University of Alberta

A Semantic-Driven Framework for Facilitating Reusability and Interoperability of Construction Simulation Modeling

By

Farzaneh Saba

A thesis submitted to the Faculty of Graduate Studies and Research
in partial fulfillment of the requirements for the degree of

Doctor of Philosophy
in
Construction Engineering and Management

Department of Civil and Environmental Engineering

Dedicated to my beloved parents

Hamidreza and Azar

And

to my lovely siblings

Kazem and Naghmeh

Abstract

This research describes a semantic-driven framework to facilitate reusability and interoperability of simulation and modeling of construction processes. An immense amount of knowledge of construction processes and simulation modeling is needed to develop construction simulation models. Knowledge intensity of construction simulation models makes the development process an effort and time consuming process. The research described in the thesis is motivated by the need to effectively reuse the captured and represented knowledge throughout the life cycle of simulation models. Our approach addresses these challenges through ontological modeling and linking construction simulation modeling concepts composed of (i) ontology of the construction process, (ii) ontology of simulation modeling constructs and elements and (iii) ontological representation of simulation models. In this research, semantic web approaches and techniques have been utilized in different aspects: structured documentation and modeling of construction processes through hierarchical concepts and relationships between them using semantic web languages such as XML, RDF, and OWL; mapping techniques for linking and knowledge extraction between modeling ontologies; and reasoning and inference for knowledge discovery. Stand-alone construction simulation

models and a large-scale HLA-based distributed simulation model of industrial construction processes have been outlined in order to illustrate the approach.

Acknowledgements

First and foremost, I would like to thank my Ph.D. supervisor, Dr. Yasser Mohamed, for his strong support and encouragement during the course of my research. I am also deeply indebted to Dr. Simaan Abourizk for his critical insight throughout the entire research process and also serving as my candidacy and doctoral committee chair.

I would like to acknowledge Dr. Jeffrey Rankin for serving as my external examiner and providing invaluable suggestions. I am also grateful to my other doctoral committee members, Dr. Roger Cheng and Dr. Michael Lipsett for their thoughtful review and supportive advice.

I would like to take this opportunity to thank Brenda Penner, Stephen Hauge, Hosein Taghados and other faculty members and staff and colleagues in construction engineering and management group who assisted me during this work.

During my work at University of Alberta I was fortunate to make lifelong friendships with many great people. Being away from family, they were the support throughout all the ups and downs of my graduate student life, especially Ali Gorji, Katayoon Navabi, Atoosa Zahabi and Mohsen Danaie, who the last has become a very special person in my life.

Last but not least, my heartfelt appreciations go to my family for their unconditional love, care and support throughout all the stages of my studies. This thesis is dedicated to them.

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List of Abbreviations

BOM	Base Object Model
C&SU	Commissioning & Start-up
CEM	Construction Engineering and Management
COSYE	Construction Synthetic Environment
DeMO	Discrete Event Model Ontology
DES	Discrete Event Simulation
DoD	Department of Defense
EPCM	Engineering, Procurement, and Construction Management
ES	Early Start
FEDEP	Federation Development and Execution Process
FOM	Federation Object Model
GUI	Graphical User Interface
HLA	High Level Architecture
HTML	Hyper Text Markup Language
IC-PRO-Onto	Infrastructure and Construction PROcess Ontology
InCon-Onto	Industrial Construction Ontology
KDD	Knowledge Discovery in Data
M&S	Modeling and Simulation
MASON	Manufacturing Semantically Ontology
OMT	Object Model Template
OWL	Web Ontology Language
PIMODES	Process Interaction Modeling Ontology for Discrete Event Simulations
QC	Quality Control
RA	Resource Allocation
RAB	Resource Allocation Base
RDF	Resource Description Framework
RTI	Run-Time Infrastructure
SISO	Simulation Interoperability Standards Organization
SPARQL	SPARQL Protocol and RDF Query Language
SPS	Special Purpose Simulation
SWRL	Semantic Web Rule Language
TBC	TopBraid Composer
UML	Unified Modeling Language
URI	Uniform Resource Identifier
W3C	World Wide Web Consortium
WBS	Work Breakdown Structure
WDP	Winner Determination Problem
WWW	World Wide Web
XML	eXtensible Markup Language

Chapter 1

Simulation modeling of construction processes

1-1 Introduction

Simulation is defined as “the process of designing a model of a real system and conducting experiments with this model for the purpose of either understanding the behaviour of the system or evaluating various strategies for the operation of the system” (Shannon 1975). Construction processes’ uniqueness, uncertainty, and complexity necessitate using simulation as a decision-making support tool.

Simulation has been an important area in construction research for three decades, during which a number of construction simulation tools have been developed. The stream of construction simulation tools began with CYCLONE (Halpin 1977) and was followed by MicroCYCLONE (Lluch and Halpin 1981), RESQUE (Chang and Carr 1987), and STROBOSCOPE (Martinez and Ioannou 1994).

Early construction simulation modeling tools were general, and could be used for simulating a wide range of applications. The tools were powerful but required the user to be fully familiar with them in order to be able to manipulate the information. To reduce the time and effort involved in simulation modeling development, the Special Purpose Simulation (SPS) tool "Simphony" was developed (Hajjar and AbouRizk 1999). Object-oriented programming was used to develop the Simphony environment so that it provides a hierarchical and modular simulation environment (Sawhney and AbouRizk 1995). Many attempts have used simulation modeling to portray and predict complex and uncertain construction processes and as an inexpensive means to test and evaluate different design and control strategies (Mohamed et al. 2007).

However, there are common drawbacks to developing models within stand-alone simulation environments: simulation models are often built as monolithic and isolated software systems which are neither able to integrate with other simulation models or applications, nor to handle large-scale construction simulation models.

In other industries, the distributed simulation modeling approach has been taken to address these challenges. Within a distributed approach, a large and complicated model is divided into smaller and more manageable components which are linked with each other in an interchangeable manner to present the entire system. High Level Architecture (HLA) is an advanced standard, developed by the United States Department of Defense (DoD), to facilitate the integration and interoperabality of distributed simulation models (Kuhl et al. 1999). HLA has been introduced to the Construction Synthetic Environment (COSYE) by AbouRizk et al. (2006).

1-2 Simulation Modelling Processes

Simulation modeling is a knowledge intensive process. In order to develop a model of construction processes, the modellers should be familiar not only with simulation and modeling tools and techniques; they should also understand the target construction processes in detail (Figure 1-1).

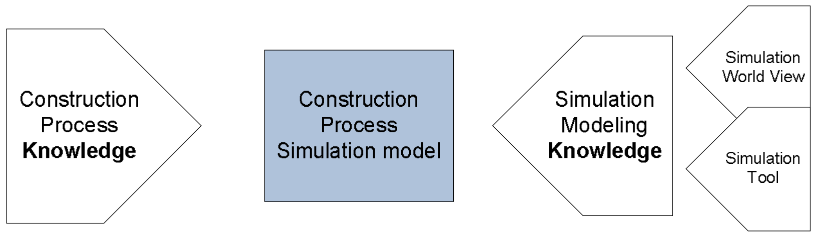
Construction Process **Knowledge**
Construction Process Simulation model
Simulation Modeling **Knowledge**
Simulation World View
Simulation Tool

Figure 1-1: Knowledge involved in construction simulation modeling

The development process for simulation and modeling starts with knowledge acquisition from construction domain experts in order to gather information about the process and specify the problem and simulation purpose. The gathered information is traditionally presented within a conceptual model through the knowledge representation and modeling process. According to the conceptual models, computer simulation models are built. After validation and verification of the models, they are put into use (Figure 1-2).

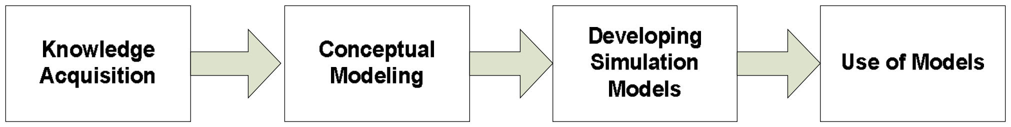

Figure 1-2: Simulation and modeling development process

Considering the amount of knowledge within simulation models and the cost and effort involved, it is important to reuse the knowledge captured through all simulation development processes, starting with knowledge acquisition through knowledge representation and knowledge modeling.

In the following section we investigate in more detail why reuse in simulation and modeling is appealing. Also, we try to come up with modeling approaches which facilitate reusing knowledge within conceptual models.

1-3 Reuse in Simulation and Modeling

Reusing simulation models leads to reducing development cost and time. According to Kasputis and Ng (2000), it will even lead to higher quality simulation studies. Considering the different processes of simulation modeling development, reuse can be feasible at any phase. After knowledge acquisition phase, the conceptual model is built which documents domain knowledge. The next step is developing the simulation model and at the end comes model execution of archiving. (Figure 1-3).

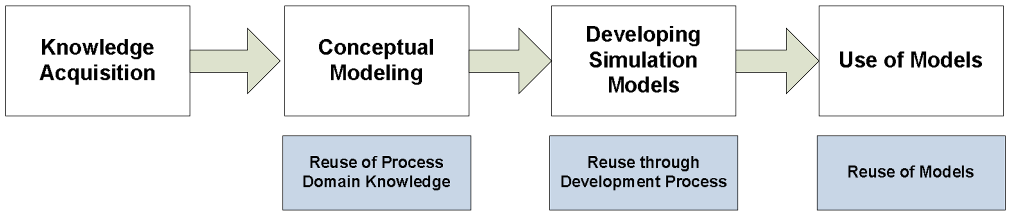
Knowledge Acquisition
Conceptual Modeling
Developing Simulation Models
Use of Models
Reuse of Process Domain Knowledge
Reuse through Development Process
Reuse of Models

Figure 1-3: Reuse opportunities for knowledge process outcomes

Within simulation practice, reuse has traditionally been addressed through the simulation model development process, utilizing simulation modeling elements' libraries and templates. Developing simulation models from reusable elements reduces development efforts and therefore speeds up composing simulation models (AbouRizk and Mohamed 2000). However, reuse challenges with regard to conceptual modeling and also after model execution and archiving has not been at researchers' focus. The following section investigates reusability at different stages of simulation development and points out the shortcomings.

Reuse of Conceptual Models: Effective conceptual modeling is vital for developing a quality simulation model but it is least understood and investigated phase in the simulation community (Robinson 2004). According to Lacy (2001), conceptual models are domain-oriented and provide a detailed representation of real-world problems describing the model requirements. Conceptual models effectively capture domain experts' knowledge. Poor documentation of conceptual models makes it difficult to effectively trace and communicate model contents. Conceptual models are usually portrayed through graphical methods such as process flow diagrams, activity cycle diagrams, Unified Modeling Language (UML) and object models. These methods of documenting conceptual models make it easier to understand the process, but they usually do not do much in terms of structuring and formalising the models.

Reuse in the Development Process: Reuse has been most practically applied through building simulation models, from reuse of a small portion of code to reuse of a simulation function or component and finally to the entire model (Figure 1-4). The stand-alone construction simulation modelling tools allow previously developed simulation components to be reused (Oloufa 1993; Hajjar et al. 2000) and provide libraries of such components.

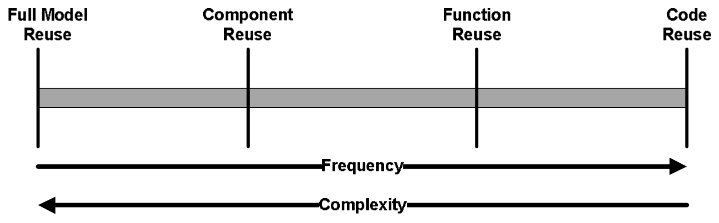

Figure 1- 4: Spectrum of model reuse (Robinson et al. 2006)

As was mentioned before, construction simulation modeling is deploying distributed simulation modeling in order to deal with large-scale construction models and interoperability and reusability challenges. Decomposing simulation models and distributing simulation efforts between different development groups cannot happen without coordination and reaching a consensus between all the involved collaborator parties about the knowledge that they are sharing. All the parties have to have a harmonized understanding around all core aspects of simulation modeling. This necessitates documented conceptual modeling.

HLA Technically encourages interoperability and reusability of simulation components (federates), by being able to combine federates in an interchangeable manner into complex simulation models (federation). However semantic coordination of components is not a straightforward matter. The reason is that the federates are treated as atomic simulation components; reusing even a portion of their internal code is almost impossible. The narrow reusability scope within distributed simulation modeling often makes the development process a complex and effort-intensive exercise (Radeski et al. 2002).

Reuse of Full Models: Reusing full models is a demanding process too, mostly because the time and cost to become familiar with other people's development overshadows the benefits of reuse. This problem can be partly traced back to a lack of effective documentation of conceptual models. In addition to conceptual modeling documentation, availability and accessibility to simulation models and their content for the users is an issue which has not been addressed.

Reuse, meaningful structuring, sharing, and discovery challenges on the web led to the spread of the semantic web as a new technology to overcome those challenges. New emerging semantic web technology can bring new opportunities to developing content-based, structured environments (built based on ontologies) which facilitate sharing, reuse, and discovery. Many domains have started adapting semantic web technologies in their fields. In this research we have tried to join this stream and adapt semantic web technology and techniques, seeking the same advantages.

1-4 Research Motivation

In simulation modeling, involved knowledge components are coming from two different worlds: the real world and the simulation implementation world (Tolk and Turnitsa 2007). The real world is reflected in conceptual models, and the implementation venue of the conceptual model is the simulation world. Ontological modeling of these components, along with the use of semantic web technologies, helps in effective sharing, linking, and knowledge discovery from these different knowledge sources.

