[arrayOfStrings.length-1];
```

```
                    System.out.println("Required model based on MMT :" );
                    System.out.println("" +
                                "" +
                                "" +
                                "" +
                                "");

                        System.out.println(attrPhase + " :"+phaseElement.getAttribute(attrPhase) );
                        System.out.println(attrDomain + " :"+ domainElement.getAttribute(attrDomain));
                        System.out.println(attrLOD + " :"+ lodElement.getAttribute(attrLOD));
                    System.out.println("================================");

                        System.out.println("Models found in the Database :");


                        InputStream in = new FileInputStream(new File((System.getProperty("user.home")+"/Desktop/thesis_ontology.owl")));
                        PelletOptions.FREEZE_BUILTIN_NAMESPACES = false;

                    Model model = ModelFactory.createOntologyModel(OntModelSpec.OWL_MEM_RULE_INF, null);

                    model.read(in, null);
                    in.close();


String queryString =
"prefix :<http://www.semanticweb.org/thato/ontologies/2012/10/9/thesis_ontology#> " +
"prefix rdfs:< " + RDFS.getURI() + ">" +
"prefix owl:< " + OWL.getURI() + ">" +
"prefix rdf:< " + RDF.getURI() + ">" +
"select  ?Model ?URL ?ProducedFrom ?LOD ?Workflow " +
"where {{ " +
"?Model rdf:type :ApplicationModel. " +
"?Model :hasDomain ?domain.     " +
"?domain :domainCode ?domaincode. " +
"FILTER (?domaincode =" + "'"+ domainElement.getAttribute(attrDomain) + "'"+ ")" +
"?Model :hasPhase ?phase." +
"?phase :name ?phasecode. " +
"FILTER (?phasecode =  "+ "'"+ neededString +"'"+")" +
"?Model :hasLevelOfDetail ?lod." +
"?lod :name ?lodcode." +
"FILTER (?lodcode =  "+ lodElement.getAttribute(attrLOD)+ ")" +
"OPTIONAL{?Model :hasURL ?URL.}" +
"}"

                + "UNION  {  "      +
                            "?ProducedFrom rdf:type :ApplicationModel. "  +
                            "?ProducedFrom :hasDomain ?domain.     " +
                        "?domain :domainCode ?domaincode. " +
                            "FILTER (?domaincode =" + "'"+ domainElement.getAttribute(attrDomain) + "'"+ ")" +
                            "?ProducedFrom :hasPhase ?phase." +
                            "?phase :name ?phasecode. " +
                            "FILTER (?phasecode =  "+ "'"+ neededString +"'"+")" +
                            "?ProducedFrom :hasLevelOfDetail ?LOD." +
                            "?LOD :name ?lodcode." +
                            "FILTER (?lodcode =  "+ lodElement.getAttribute(attrLOD)+"+"+"1"+ ")" +
                        "?ProducedFrom :usingWorkflow ?Workflow." +
                            "?Workflow :name ?workflow."+
                            "FILTER (?workflow = 'Workflow1' )" +
                            "}"

+"}" ;


                    Query query = QueryFactory.create(queryString);
                    QueryExecution qe = QueryExecutionFactory.create(query, model);
                    ResultSet results = qe.execSelect();
                    ResultSetFormatter.out(System.out, results, query);
                    qe.close();


                }
            }

            catch(Exception ex) {

                System.out.println(ex.getMessage());
```

```
        }

        System.out.println("Done");
        JFrame parent = new JFrame();
    String multiLineMsg[]={"Done, Please check the result on the Output file on your Desktop!"};
    JOptionPane.showMessageDialog(parent, multiLineMsg);
    System.exit(0);