In this thesis throughout the different stages of simulation and modeling, ontological modelling and semantic web technologies are utilized, with the goal of facilitating reuse and interoperability of simulation models.

1-5 Thesis Objectives and Anticipated Contributions

The objective of the research in this thesis is to facilitate interoperability and reusability of involved simulation modeling components through the entire life cycle of simulation models, from conceptual modeling to simulation development and the simulation model use phase. This is to be investigated for the case study of an industrial construction simulation model. We expect to achieve the following contributions:

1- To facilitate reusability at the conceptual level, the domain knowledge of industrial construction is formalized and structured through Industrial Construction (In-Con) ontology. It also demonstrates the use of ontological mapping tools and techniques to enable interoperability and the reuse of captured knowledge.

2- To facilitate reuse at the development phase for distributed simulation modelling of construction processes, an element-based approach is pursued. The simulation elements' properties are characterized based on simulation-process interaction ontology.

3- To maintain the reuse of the simulation model after development, the research introduces a semantic representation, sharing, and discovery of construction simulation models.

1-6 Research Methodology

In order to accomplish the proposed research objectives, the following approach will be pursued:

1- The industrial construction processes will be understood from the perspective of domain experts and by performing different construction and simulation projects.

2- Industrial construction processes will be analysed and modeled within large-scale simulation models.

3- The literature on modeling reuse, interoperability and composability will be studied, and ontologies and the semantic web will be exploited to facilitate simulation modelling reuse.

4- Semantic web techniques and technologies will be applied throughout the different stages of simulation modeling development:

   a. Capture and formalize the construction domain knowledge within ontologies, following the process modeling approach through concepts' hierarchies and relationships between them expressed in semantic web languages.

   b. Ontologically model all the simulation components and link them through mapping techniques in order to make it easier to reuse knowledge and identify an element-based approach for developing simulation models.

   c. Semantic representation of simulation models with the aim of easy discovery and reuse of simulation model components are included through an environment which supports storage and sharing of simulation models and knowledge extraction and discovery.

1-7 Thesis Organization

In Chapter 2, the industrial construction processes and project management challenges are explained, and different simulation models targeting this area are presented. Chapter 3 of the thesis presents capturing and formalizing the construction domain knowledge within ontologies. Through interoperability of ontological components, the knowledge residing in them is carried forward to simulation modeling application. Chapter 4 tackles reusability challenges of the construction distributed simulation modeling environment, using ontolgies for creating a more collaborative environment between different involved groups. Chapter 5 introduces a prototype of modelling repositories which facilitates accessing and sharing of simulation models' content and knowledge discovery through reasoning and inference. A final discussion and recommendations for future research are provided in Chapter 6 (Figure 1-5).

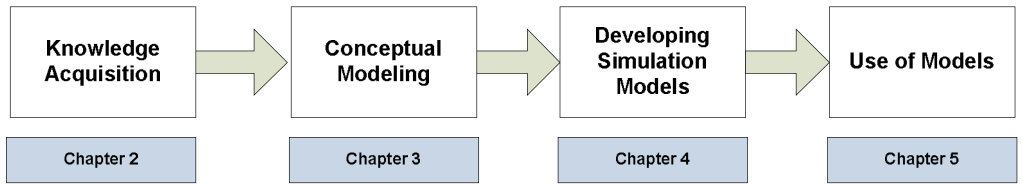

Figure 1-5: Thesis organization

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Chapter 2

Industrial Construction Domain and Related Models

2-1 Introduction

Construction processes are intrinsically complex and associated with many uncertainty and randomness (Halpin et al. 2003). One of the ever growing construction processes are "Industrial construction" for constructing petrochemical and oil/gas production facilities (Barrie and Paulson 1992). Industrial construction involves a complex production network system consisting of multiple supply chains associated with many constraints and uncertainties which complicate reliable project planning and estimation. Many attempts have been used simulation modeling to portray and predict highly variable behaviours in the production network of industrial construction and as an inexpensive means to test and evaluate different design and control strategies (Mohamed et al. 2007). Both stand-alone simulation modeling and distributed simulation modeling have been deployed to model industrial construction processes. However, there are common drawbacks to models developed within stand-alone simulation environments; each portion of the industrial construction process is modeled in isolation, so that the simulation model does not reflect the effects of dependencies and variations along multiple supply chains. The only effort to simulate the entire industrial construction process in a detailed manner was carried out by Wang et al., who faced many shortcomings using a stand-alone simulation modeling tool. Shortfalls such as lack of re-use, composability and interoperability, standardization, computing ability, and versatility in simulating large-scale industrial construction are identified (Wang et al. 2005).

In other industries, such as transportation and manufacturing (Kelin et al. 1998) (Lee et al. 2003), Distributed simulation modeling approach has been taken to address these challenges. Within a distributed approach, a large and complicated Model is divided to smaller and more manageable components which are inter-linked with each other in an interchangeable manner to present the entire system. High Level Architecture (HLA) is an advanced standard, developed by the United States Department of Defense (DoD) to facilitate the integration and interoperabality of distributed simulation models (Kuhl et al. 1999).

The Construction Synthetic Environment (COSYE) which is an HLA-based distributed simulation environment has been developed by AbouRizk et al. (2006). COSYE has been applied to model various large-scale construction and industrial construction projects. In this chapter two instances of distributed simulation models of industrial construction processes are presented.

2-2 Industrial Construction

"Industrial construction" is a type of construction which is increasingly growing in Alberta. Industrial construction projects are, essentially involved in constructing utilities and industries such as petrochemical and oil/gas production facilities. These projects are more complex than other construction projects for the following reasons (Hammad 2009):

1- They involve a large number of stakeholders including owners, project management team, engineers, suppliers, fabricators, constructors, environmental and other governmental agencies, plant operators and maintainers, and the general public. These stakeholders often have different and even conflicting interests.

2- The industrial plants are significantly more complex than other types of construction projects. Industrial plants are typically complex steel mazes including features such as processing units, tanks, vessels, pumps, heat exchangers, pipe-racks, connecting pipes, valves, measurement instrumentations, electrical and instrumentation cables, transformers, administration buildings, control rooms, and special purpose items. Industrial plants are exposed to explosive and hazardous materials. Small mistakes in construction of any of these items can lead to significant damage.

3- Because of their complicated managerial and technical nature, industrial construction projects require substantial amounts of project management coordination.

The life cycle of an industrial construction project includes five main phases: pre-engineering, engineering, procurement, construction and Commissioning & Start-up (C&SU). The pre-engineering phase takes place at the initiation stage of the industrial project. Engineering, procurement, and construction form the planning and execution life-cycle phases of industrial projects; and the C&SU phase takes place during the closeout stage when delivering the project to the owners (Figure 2-1). Industrial construction projects are broken down into smaller projects performed by different contractors. The involved contractors are the Engineering, Procurement, and Construction Management (EPCM) offices. Construction phase which is the focus of this research involves fabrication shops and module assembly yards and site installation.

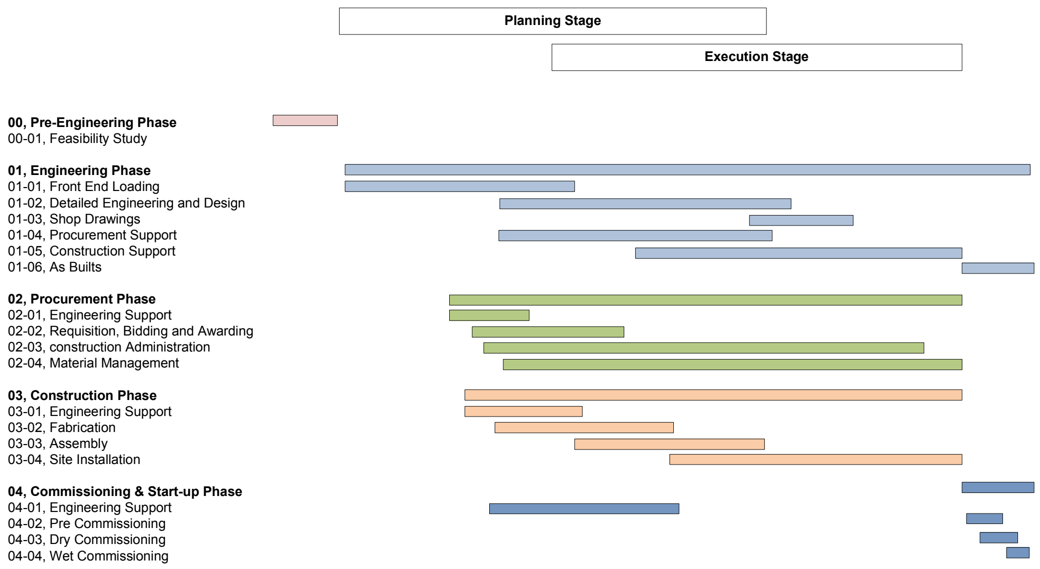


Figure 2-1: Industrial Construction Project Life cycle (adapted from Hammad, 2009)

2-2.1 Construction phase

Industrial construction has adapted modular construction which makes industrial construction much different from other construction projects. According to Gupta et al. within industrial construction modularization, “various materials, pre-fabricated components, and process equipment are joined together at a location remote from the construction site for subsequent installation as one unit.” Modular construction is a more efficient approach towards improving a project’s quality, productivity and safety (Gupta et al. 1997).

Pipe spools and steel structures are fabricated through the shop fabrication process and modules are assembled through assembly process at module yards. Afterwards they are shipped to and installed in the final construction site. The material is obtained during the procurement phase and the shop drawings in the engineering phase.

In structural steel fabrication shops, the structural skeletons of the modules are fabricated through cutting, drilling, fitting, welding, inspection, painting, and fire-proofing processes. In spool fabrication shops, spools are fabricated from pipes and fittings through cutting roll fitting and welding, position fitting and welding, quality checking, stress relief, hydro testing, inspection, and painting. The structural steel, pipe spools and other module components such as mechanical equipment, electrical, and instrumentation cables are shipped to the module assembly yard and assembled to form a complete module. Subsequently the modules shipped and installed as a plant module component.

The following section describes in more detail the complexities and constraints in the industrial construction processes, with a focus on spool fabrication, module assembly, and site installation. After that, there is an explanation of some of the research that has been conducted on modeling the industrial construction processes.

2-2.2 Industrial Construction: fabrication, assembly, and site installation

The process of industrial construction is managed by industrial construction contractors. Their facilities, including fabrication shops and module assembly yards, are not as temporary as construction site set-ups, and at the same time are not the same as manufacturing shops.

The main difference of industrial construction (Figure 2-2) with building and infrastructure construction is the complication of industrial construction structures and uncertainties within construction process. The industrial plants are complex steel structures formed from the installation of steel structures, pipe spools, and module assemblies. Each of these products has unique characteristics which make mass production impossible and complicate the fabrication and module assembly processes.

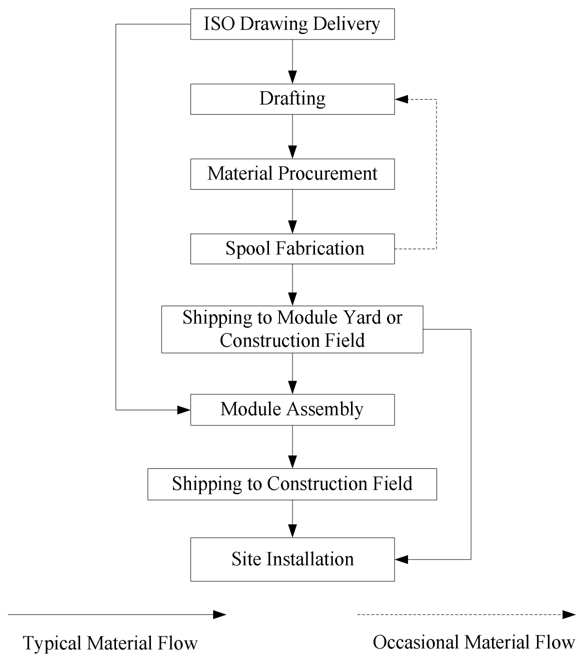


Figure 2-2: Typical Production process of Industrial Construction (adapted from Wang, 2006)

Typically, the industrial construction process starts with receiving Isometric (ISO) drawings from the client. The ISO drawings are redrafted to create fabricable spool drawings along with detailed information about the welds. The material including the pipes and the fittings are supplied by the clients or procured by the contractors. The process of fabricating a spool starts based on its related module assembly priority and the availability of material. After fabrication, the spools are either shipped to the construction site or to the module yard. At the module yard, the pipe spool and equipment are assembled on a steel structure as a module. Finally these modules are shipped to the construction field for the final site installation. In the following, each process is explained in more detail.

Drafting and Material Procurement:

The spool shop drawings are drafted based on the ISO drawings and other requirements received from the clients. Along with spool drawings, the bill of material is generated from material takeoff. The shop drawings contain detailed information about the job and control number, and information about the spool specifications such as needed material and welds and other finishing requirements. The shop drawings are issued to the fabrication shop and are put into process according to their priority.

Pipe spool materials including pipes and different types of fittings are either supplied or procured by the clients. Each material has a barcode which makes it trackable through the process.

Spool Fabrication:

Fabrication shops usually have multiple shops customized for specific materials within specific range of size and length. Upon receiving the shop drawing, the shop foremen or superintendents decide on the fabrication sequences and assign different stations which should perform the cutting, fitting and welding processes on the spool components. This decision is made in a heuristic manner and mainly based on experience.

Raw materials (e.g. pipes and fittings such as elbows, flanges, and tees) make up the initial input of the spool fabrication process. These are assembled into spool components and, finally, the final spool product. The major fabrication operations include cutting, roll-fitting, roll-welding, position-fitting, and position-welding. First, the raw pipes go through the cutting process to be cut to the required length according to the shop drawing. According to the sequencing order, the cut pieces are stored in waiting areas and then along with the related fitting they are handled to the fitting tables. The fitted joints are then welded together. All the spool components go through this process until the components of one spool are fitted and welded. At the final stage of spool composition, based on spool configuration and type of weld, it might need position fitting and welding. Position fitting and welding are more expensive than roll fitting and welding, which is why foremen try to minimize the number of position welds in their sequences. After each round of fitting and welding on spool components, a quality control crew reviews the work. Depending on the clients' specifications, the spool might need to go through stress relief, hydro-testing, and painting.

Factors such as shop layout, dispatching rules, buffer location, and different production flows and sequencing order can also affect the fabrication process.

Module Assembly

Fabricated spools are shipped to the module yard assembly. Along with other module components such as mechanical equipment, and electrical and instrumentation cables, the spools are assembled on a steel structure to form a module. Delays in spool delivery usually have a significant effect on the module assembly processes.

The module assembly (e.g., structural steel erection, equipment installation, electrical work, heat-tracing, insulation, fireproofing, and instrumentation) is done layer by layer. Space limitation in module yards and multiple involved trades pose many limitations on planning module assembly yard activities. That is why module yard scheduling is a multi-project resource-constrained scheduling problem. After assembling the modules, they are shipped to the construction site for final installation.

Site installation

Site installation refers to all the final installation activities including site preparation, rough and final grading, pilling, foundations, module installations, electrical and instrumentation cable wiring, etc. The most challenging process is the modules' heavy lifting . These heavy lifts are usually done using mobile cranes. The configuration and allocation of the cranes are determined based on obstructions in the site, construction sequences, site congestion and many other factors.

2-3 Modeling Industrial Construction Processes

A number of modeling attempts have been made to investigate and address the challenges of industrial construction. Among the modeling approaches used for this purpose are Special Purpose Simulation (SPS) modeling, distributed simulation modeling, and knowledge discovery methods.

The following are some models based on SPS modeling:

Song (2004) used a simulation modeling approach to estimate productivity of the structural steel drafting and fabrication processes. He developed a virtual steel fabrication shop to assign the products their unique characteristics. Each simulation entity contains product model features including physical characteristics and also Work Breakdown Structure (WBS) features. The WBS consists of five levels including division, load-list, drawing, piece, and component specifications. The modeled fabrication processes consist of drawings detailing process, fitting, welding, surface preparation, surface protection, and shipping.

Wang (2006) developed a model of pipe spool fabrication to facilitate implementing lean concepts in industrial construction. He used SPS modeling to compare the traditional batch-and-queue system with a flow production system in a pipe-spool fabrication shop. He also built a large-scale simulation model of the entire industrial construction processes in a detailed manner. However, he faced many limitations using traditional simulation modeling. The shortcomings included lack of re-use, composability, standardization, computing ability, and versatility in simulating large-scale industrial construction.

Mohamed et al. (2007) and Taghaddos et al. (2009) devised simulation-based scheduling for the module assembly process that follows factors such as physical and logical constraints and different heuristic rules.

Hammad (2009) investigated improving resources management practices by forecasting future project needs through analysing existing historical data from completed projects. He built his framework based on a Knowledge Discovery in Data (KDD) approach with a focus on labour resources.

As part of the research for this thesis, the author has been involved in couple of industrial construction modeling projects. Both of these projects are the result of group work and are modeled in the Construction Synthetic Environment (COSYE), which is based on High Level Architecture (HLA), a standard that facilitates distributed simulation modeling. The HLA supports building complex virtual environments representing the real world while allowing any interaction of computer models, people, and instrumented real equipment.

The first modeling project is the first time that an interactive 3D visualization has been attached to a large-scale simulation model of the entire industrial construction project.

The second modeling project is an interactive heavy lift model which models mobile crane heavy lifts in construction sites. The model's interactive environment makes it suitable for both modeling and training purposes. Sections 2-3 and 2-4 describe these two projects. Section 2-5 explains what lessons were learned.

2-4 Distributed Large-scale Industrial Construction Modeling[1]

2-4.1 HLA based large-scale industrial construction modeling

The stated examples of industrial construction processes show that stand-alone process interaction models are fully capable of modeling the complicated simulation features of industrial construction.

However, there is a common drawback to these models; each portion of the industrial construction process is modeled in isolation, so that the simulation model does not reflect the effects of dependencies and variations along multiple supply chains. For instance, the start of a module assembly process is dependent on the delivery of fabricated spools.

The only effort, in construction engineering and management, to simulate the entire industrial construction process in a detailed manner was carried out by Wang et al., who faced many limitations using traditional simulation modeling. Shortcomings included a lack of re-use, composability, standardization, computing ability, and versatility in simulating large-scale industrial construction (Wang 2006).

In other industries, different approaches have been taken to address these challenges. The United States Department of Defence (DoD) has developed HLA to facilitate the integration of distributed simulation models within an HLA environment. HLA allows a large scale model to be decomposed into a number of smaller and more manageable components (i.e. federates), while maintaining interoperability between them. In the last decade, HLA has been increasingly

[1] *A version of Section 2-4 has been published under "Developing Complex Distributed Simulation for Industrial Plant Construction using High Level Architecture" in Proceedings of the 2010 Winter Simulation Conference, B. Johansson, S. Jain, J. Montoya-Torres, J. Hugan, and E. Yücesan, eds*

deployed in a broad range of simulation application areas, including the transportation and the manufacturing industries (Klein et al. 2010, Lee et al. 2003).

The University of Alberta has developed an HLA-based simulation environment in construction that is referred to as a Construction Synthetic Environment (COSYE) (AbouRizk et al. 2009). COSYE has already been applied to model various large-scale construction and industrial construction projects.

2-4.2 Industrial construction simulation background

These construction simulation tools are effective when the level of abstraction is manageable. However, the industrial construction process includes drafting, material procurement and supply, shop fabrication, module assembly, and on-site installation. Using SPS, it is possible to simulate either a simplified version of the entire process at a high level of abstraction, or a detailed version of just a portion of the process such as fabrication or module assembly. The problem with both of these approaches is that they fail to capture comprehensively and exhaustively the entire industrial construction process. The first approach (a high level of abstraction) does not include an acceptable level of detail reflecting the product features and process interactions; the second approach (a detailed version of a portion of the process) simulates a range of interactive, interdependent processes in isolation from each other. Both of these approaches result in unanswered questions and vague areas in the planning and management of construction projects. Moreover, it is unacceptable to claim accuracy of results and refer management and planning decisions to predicted results based on an incomplete simulation process.

Wang (2006) pioneered simulating the entire industrial construction process in detail, but faced many limitations in using SPS. Among the shortcomings he identified are a lack of knowledge re-use, composability, standardization, computing ability, and versatility in simulating large-scale industrial construction. These limitations are addressed by the HLA system.

HLA was developed in the context of defence applications in the mid-1990s, and then standardized by IEEE. HLA's main purpose is to support component-based simulation so that the development effort is distributed among multiple groups with specific professional interests. HLA also allows end-users to customize their own combination of simulation components (federates) from a repository based on their own requirements and interests. The component models communicate through a Run Time Infrastructure (RTI) using standard HLA-compliant protocols. HLA supports the interaction of simulation components and facilitates their reusability and interoperability. The components are independently modeled and executed, and developers can define their own set of object and interaction classes for data exchange with other simulation components. This underlying common object model or "interchange document," is known within HLA terminology as the Federation Object Model (FOM). According to HLA rules, each simulation model (federation) should have an HLA Federation Object Model constructed in accordance with an Object Model Template (OMT) (IEEE 2000.Std 1516.2 2000). OMT provides a common framework for HLA object model documentation with a standard format and syntax. However, it is challenging, expensive, and time-consuming to develop a comprehensive FOM from scratch which fully represents all the involved objects and interactions associated with the simulation model

The Run-Time Infrastructure (RTI) is the federation's backbone. It provides software services such as synchronizations, communication, and data exchange between the federate to support an HLA-compliant simulation. The COSYE provides a powerful RTI which conforms to HLA specifications. Employing COSYE facilitates modeling of industrial construction and overcoming the above-mentioned challenges of traditional construction simulations.

2-4.3 Industrial construction federation

The current industrial construction federation includes fabrication shop, module yard, and site manager federates. In addition, some domain-independent federates are designed as supportive federates to serve one or several federates in the industrial construction federation. These federates include the calendar, resource allocation, and visualization federates. Figure 2-3 lists the designed federates in the industrial construction federation.

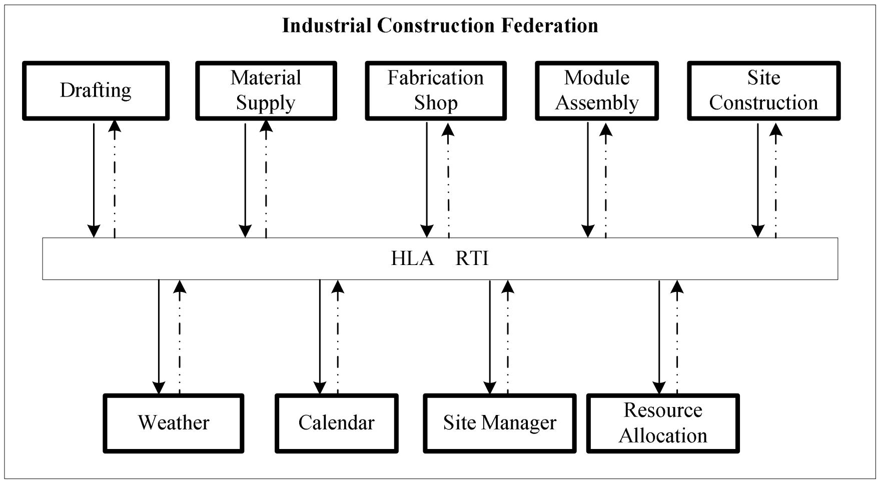


Figure 2-3: Industrial Construction Federation

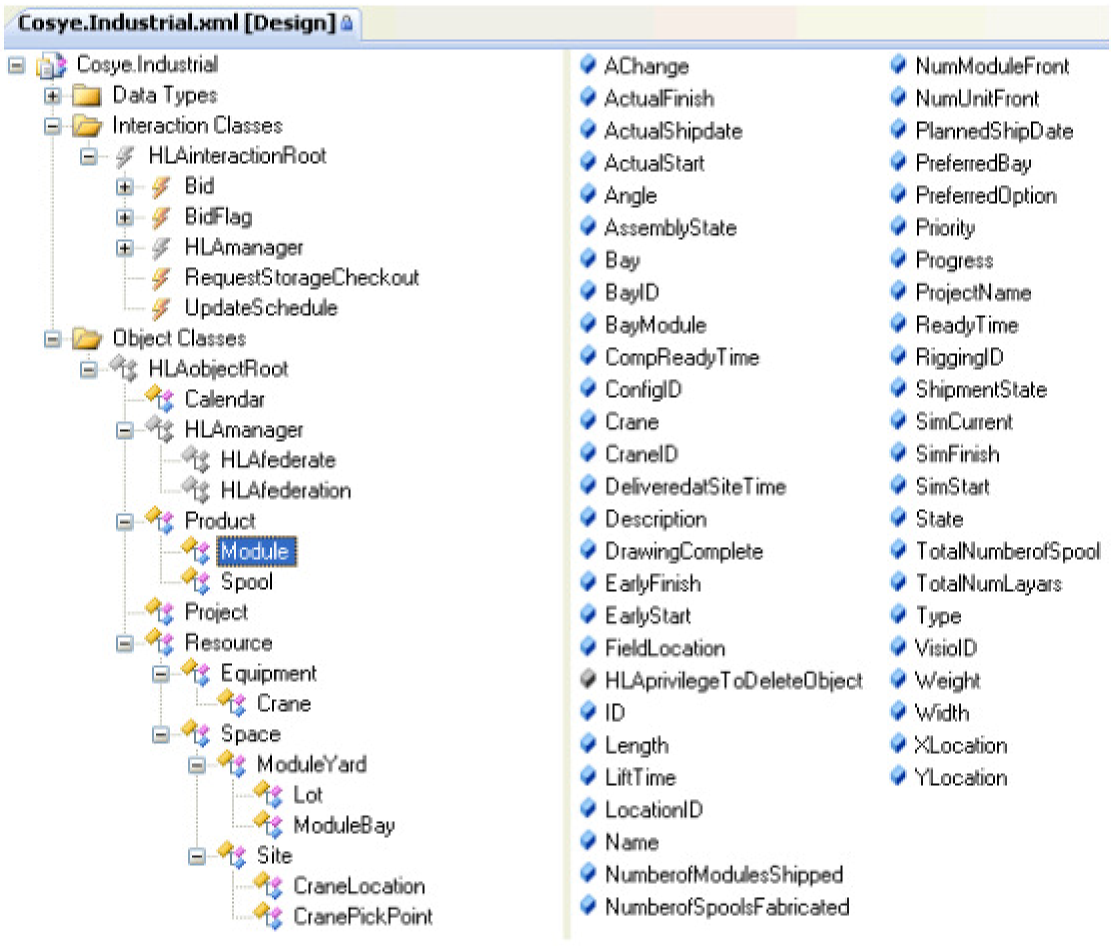
The following sections briefly explain the industrial construction federation's FOM and some of the developed federates. The author has been responsible for technical coordination between group members and finalizing the FOM and also developing the fabrication shop federate.