}


}
```

E Multimodel.xml

```
<?xml version="1.0"?>
<container guid="0d84c6cf-3300-4753-9c8b-f7bb763e5da1" formatVersion="1.0">
	<meta>
		<origin>
			<created>2012-09-13T09:33:12</created>
			<creatorId>dej</creatorId>
			<appVersion>3.2.134</appVersion>
			<application>iTWO64</application>
		</origin>
		<info>
			<i k="ContainerDescription" t="xs:string" v="MMC-Datenaustausch zur Leistungsfeststellung."/>
			<i k="ContainerFromTemplate" t="xs:string" v="Auftrag_Leistungsfeststellung.mmt"/>
			<i k="ContainerName" t="xs:string" v="Leistungsfeststellung 2012-04"/>
			<i k="ContainerType" t="xs:string" v="MMC Leistungsfeststellung"/>
			<i k="TemplateName" t="xs:string" v="Leistungsfeststellung"/>
		</info>
	</meta>
	<models>
		<model contextId="\Projekte\Mefisto\M04 V2 (AusfÃŒhrung)\Projektvarianten\01" type="BoQ" id="FM1">
			<meta>
				<origin>
					<created>2012-09-13T09:33:12</created>
					<creatorId>dej</creatorId>
					<appVersion>3.2.134</appVersion>
					<application>iTWO64</application>
				</origin>
				<info>
					<i k="ModelName" t="xs:string" v="Leistungsverzeichnis "/>
				</info>
				<phase phaseCode="&#x3e;PRCR&#x3e;BDDG" phaseDesc="Angebotserstellung"/>
				<domain domainDesc="Angebotsabgabe" domainCode="SPM.BOQ.BDP"/>
				<levelOfDetail levelOfDetailDesc="Bauwerkselemente, Objektplanung" levelOfDetailCode="[4]"/>
			</meta>
			<content format="gaebxml" id="1" formatVersion="3.1">
				<contentOptions>
					<i k="description" t="xs:boolean" v="0"/>
					<i k="extension" t="xs:string" v="DA81"/>
					<i k="qtosplit" t="xs:boolean" v="0"/>
					<i k="unitrate" t="xs:boolean" v="1"/>
					<i k="unitrate_breakdown" t="xs:boolean" v="1"/>
				</contentOptions>
				<file namespace="BoQ1">file:///BoQ/1/LV 1.X81</file>
			</content>
		</model>
		<model contextId="\Projekte\Mefisto\M04 V2 (AusfÃŒhrung)\Projektvarianten\01" type="Object" id="FM2">
			<meta>
				<origin>
					<created>2012-09-13T09:33:12</created>
					<creatorId>dej</creatorId>
					<appVersion>3.2.134</appVersion>
					<application>iTWO64</application>
				</origin>
				<info>
					<i k="ModelName" t="xs:string" v="GebÃ€udemodell"/>
				</info>
				<phase phaseCode="&#x3e;PRCR&#x3e;BDDG" phaseDesc="Angebotserstellung"/>
				<domain domainDesc="GebÃ€udemodell" domainCode="BIM"/>
				<levelOfDetail levelOfDetailDesc="Bauwerkselemente, Objektplanung" levelOfDetailCode="[4]"/>
			</meta>
			<content format="ifc" id="c1" formatVersion="2x3">
				<file>file:///Object/c1/BW.ifc</file>
			</content>
			<content format="cpixml" id="c2" formatVersion="1.4">
```

```
                        <file>file:///Object/c2/BW.cpixml</file>
                        <file>file:///Object/c2/buildingStructure.cpixml</file>
                    </content>
                </model>
                <model contextId="\Projekte\Mefisto\M04 V2 (AusfÃŒhrung)\Projektvarianten\01" type="QTO" id="FM3">
                    <meta>
                        <origin>
                            <created>2012-09-13T09:33:12</created>
                            <creatorId>dej</creatorId>
                            <appVersion>3.2.134</appVersion>
                            <application>iTWO64</application>
                        </origin>
                        <info>
                            <i k="ModelName" t="xs:string" v="Teilmengen BoQ-BIM"/>
                        </info>
                        <phase phaseCode="&#x3e;PRCR&#x3e;BDDG" phaseDesc="Angebotserstellung"/>
                        <domain domainDesc="Modellberechnete Mengen" domainCode="SPM.QTO.MCQ"/>
                        <levelOfDetail levelOfDetailDesc="Bauwerkselemente, Objektplanung" levelOfDetailCode="[4]"/>
                    </meta>
                    <subset subsetCode="RE" subsetDesc="RE-Mengen">
                        <subsetFilter application="M2A2">BQ(1)</subsetFilter>
                        <subsetFilter application="iTWO">BQ(1)</subsetFilter>
                    </subset>
                    <content format="xml" id="1" formatVersion="1.1">
                        <file namespace="QTO1">file:///QTO/1/1 LV VA.xml</file>
                        <file namespace="QTO2">file:///QTO/1/1 RE LE.xml</file>
                    </content>
                </model>
            </models>
            <linkModels>
                <linkModel type="QuantitySplit" id="L1">
                    <meta>
                        <origin>
                            <created>2012-09-13T09:33:12</created>
                            <creatorId>dej</creatorId>
                            <appVersion>3.2.134</appVersion>
                            <application>iTWO64</application>
                        </origin>
                        <info>
                            <i k="ModelName" t="xs:string" v="Linkmodell"/>
                        </info>
                        <domain domainDesc="Link Model" domainCode="LKM.QSP"/>
                    </meta>
                    <subset>
                        <subsetFilter application="iTWO">NotEmpty[FM3]</subsetFilter>
                    </subset>
                    <models>
                        <model id="FM1"/>
                        <model id="FM2"/>
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                                <element type="Alternative" id="\Projekte\Mefisto\M04 V2 (AusfÃŒhrung)\Projektvarianten\01">
                                    <name>01 Auftrag vom 20.03.2012</name>
                                </element>
                            </element>
                        </element>
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</container>
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F Request.mmt

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