2-4.4 Federation object model of the industrial construction federation

The Federation Object Model (FOM), which is developed based on the Object Model Template (OMT), provides the interchange document between simulation components. However, the OMT is not instructive as to how the commonly used and accepted object classes, attributes, and interactions might be identified, or whether or not they are semantically comprehensive or representative of the knowledge domain. In other words, OMT does not offer a methodology that promises reusable and flexible simulation object model components, limiting the capacity and capabilities of HLA (Base Object Model Study Group 2006).

Therefore, the FOM should not only follow HLA rules and the Object Model Template (OMT) but it should also be comprehensive so that it preserves logical connections, both syntactically and semantically, among the simulation components. For the industrial construction federation development, the high level construction ontology has been used as the FOM reference library (explained more in Chapter 4). Figure 2-4-1 and 2-4-2 show different FOM components for “space” and “module” object classes. These components include different attributes having different properties regarding their data type and sharing and communication.

The COSYE research team has followed the same ontology throughout various construction engineering developments in order to increase technical and syntactical interoperability. Each of these concepts is elaborated for specific federations.

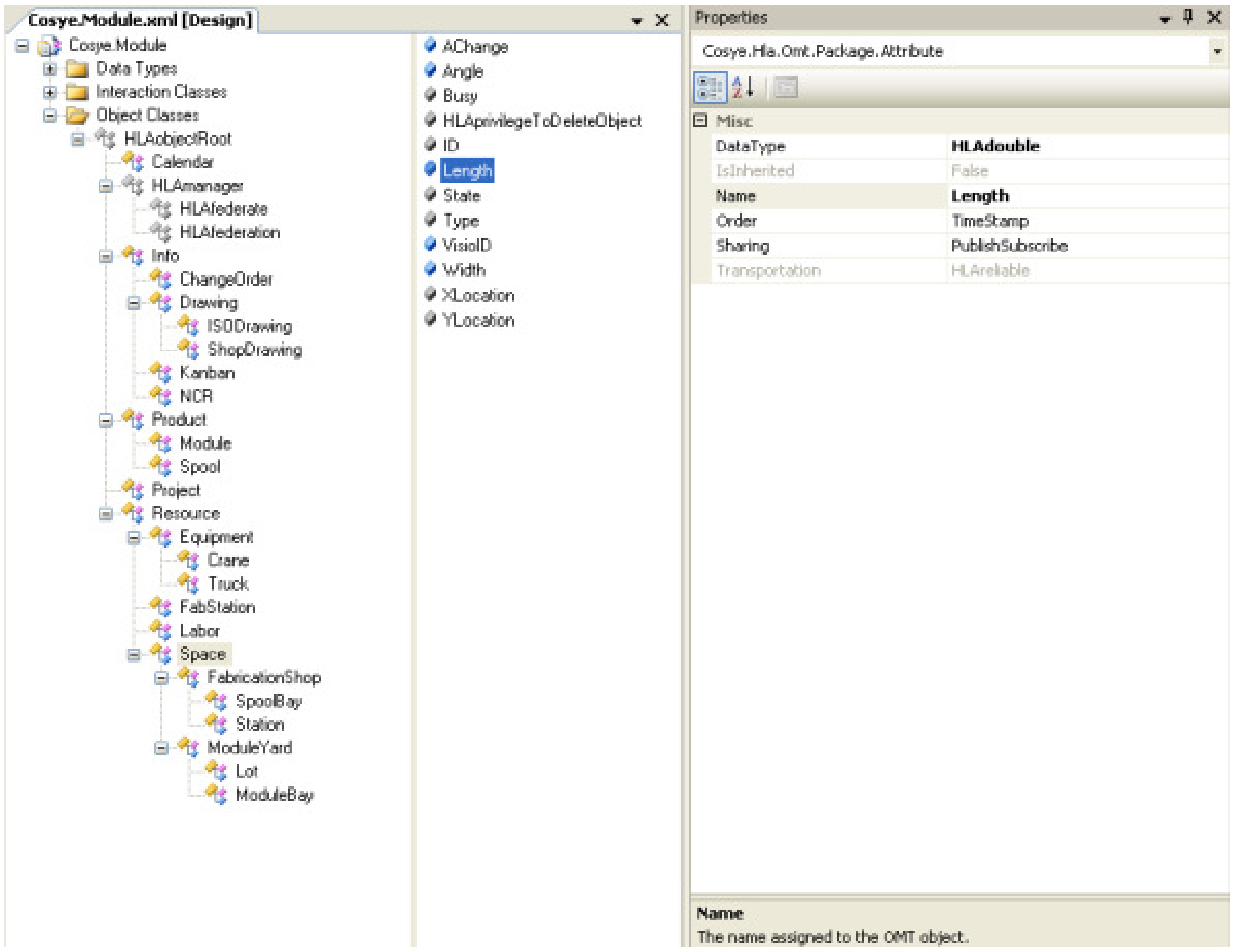


Cosye.Industrial.xml [Design]

```
Cosye.Industrial
    Data Types
    Interaction Classes
        HLAinteractionRoot
            Bid
            BidFlag
            HLAmanager
            RequestStorageCheckout
            UpdateSchedule
    Object Classes
        HLAobjectRoot
            Calendar
            HLAmanager
                HLAfederate
                HLAfederation
            Product
                Module
                Spool
            Project
            Resource
                Equipment
                    Crane
                Space
                    ModuleYard
                        Lot
                        ModuleBay
                    Site
                        CraneLocation
                        CranePickPoint
```

```
AChange                       NumModuleFront
ActualFinish                  NumUnitFront
ActualShipdate                PlannedShipDate
ActualStart                   PreferredBay
Angle                         PreferredOption
AssemblyState                 Priority
Bay                           Progress
BayID                         ProjectName
BayModule                     ReadyTime
CompReadyTime                 RiggingID
ConfigID                      ShipmentState
Crane                         SimCurrent
CraneID                       SimFinish
DeliveredatSiteTime           SimStart
Description                   State
DrawingComplete               TotalNumberofSpool
EarlyFinish                   TotalNumLayars
EarlyStart                    Type
FieldLocation                 VisioID
HLAprivilegeToDeleteObject    Weight
ID                            Width
Length                        XLocation
LiftTime                      YLocation
LocationID
Name
NumberofModulesShipped
NumberofSpoolsFabricated
```

Figure 2-4-1: Industrial Construction Federation Object Model (FOM)



Cosye.Hla.Omt.Package.Attribute

Misc

DataType	HLAdouble
IsInherited	False
Name	Length
Order	TimeStamp
Sharing	PublishSubscribe
Transportation	HLAreliable

Name
The name assigned to the OMT object.

Figure 2-4-2: Industrial Construction Federation Object Model (FOM)

2-4.5 Fabrication shop federate

The objective of this federate is to simulate the process of fabricating spools in the fabrication shop. There are several stations in the spool fabrication shop, including cutting, fitting, welding, Quality Control (QC) checking, stress relief, hydro testing, painting, and other surface finishings. Figure 2-5 depicts the typical processes of a spool fabrication shop.

The fabrication shop federate reads the required information about the spools specifications and different work satiations from the database. Then it simulates the fabrication of a spool going through various stations in the fabrication shop. Once all the spools are fabricated in the shop, the fabrication shop sends a message to the module yard federate giving the green light to start the assembly process in the module assembly yard.

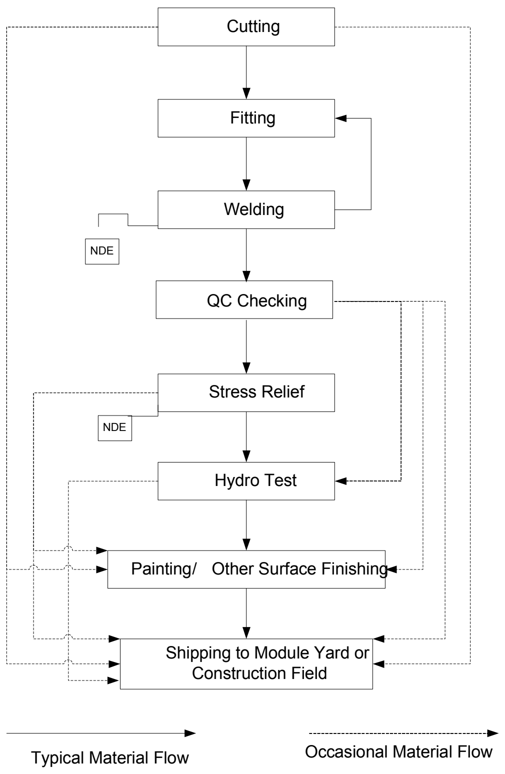


Figure 2-5: Shop Fabrication Process

The spool fabrication federate was initially developed with many simplifying assumptions. Then the model was evolved to depict the real-world fabrication processes. Chapter 4 describes details of the final spool fabrication federate.

2-4.6 Module assembly federate

The stand-alone simulation models, mentioned in section 2-2, were modified to comply with HLA rules and are now the module yard federates. In the previous model, all the modules were generated at the beginning of the simulation model and scheduled at their Early Start (ES) time. Now, in contrast, a module in the industrial construction federation is generated at the fabrication shop federate once all the required spools are fabricated in the spool fabrication shop. Then the fabrication shop federate updates the state of the module from “Fabrication Shop” to “Module Yard.” Once this change is reflected to the module yard federate via the RTI, the federate starts the assembly process at the earlier of either the Early Start (ES) time of the module or the current time of the module assembly federate.

The most important enhancement in the module yard federate over the previous simulation models is separating the optimization component as an independent federate, referred to as the Resource Allocation (RA) federate. All the modules that are looking for space wait in a queue and determine their utility function over different resource alternatives. This utility function represents numerous affecting factors in the space allocation problem, including the modules’ total float, the amount of blocking in a bay because another module in a bay was delivered late, and the amount of waste space (i.e., not enough to place a module) in a bay (Taghaddos et al. 2010). Once the RA federate assigns the available resources to the bidding entity by maximizing the overall utility function (i.e., social welfare), it sends some interactions to the module yard federate to declare the winning modules. After receiving an interaction from the RA federate, the modules in the bays schedule an event to capture space. After capturing the bay, a number of activities (i.e., structural steel, piping, electrical, tracing, insulation) must take place before a module can be shipped to the site.

2-4.7 Site construction federate

The site construction federate is another main simulation federate designed to simulate crane operations and modular construction. Once a module is assembled in the module assembly yard, it is shipped to the construction site by a transporter. Then it has to be lifted to its predetermined position, once a proper mobile crane in an accessible location with suitable configuration and rigging is available and the predecessor modules (e.g., the bottom modules) are placed in advance. There are also several other constraints in this problem, elaborated in Taghaddos et al. (2010). The simulation model reads the objects, cranes, locations, pick points, crane options, and other general information from the database. The information flow of this federate is described in Figure 2-6. The simulation model considers the cranes, locations and pick-point as the main resources.

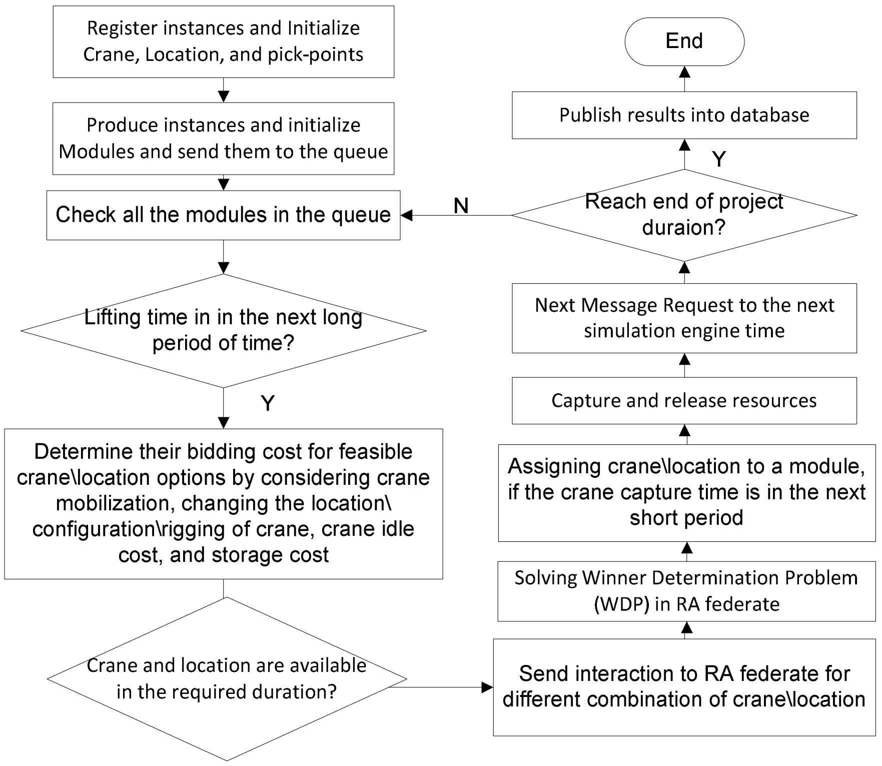

Register instances and Initialize Crane, Location, and pick-points
Produce instances and initialize Modules and send them to the queue
Check all the modules in the queue
Lifting time in in the next long period of time?
Y
Determine their bidding cost for feasible crane\location options by considering crane mobilization, changing the location\ configuration\rigging of crane, crane idle cost, and storage cost
Crane and location are available in the required duration?
Send interaction to RA federate for different combination of crane\location
Solving Winner Determination Problem (WDP) in RA federate
Assigning crane\location to a module, if the crane capture time is in the next short period
Capture and release resources
Next Message Request to the next simulation engine time
Reach end of project duraion?
N
Y
Publish results into database
End

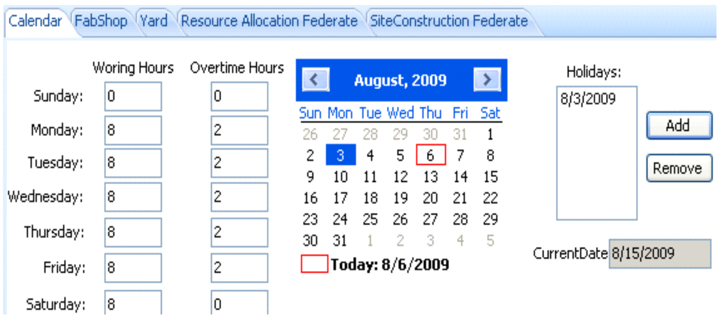
Figure 2-6: Typical site manager process

As in the module yard federate, the simulation model of the site construction federate is developed based on the standalone simulation model of the site construction. This federate also takes advantage of the RA federate to allocate the resources optimally to the modules. The bid price for each module is calculated by approximating the real cost incurred in the construction, which is the summation of the actual lifting cost, delay cost and the idle cost of the crane (Taghaddos et al. 2010).

The other feature of this federate is its connection with the module yard federate. The arrival time of the modules to the yard depends on the work load and capacity of the assembly yard. Moreover, the schedule in the yard should be adjusted based on the lifting schedule in the yard. For example, if a module is delivered to the site and then there is no crane to lift the module, it has to be shipped again to storage, incurring extra cost for transporting, loading, unloading and storing. Therefore, it would save on costs if the module was sitting in the yard and the effort in the yard was put towards another module more urgently needed on the construction site.

2-4.8 Calendar federate

The main role of this generic federate is to take into consideration national holidays and long weekends, as well as the number of working hours and overtime hours during the project. This federate provides a form, shown in Figure 2-7, to input the working hours and overtime hours during the week. This form also enables the simulator to determine the holidays (e.g., long weekends) during the project. The calendar federate synchronizes federate time with calendar time. Thus, all federates that are interested in advancing time according to the calendar can register for this federate's updates.



	Woring Hours	Overtime Hours
Sunday:	0	0
Monday:	8	2
Tuesday:	8	2
Wednesday:	8	2
Thursday:	8	2
Friday:	8	2
Saturday:	8	0

August, 2009

Sun	Mon	Tue	Wed	Thu	Fri	Sat
26	27	28	29	30	31	1
2	3	4	5	6	7	8
9	10	11	12	13	14	15
16	17	18	19	20	21	22
23	24	25	26	27	28	29
30	31	1	2	3	4	5

Today: 8/6/2009

Holidays: 8/3/2009

CurrentDate 8/15/2009

Figure 2-7: Calendar federate

2-4.9 Resource allocation federate

This federate is designed to act as an auctioneer to allocate resources among the bidding agents. In other words, this federate is supposed to solve the Winner Determination Problem (WDP) in the combinatorial optimization. Currently this federate can allocate two types of resources (crane and location) to a number of bidding agents based on a greedy algorithm or ascending-auction algorithm. This federate can easily be expanded to allocate n type of resources to several agents using a combinatorial optimization. Figure 2-8 shows the schematic view of communication between the RA federate and other simulation federates (e.g., module yard federate) in the industrial federation. Initially, this federate operated through a database, but currently it works through interaction. This federate currently works with the module yard federate as well as the site construction federate.

The RA federate is called from the module yard federate on a regular basis to maximize the bidding agents' social welfare. Moreover, the module yard federate inherits from the Resource Allocation Base (RAB) federate to automate its communication with the RA federate. Figure 2-7 shows results in the RA federate for one of the site construction auctions.

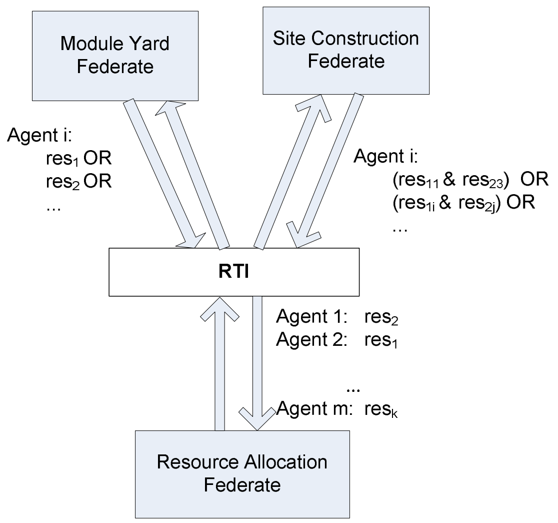
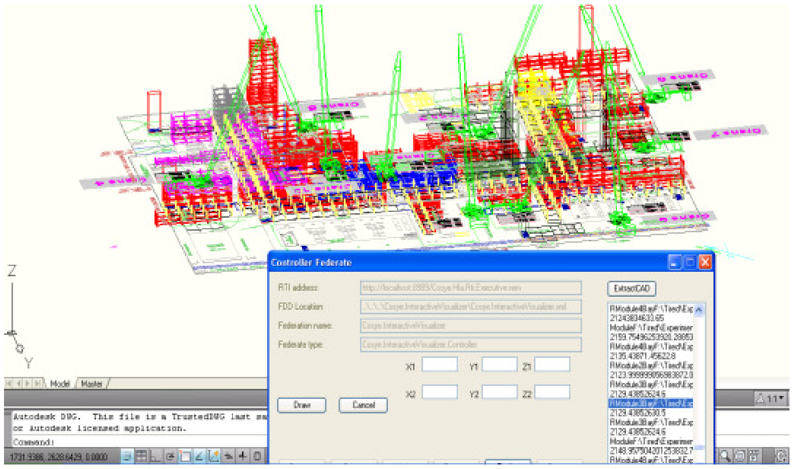

Module Yard Federate
Site Construction Federate
Agent i: res_1 OR res_2 OR ...
Agent i: (res_{11} & res_{23}) OR (res_{1i} & res_{2j}) OR ...
RTI
Agent 1: res_2
Agent 2: res_1
...
Agent m: res_k
Resource Allocation Federate

Figure 2-8: Communication between RA and simulation federates

2-4.10 Visualization federate

The visualization federate helps to visualize the assembly process in the module yard as well as in the site interactively, while the module yard and site construction federates are running. This federate provides the different parties a common understanding of the field processes and operations. This federate is developed using Blender, an open source environment that can be integrated with the .NET framework. The Blender gaming engine updates a module location after receiving the respective message from the site construction simulation. The Site Viewer federate then sends reflected attribute values to the visualization model, which automatically updates the site during run time, putting each module in its predefined location. This federate has been recently replaced by a 3D visualization federate, which is under development (Figure 2-9).



RTI address: http://localhost:8989/Cosye.Hla.Rti.Executive.rem
FDD Location: ..\..\..\Cosye.InteractiveVisualizer\Cosye.InteractiveVisualizer.xml
Federation name: Cosye.InteractiveVisualizer
Federate type: Cosye.InteractiveVisualizer.Controller

```
RModule48.ayF:\Tiend\Exp
21243834633.65
ModuleF:\Tiend\Experimer
2159.75496253920.28853
RModule48.ayF:\Tiend\Exp
2135.43871.456228
RModule28.ayF:\Tiend\Exp
2123.9999990969838720
RModule38.ayF:\Tiend\Exp
2129.43852624.6
RModule38.ayF:\Tiend\Exp
2129.43852630.5
RModule38.ayF:\Tiend\Exp
2129.43852624.6
ModuleF:\Tiend\Experimer
2148.957504201253832.7
RModule48.ayF:\Tiend\Exp
```

```
Autodesk DWG.  This file is a TrustedDWG last sa
or Autodesk licensed application.
Command:
1731.9386, 2628.6429, 0.0000
```

Figure 2-9: 3D visualization of site installation

2-4.11 Summary of industrial construction project

Within the COSYE environment, large-scale industrial construction was decomposed into several federates developed by different individuals based on their interest and expertise.

Decomposition saves development time and effort and helps the developer to focus on a portion of the process, while the interaction with other industrial construction federates ensures comprehensive simulation of the entire industrial construction. Decomposition also makes it easier to reuse other simulation components: supportive federates such as calendar can be built once and reused with other federations interested in the same functionality. Also, because decomposition happens both on a development and execution level, the execution of simulation components on different engines provides sufficient computing capacity to execute the entire federation.

This decomposition also allows independence of the federates. Each of the industrial construction federates, according to their needs, could use different simulation world views with different time scales. In industrial construction, mostly the process-interaction discrete event simulation world view provided by Simphony.NET services was used; however, for resource allocation, the federate agent-based simulation was employed. With regard to the time scale, in the shop fabrication process, the task duration might be on the order of seconds; however, in other federates larger time scales have been used. As may be imagined, this eases development considerably.

2-5 Heavy-lift Interactive Federation[2]

In construction, heavy lifting is widely used for module installation or replacement, or installing other pieces of equipment. For this purpose, mobile cranes are commonly utilized in North America and they become critical resources for construction sites. In addition, mobile cranes locate at different places with different configurations for servicing different construction

[2] *Section 2-5 has been submitted for the course project "Advanced Topics in Construction Engineering and Management: Advanced Simulation" Spring term 2010. Instructuor: Dr. Yasser Mohamed. Students:Jangmi Hong, ManaMoghadam, Chunxia Li, Fayyad Sabha, Ronald Ekyalimpa, Carlos V. Gonzalez. Teaching Assistants: Di Hu, Farzaneh Saba.*

sequences while considering other factors such as site obstructions and congestion. By interviewing several lift experts, Varghese et al. (1997) identified lift criteria for lift planning: availability of the crane, access to site, access to lift area, crane location, lift path clearances and safety factors, ground support during lift, and removal from lift area. These criteria can be used for evaluating the lift's feasibility. These feasibilities are influenced by other factors such as crane type, crane configuration, site layout, and construction sequence or schedule.

The heavy lift interactive federation was originally developed as a graduate level course (Advanced Topics in Construction Engineering and Management: Advanced Simulation) project. The HLA implementation described here was mainly a training exercise for graduate students learning about distributed simulation and HLA for the first time. The main objective was to define the problem in a way that magnifies the most important capabilities of a distributed simulation approach. Students were divided into five groups and assigned the development of one federate in the federation. The author was one of the teaching assistants and involved in developing one of the federates (Player federate). The gaming and interactive aspects of the federation provided a medium for the student to learn and explore the capabilities of the distributed simulation framework. The development of the federation was completed after several cycles of developments in the class.

2-5.1 Federation description

The project was proposed to simulate the process of crane selection and crane operation for lifting and placing modules at industrial construction sites. The project considers factors such as crane availability and suitability, and crane operating time and related costs, as well as module storage consideration. Also, the project supports decision-making for the user by providing certain options with detailed information. The user can place lift orders based on the information.

According to the project scope's function requirement, the whole federation is made up of four federates:, lift scenario generation federate, player federate, operation simulation federate and an auxiliary federate, which is the visualization federate (Figure 2-10).

This federation's purpose is to serve as a training tool at the university and industry in the subject area of designing and analyzing mobile crane operations in the construction domain. The scenario federate, player federate and operations federate were the core federates for this project. The tool was designed such that it has one administrator and a number of players running it simultaneously on different computers (as a distributed simulation). Typically, the administrator would control the scenario federate and the operations federate while the players/trainees would use/interact with the player federate. The administrator would generate input (crane & module instances and lift options) for the federation. This would serve as input to the player(s). The player(s) would select which modules would be lifted by which cranes and which would be sent to storage. Player selections would be sent to the operations federate as lift orders that would then be processed by the operations federate. The player would then get to view the results/implications of the decisions he/she made in terms of cost and time.

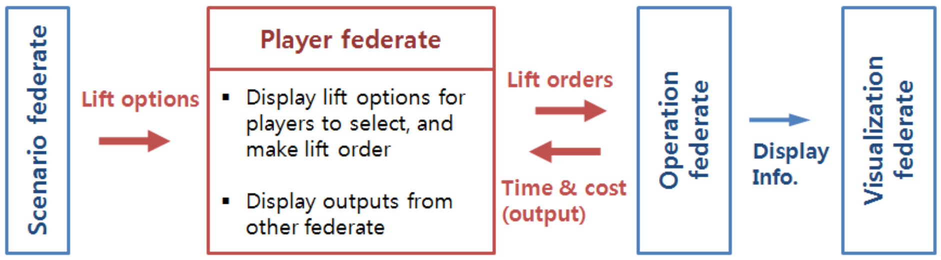
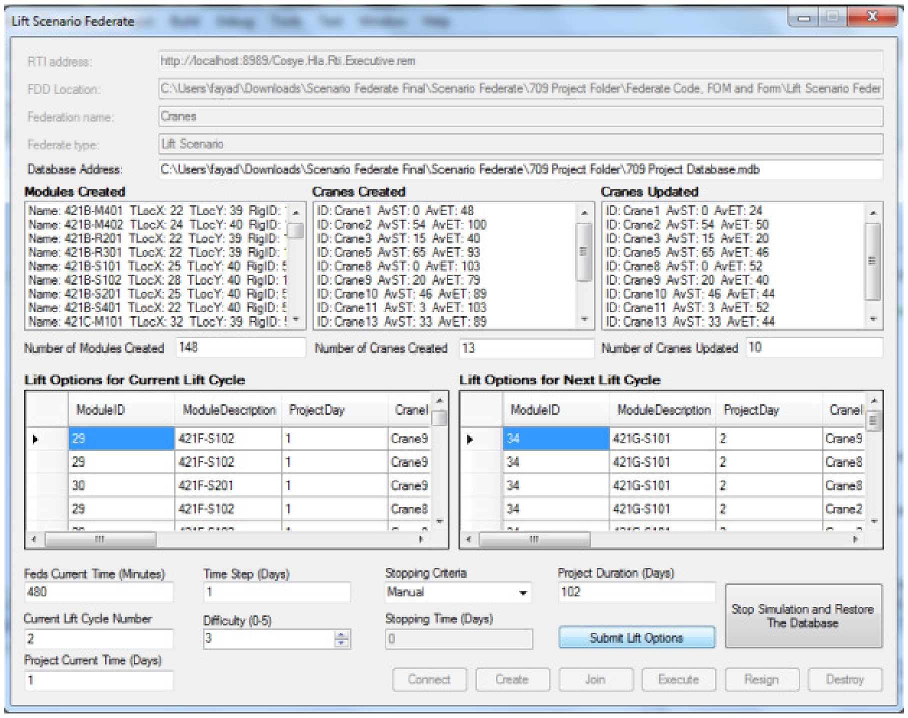


Figure 2-10: Heavy lift federation

Operation federate is a discrete event simulation federate for simulating the lifting operations and estimating their time and cost. This federate will subscribe lift orders from the player federate and take it as the main entity in the whole federate. It will make the crane and crane location in the lift object resources. The crane resource availability depends on the lift scenario federate. This federate keeps track of crane's current location and configuration and will change (configuring, moving, rigging, and lifting) these based on the requirements of the coming orders. It will also publish information regarding the crane resource's queue length and current locations, as well as the finished orders and the time they were finished. In addition, it will update information about the project's overall cost and time.

The lift scenario federate (2-11) is a scaled time-stepped federate. It is responsible for generating modules and lift options for modules for this time step and also the ones that are for the next period. While considering the difficulty parameter, the actual arrival at a certain period may be varied from previously forecasted ones. The crane availability or available period is also controlled in this federate and can be modified based on a difficulty factor.


Lift Scenario Federate

RTI address: http://localhost:8989/Cosye.Hla.Rti.Executive.rem
FDD Location: C:\Users\fayad\Downloads\Scenario Federate Final\Scenario Federate\709 Project Folder\Federate Code, FOM and Form\Lift Scenario Feder
Federation name: Cranes
Federate type: Lift Scenario
Database Address: C:\Users\fayad\Downloads\Scenario Federate Final\Scenario Federate\709 Project Folder\709 Project Database.mdb

Modules Created

```
Name: 421B-M401  TLocX: 22  TLocY: 39  RigID:
Name: 421B-M402  TLocX: 24  TLocY: 40  RigID:
Name: 421B-R201  TLocX: 22  TLocY: 39  RigID:
Name: 421B-R301  TLocX: 22  TLocY: 39  RigID:
Name: 421B-S101  TLocX: 25  TLocY: 40  RigID: 5
Name: 421B-S102  TLocX: 28  TLocY: 40  RigID: 1
Name: 421B-S201  TLocX: 25  TLocY: 40  RigID: 5
Name: 421B-S401  TLocX: 22  TLocY: 40  RigID: 5
Name: 421C-M101  TLocX: 32  TLocY: 39  RigID: 5
```

Cranes Created

```
ID: Crane1  AvST: 0  AvET: 48
ID: Crane2  AvST: 54  AvET: 100
ID: Crane3  AvST: 15  AvET: 40
ID: Crane5  AvST: 65  AvET: 93
ID: Crane8  AvST: 0  AvET: 103
ID: Crane9  AvST: 20  AvET: 79
ID: Crane10  AvST: 46  AvET: 89
ID: Crane11  AvST: 3  AvET: 103
ID: Crane13  AvST: 33  AvET: 89
```

Cranes Updated

```
ID: Crane1  AvST: 0  AvET: 24
ID: Crane2  AvST: 54  AvET: 50
ID: Crane3  AvST: 15  AvET: 20
ID: Crane5  AvST: 65  AvET: 46
ID: Crane8  AvST: 0  AvET: 52
ID: Crane9  AvST: 20  AvET: 40
ID: Crane10  AvST: 46  AvET: 44
ID: Crane11  AvST: 3  AvET: 52
ID: Crane13  AvST: 33  AvET: 44
```

Number of Modules Created: 148
Number of Cranes Created: 13
Number of Cranes Updated: 10

Lift Options for Current Lift Cycle

ModuleID	ModuleDescription	ProjectDay	CraneI
29	421F-S102	1	Crane9
29	421F-S102	1	Crane9
30	421F-S201	1	Crane9
29	421F-S102	1	Crane8

Lift Options for Next Lift Cycle

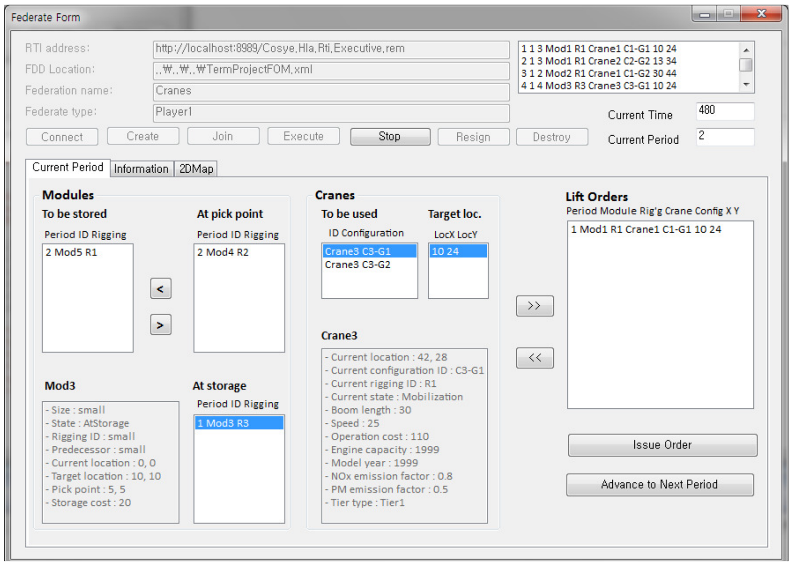
ModuleID	ModuleDescription	ProjectDay	CraneI
34	421G-S101	2	Crane9
34	421G-S101	2	Crane8
34	421G-S101	2	Crane8
34	421G-S101	2	Crane2

Feds Current Time (Minutes): 480
Current Lift Cycle Number: 2
Project Current Time (Days): 1
Time Step (Days): 1
Difficulty (0-5): 3
Stopping Criteria: Manual
Stopping Time (Days): 0
Project Duration (Days): 102

Figure 2-11: Lift Scenario Federate

The player federate is also a scaled time-stepped federate. It is the main user interface for interacting with the federation. It will provide a current lift of modules arriving; a modules lift for the next period, a list of modules in storage, and locations of current cranes on site and their last on-site available date. The user can issue lift orders based on this information. Also, the player federate will subscribe outcomes from other federates, such as time spent by different cranes on configuring, moving, and lifting; the queue length of different cranes; and the total cost and emissions to date for the lifting operations.

The player federate provides the main user interface for interacting with the federation. It displays a current list of modules arriving and waiting for a decision. A player can place lift orders by selecting a crane and its next location. He/she can also put a certain module in storage. The modules for the next decision period and a 2D map displaying the cranes' current location and state are shown as references. The total cost and working time of each crane are presented at the end of each period. Figure 2-12 shows the interaction between the player federate and the other federates.



RTI address: http://localhost:8989/Cosye.Hla.Rti.Executive.rem
FDD Location: ..₩..₩..₩TermProjectFOM.xml
Federation name: Cranes
Federate type: Player1

```
1 1 3 Mod1 R1 Crane1 C1-G1 10 24
2 1 3 Mod1 R1 Crane2 C2-G2 13 34
3 1 2 Mod2 R1 Crane1 C1-G2 30 44
4 1 4 Mod3 R3 Crane3 C3-G1 10 24
```

Current Time 480
Current Period 2

Modules

To be stored
Period ID Rigging
2 Mod5 R1

At pick point
Period ID Rigging
2 Mod4 R2

Mod3
- Size : small
- State : AtStorage
- Rigging ID : small
- Predecessor : small
- Current location : 0, 0
- Target location : 10, 10
- Pick point : 5, 5
- Storage cost : 20

At storage
Period ID Rigging
1 Mod3 R3

Cranes

To be used
ID Configuration
Crane3 C3-G1
Crane3 C3-G2

Target loc.
LocX LocY
10 24

Crane3
- Current location : 42, 28
- Current configuration ID : C3-G1
- Current rigging ID : R1
- Current state : Mobilization
- Boom length : 30
- Speed : 25
- Operation cost : 110
- Engine capacity : 1999
- Model year : 1999
- NOx emission factor : 0.8
- PM emission factor : 0.5
- Tier type : Tier1

Lift Orders
Period Module Rig'g Crane Config X Y
1 Mod1 R1 Crane1 C1-G1 10 24

Figure 2-12: Player Federate main tab

The visualization federate is a time-stepped federate. It is for visualizing the crane and module movement. This federate has its own time advancement mechanism. But it needs to reflect the crane information and module information from other federates. The crane ID will be subscribed from the lift scenario federate. Its Current Location coordination will be subscribed from the operation federate. Figure 2-13 shows the logic behind the federate.

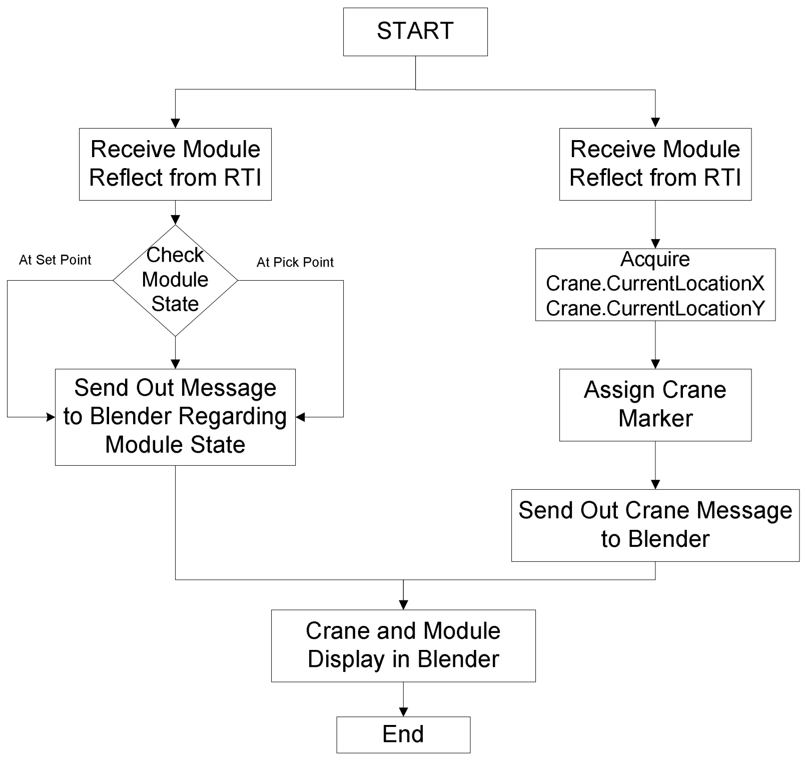

START
Receive Module Reflect from RTI
Receive Module Reflect from RTI
At Set Point
Check Module State
At Pick Point
Acquire Crane.CurrentLocationX Crane.CurrentLocationY
Send Out Message to Blender Regarding Module State
Assign Crane Marker
Send Out Crane Message to Blender
Crane and Module Display in Blender
End

Figure 2-13: Flowchart of Visualization Federate Logic

In this part, several snapshots of the visualization federate are presented. Figure 2-15 is a snapshot of the site layout before the simulation, and Figure 2-16 is a snapshot of the real time visualization of simulation results.

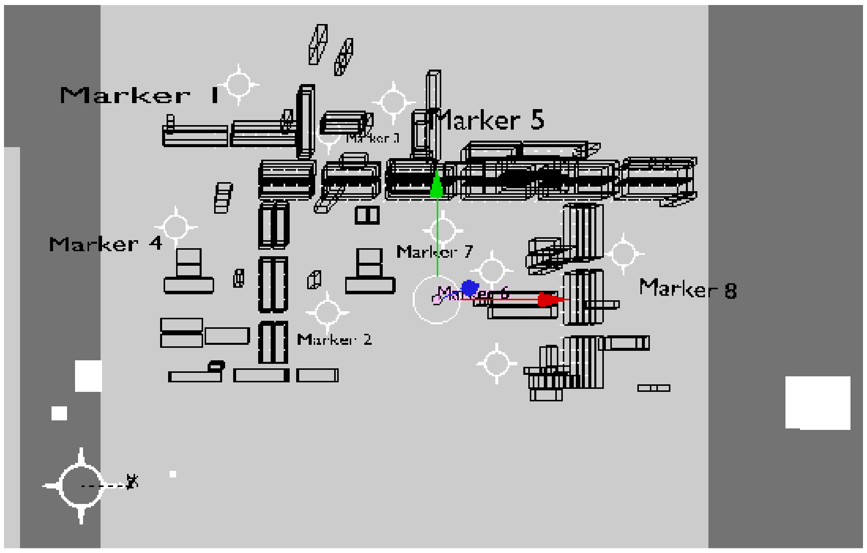


Figure 2-14: Site layout and marker distribution

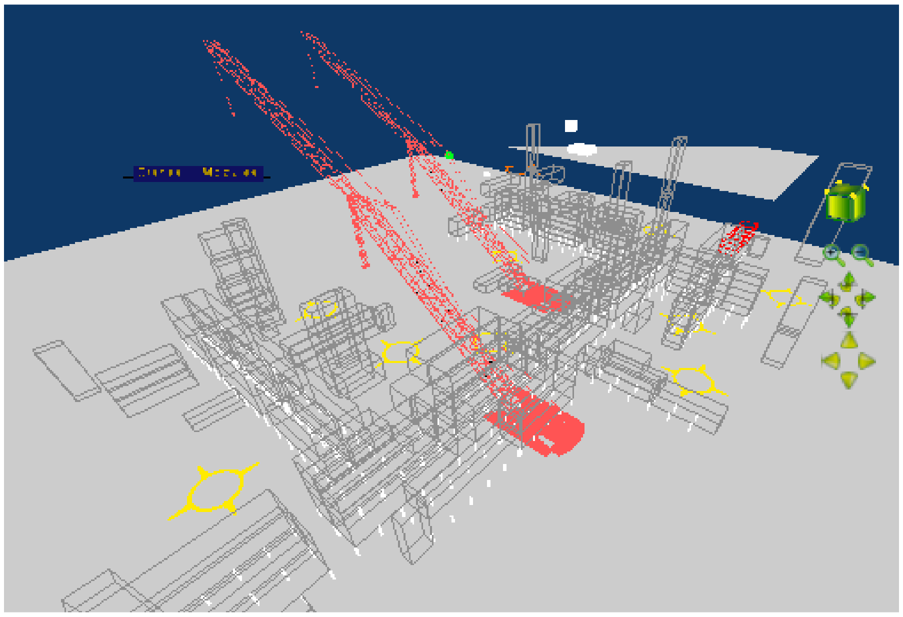


Figure 2-15: Snapshot of real time simulation – visualization result

2-6 Lessons Learned

Comparison between SPS and HLA-based distributed modeling:

- SPS *easiness* vs. *complexity* of distributed modeling: SPS modeling tools such as Simphony are much easier to learn compared to HLA-based distributed modeling. SPS tools usually come with a library of reusable components which facilitates model development. That is why, for quick modeling of the construction process, SPS is the optimum means and the reason it has been easier to persuade industry to use SPS tools.
- *Monolithic* vs. *distributed*: SPS tools keep all information within one model; however, in distributed modeling, decomposed models and information can be located from geographic disperse locations.
- *Static* vs. *dynamic*: In SPS tools, once the simulation starts neither the model nor the input information can be changed. But in distributed modeling during runtime, information can be dynamically received by the federates. This feature makes distributed models interactive; for instance, in the industrial construction federation, the user can dynamically change the construction site input data using the visualization federate. The federation is able to re-simulate the process based on the changed input information.
- *Single application* vs. *multi-application:* The SPS tools' function is exclusively process modeling. However, in distributed modeling it can be used for a wide range of varying applications. One of the most important, through the interactive nature of distributed simulation, is for training purposes. The heavy lift interactive federation, which was discussed earlier, can be used for training purposes.

In addition to many advantages, distributed simulation modeling has its own special challenges. The most important is coordination between all the involved groups. Here are some approaches that helped us to lessen the challenge while developing the "industrial construction" and "heavy lift" federations.

- Defining a clear project scope:
    - Modeling problem and objectives
    - Project scope should be finalized with members from all groups present..

- Uniformity and Consistency in Model Representation
    - Such as consensus on the most important one-time scale of all the scales being used.
- Proper decomposition of model
- Developing a comprehensive FOM

With proper decomposition, each involved party knows their requirements (e.g., subscribing object classes, attributes, interactions, parameters) from other federates and also deliverables to other federates' requirements (e.g. publishing object classes, attributes, interactions, parameters). The changes in FOM should be minimized by developing a comprehensive FOM; however sometimes changes are inevitable.

All the parties should be updated on any changes. We kept track of these by setting up an online spreadsheet (Table 2-1) expressing the interest of all federates and updating all the group members via email in case of any changes and special requests from other federates.

- Independent development through testing federates:

Through the process of federates' construction, the developers should be able to independently follow the development process. This is possible by using temporary test federates, which play the role of the other federates' interface. These test federates provide the FOM components to which the developing federate has subscribed in accordance with the agreed time management. Also, there are federates which play the role of recipient federates, receiving the message that the developing federate is publishing.

Within this approach all the participants can go through the development process without being held back by waiting for other groups' development. Through different stages of development, testing sessions were set up. Through testing sessions, groups would give a report on their progress and the challenges they were facing. Also, the entire federation components were linked together so that the federation performance could be tested.

This way of approaching distributed simulation modeling in the COSYE environment, facilitates more efficient development process.

Table 2-1: FOM shared spreadsheet

ObjectClass	DataType	Name of Federate				
		Operation	Player	LiftScenario	Visualization	Emissions
Crane						
ID	String	S	S	P	S	S
Speed	Double	S	S	P	S	
ConfigurationID	String	P/S	S	P		
RiggingID	String	P/S	S	P		
CostPerHour	Double	S	S	P		
InitialLocation_X	Integer	P/S	S	P		
InitialLocation_Y	Integer	P/S	S	P		
SiteAvailability	Enumerate	P/S	S	P		
Totalworktime	Double	P	S	P		S
Totalcost	Double	P	S	P		
State	Enumerate	P/S	S	P		
CurrentLocationX	Integer	P/S	S	P	S	
CurrentLocationY	Integer	P/S	S	P	S	
HorsePower	Integer		S	P		P/S
TargetLocationX	Integer	P/S		P	S	
TargetLocationY	Integer	P/S		P	S	
LoadRating	Single		S	P		
ModelYear	Integer		S	P		P/S
NOxEmissionFactor	Double		S	P		P/S
NOxTotalEmission	Double		S	P		P
PMEmissionFactor	Double		S	P		P/S
PMTotalEmission	Double		S	P		P
TierType	Enumerate		S	P		P/S
Boomlength	Double		S	P	S	
WorkStartTime	Double			P		
WorkingTime	Double			P		
Module						
ID	String	S	S	P		
Location_X	Integer	P/S	S	P		
Location_Y	Integer	P/S	S	P		
Size	Enumerate	S	S	P		
State	Enumerate	P/S	S	P		
RiggingID	String		S	P		
TargetLocationX	Integer		S	P	S	
TargetLocationY	Integer		S	P	S	
PickPointX	Integer		S	P	S	
PickPointY	Integer		S	P	S	
StorageCostPerHour	Double		S	P		
ScenarioLiftOptionCurrent						
CraneID	String		S	P		
ModuleID	String		S	P		
CraneTargetLocationX	Integer		S	P		
CraneTargetLocationY	Integer		S	P		
ConfigureID	String		S	P		
PeriodFlag	String		S	p		
ScenarioLiftOptionNext						
CraneID	Object Instance Handle		S	P		
ModuleID	Object Instance Handle		S	P		
CraneTargetLocationX	Integer		S	P		
CraneTargetLocationY	Integer		S	P		
ConfigureID	String		S	P		
PeriodFlag	String		S	p		
PlayerLiftOrder						
CraneID	Object Instance Handle	S	P			
ModuleID	Object Instance Handle	S	P			
CraneTargetLocationX	Integer	S	P			
CraneTargetLocationY	Integer	S	P			
ConfigureID	String	S	P			
RiggingID	string	S	P			
ModuleState	Enumerate	S	P			
Interaction Class						
TimeStep			S	P		

For instance, developing a comprehensive FOM from scratch, which fully represents all the involved objects and interactions associated with a simulation model is challenging, expensive, and time-consuming. That is why, in Chapter 4, an alternative method is suggested to extract FOMs from ontologies that represent formalized construction domain knowledge. Industrial construction domain knowledge is captured in InCon ontology and the FOM is extracted from the ontology through semantic query languages.

Moreover, in the industrial construction federation and heavy lift interactive federation, explained in this chapter, the COSYE federates were developed by writing C# or Visual Basic code within the Visual Studio environment. This makes the development process in COSYE difficult when compared to a visual modeling environment such as Simphony. In Chapter 4, component-based simulation modeling in the COSYE environment is pursued. The idea is to create a set of modeling elements that provide access to the various HLA services and simulation modeling services. This approach facilitates developing simulation modeling through reusing modeling elements. Chapter 4 focuses on characteristics of these modelling elements and suggests an ontology-driven approach towards developing them.

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Chapter 3

Ontological Conceptual Modeling of Industrial Construction Processes to Enhance Interoperability and Reuse

3-1 Introduction

In response to the increasing complexity of construction systems, the development of sophisticated methods and tools for the modeling and analysis of these systems is needed. Simulation has been a formal topic in construction engineering research for almost three decades, but still has not been embraced as a practical tool in the industry. One of the primary reasons for this lack of research transfer is that building simulation models needs significant amount of knowledge and data acquisition. Moreover the process of building a simulation model is very time consuming and costly which is a drawback for industry to use simulation as a useful tool.

The reuse of simulation components is a key feature for cost-effective development. Although many construction simulation approaches currently allow for the reuse of previously developed components (Hajjar et al. 2000; Oloufa 1993) and provide libraries of such components, still reuse of earlier developments is not a common practice because of lack of effective traceability and communication in constructing simulation models.

Documenting and formal conceptual modeling in structural manner enhances the quality and efficiency of simulation development and also it is a potential way to capture and share the knowledge within simulation models.

3-2 Conceptual modeling

In Modeling and Simulation (M&S), modeling focuses on purposeful abstraction of the real world model (Zeigler 1976) and simulation relies on implementing models (Tolk 2007). The modeling part in the M&S community is usually known as conceptual modeling. According to Robinson (2006), a conceptual model is "a non-software specific description of a simulation model that is to be developed, describing the objectives, inputs, outputs, content, assumptions and simplifications of the model". Figure 3-1 depicts the relationship between the real world, conceptual model and simulation model.

Conceptual modeling is known as the most important aspect of a simulation project; however, it is the least understood part and in most simulation developments, it is missing. There have been attempts to provide a guideline for developing a conceptual model. Shannon (1975) describes four steps as follows:

1- Specification of the model's purpose.

2- Specification of the model's components.

3- Specification of the parameters and variables associated with the components.

4- Specification of the relationships between the components, parameters, and variables.

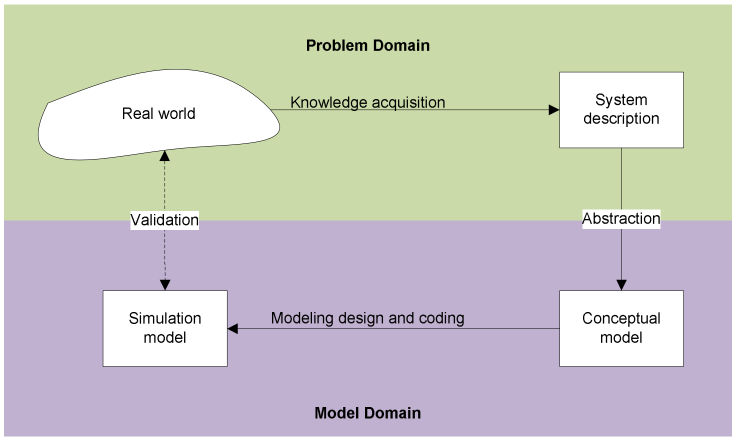


Figure 3-1: Simulation project life-cycle (adapted from Kotiadis and Robinson, 2008)

The presentation and documentation of conceptual models is another area of developing conceptual models that has yet to be investigated; in many cases, there is no documentation at all other than the use of diagramming techniques such as process flow diagrams and event graphs (Robinson 2004). But documenting and formalizing conceptual models in a structural manner not only enhances the quality and efficiency of simulation development, it also enhances the potential reuse of the captured knowledge within conceptual models.

In the military domain, conceptual modeling and its documentation has been investigated more than in any other domain. Military simulations often involve large-scale models which lead to more interest in the structure documentation of conceptual models and their reuse (Robinson 2006). The Base Object Model (BOM) is a Simulation Interoperability Standards Organization (SISO) standard conceptual modeling documentation. Thus, BOM portrays the necessary information about the simulation model, the simulation model's components including events and entities and the behavior of simulation components such as a pattern of interplay and the entities' state. This information is leveraged into BOM meta-data (Gustavson and Chase 2007).

In the following BOM, the components are described; its meta-data represents the model identification, conceptual model definition, model mapping, object model interface and interaction classes (Figure 3-2).

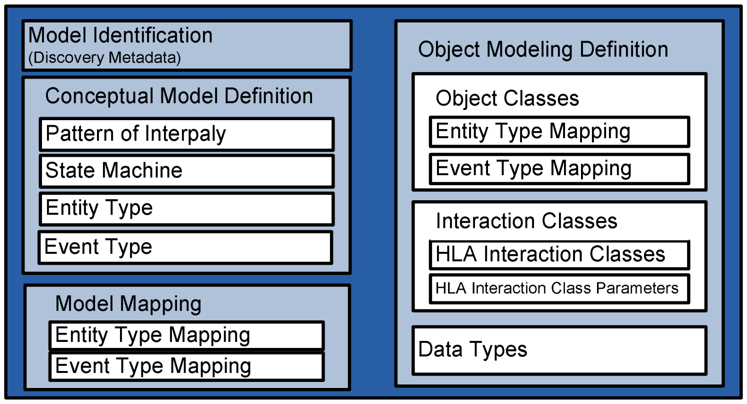


Figure 3-2: The BOM structure (adapted from BOM standard, 2006)

- Model Identification: This part of the BOM contains the general information about the BOM.

- Conceptual Model Definition: The BOM conceptual model definition provides the pattern of interplay, the state of an entity, the entity types, and event types.

- Model Mapping: In model mapping, existing entities and event relationships are presented in the abstract, so that the conceptual model has the potential to be mapped to the actual simulation model.

- Object Modeling Definition: The object model definition represents the interface of the conceptual model.

Some studies have been conducted with the aim of carrying BOMs forward as simulation components through the development process and composing models from BOMs (Moradi 2007).

3-2.1 Conceptual modeling and model reusability

The first step towards reusing other people's models, is understanding their development. However, in the current practice the conceptual model usually just exists in the developer's mind and even if captured it is in loose forms which do not reflect enough of the model. Lack of proper communication and traceability of the models' content leads to less reuse of simulation models.

A conceptual model is similar to a communication bridge, connecting real world to computer model. Proper documentation of conceptual models helps with understanding the model and increases the likelihood of reusing the simulation model; however there is not any common documentation method in the simulation community.

3-2.2 Conceptual modeling and modeling composability

Interoperability is traditionally referred to technical interoperability; however, according to Tolk (2007), the term interoperability for systems means the ability to communicate effectively both syntactically and semantically. The following is a more detailed definition for these terms:

- Interoperability addresses software and implementation details of systems interoperation such as data exchange. More specifically, in M&S it deals with simulation implementation and execution.

- Composability, on the other hand, deals with the alignment of concepts on the modeling level. Composability is concerned with the alignment of conceptual models, which are the underlying abstractions of reality in simulation models.

Tolk and Muguira (2003) suggest a hierarchy for different levels of models' interoperability in the M&S community (Figure 3-3).

Technical interoperability: communication technology infrastructure, which is concerned with exchanging bits and bytes.

Syntactic interoperability: using common data structures for exchanging data and using common protocols.

Semantic interoperability: using common references in order to understand the meaning of data and their association between concepts and the real world.

Pragmatic interoperability: understanding the intent of using data when systems, simulations, or applications are involved.

Dynamic interoperability: understanding the effects of exchanging data in sending and receiving services, which happens through using common execution models.

Conceptual interoperability is achieved when all involved groups understand, with no ambiguity, the capabilities and constraints of simulation models.

In the following ontologies are introduced as the proper means for documenting conceptual models.

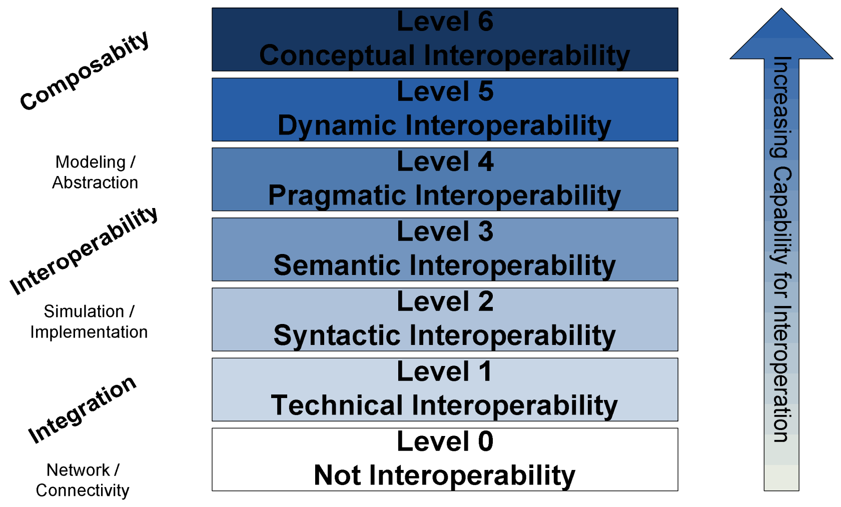

Composabity
Modeling / Abstraction
Interoperability
Simulation / Implementation
Integration
Network / Connectivity
Level 6 Conceptual Interoperability
Level 5 Dynamic Interoperability
Level 4 Pragmatic Interoperability
Level 3 Semantic Interoperability
Level 2 Syntactic Interoperability
Level 1 Technical Interoperability
Level 0 Not Interoperability
Increasing Capability for Interoperation

Figure 3-3: Levels of conceptual interoperability model (adapted from Tolk and Muguira, 2003)

3-3 Ontologies and Conceptual Modeling

The term ontology means an "explicit specification of a conceptualization" (Gruber 1995). A conceptualization provides an abstract view of the real world. Simulation models are knowledge-based models, explicitly or implicitly committed to conceptualization. Following the definition of ontology, we believe that ontologies are the best means for documenting the conceptual models and dealing with reusability and interoperability challenges of simulation models.

Within ontologies, what is captured is a formalized understanding of the domain conceptualization which declares the domain's specifications and the assumptions made towards developing the simulation models. Therefore, the ontology of a domain facilitates analysis of domain knowledge and improves the reuse and interoperability of systems that are built based on it (Uschold and Gruninger 1996).

The spectrum of ontological semantics goes from weak semantics to strong. The semantics are improved by increasing the meta-data to capture more information. Figure 3-4 describes different categories of semantic representation from weak to strong semantics (Obstr 2006). Each category can be explained as follows:

Data dictionaries: This category has the weakest semantics and contains the "terms" used in the domain.

Thesaurus and Taxonomies: The thesaurus category evolves as equivalence, homographic, hierarchical, and associative relationships among terms are indentified. Taxonomies contain a higher level of semantics because of having a structured classification.

Data models: Compared to lower level categories, this category is enriched in pragmatics and semantics but still falls under semi-formal or semi-informal ontologies.

Ontologies: Ontologies are not just hierarchical structures containing all the entities. In addition to entities, ontologies present the relationships between the entities and the rules governing the domain knowledge.

Logical models: Logical models are semantically the strongest in this category. Logical expressions are explicitly specified through axiomatic approaches.

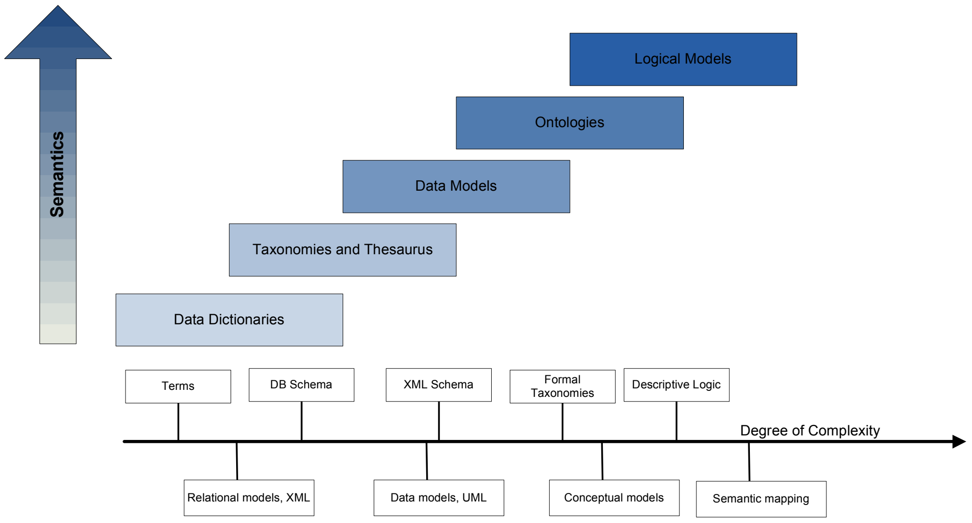


Figure 3-4: Ontological spectrum (adapted from Obstr, 2006)

3-4 Methodologies for Ontology Development

Ontology includes the taxonomy of concepts and their properties and an indication of how concepts are inter-related, which collectively impose a structure on the domain. The shared understanding of the domain through ontologies facilitates the domain's accurate and effective communication, which leads to benefits such as models' composability and reuse (Uschold 98).

There is no single method for developing domain ontologies. However, still there are various guidelines for ontology design and development. As an example, Uschold and Gruninger (1996) present a five-phase methodology as follows:

1- *Identify purpose and scope*: Identifying the scope, purpose, intended use of ontology, and the targeted user.

2- *Building the ontology:*

   a. Ontology capture: Identifying the most important concepts and relationships in the domain of interest. Identifying the terms to refer to the concepts and relationships.

   b. Coding the ontology: Explicitly representing the knowledge capture in the previous phase using ontology representation languages such as Web Ontology Language (OWL) or Resource Description Framework (RDF).

   c. Integrating existing ontologies: Using existing ontologies if appropriate.

3- *Evaluating the Ontology*: Evaluating the ontology with respect to defined requirements. The requirements can be captured through competency questions.

4- *Documentation*

5- *Guidelines for each phase*

Uschold and Gruninger's methodology is followed in this research for developing an Industrial Construction Ontology (InCon-Onto).

3-5 Industrial Construction Ontology (InCon-Onto) Development

3-5.1 Purpose and scope of InCon-Onto

The purpose of InCon-Onto is to provide a proper formalization of the industrial construction processes. This documentation is human understandable and also computer interpretable. The industrial construction processes are structured based on process modeling principals. So that the knowledge within them can be deployed in different process oriented modeling application.

The industrial construction processes are modeled through the following specifications:

- The ontology presents the industrial construction domain through concepts and the relationships amongst them.
- The set of classes arranged in hierarchal taxonomy represents the domain concepts.
- The concepts' hierarchy represents the concepts starting from general concepts decomposing into specialized concepts.
- The ontology represents the industrial construction processes and their characteristics.
- The ontology represents the related concepts around the industrial construction processes along with the properties.
- The ontology represents relationships between the processes and other related concepts.
- In construction, the pattern of process is captured through process modeling.

3-5.2 Building the InCon-Onto

3-5.2.1 Ontology capture

The next sections explain our approach towards capturing the industrial construction abstract picture. We start by introducing the 5Ws (who, what, where, why, when), which is a very general abstraction method used in journalism and literature. We then move into process modeling to abstract industrial construction process. In order to get familiar with the process of classification and the decomposition of process, we probed some other existing ontologies in similar domains such as construction and manufacturing.

3-5.2.2 Capturing InCon-Onto

Using models to structure the acquired knowledge from domain experts and other sources reduces complexity, improves communication and enhances our understanding of the domain. A very general and basic method for understanding a task is the 5Ws (wikipedia):

1- **Who** is accomplishing the task?
2- **What** task must be accomplished?
3- **Where is** the task performed?
4- **When** is the task done?
5- **Why** is the task done?

When it comes to construction processes, the 5Ws can be expressed within process modeling concepts (Figure 3-5):

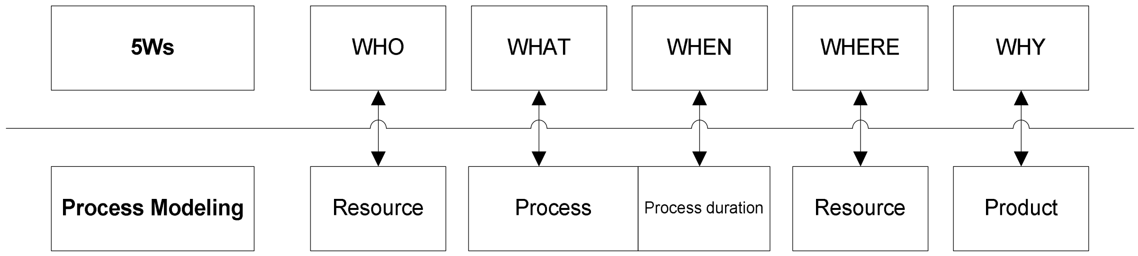


Figure 3-5: Process modeling correspondence to 5Ws

According to Kawalek (2004), process modeling refers to a collection of techniques used to portray the behavior of systems. The industrial construction process expressed within process modeling concepts can now become formalized within machine-readable ontology representation.

3-5.2.3 Integrating existing ontologies

Many domains have started developing ontologies in their fields. The construction research community has also joined the stream to convey advantages to the community. Construction ontologies have been developed to allow domain users to share, in a structured manner, a common understanding of the information in the construction domain. These ontologies allow for the reuse of domain knowledge as "reference libraries", which is extensible, and its future growth is possible. Ontologies can be modified when necessary and used by different applications. Very few projects have been undertaken to formalize the construction domain within ontologies. The existing ontologies are more focused on building industry and project management aspects of construction engineering. The following are instances of these ontologies, which have mostly been developed in Dr. El- Diraby's research group at the University of Toronto:

- IC-PRO-Onto: an Infrastructure and Construction PROcess Ontology (El-Gohary and El-Dibary 2010)
- BCTaxo: a semantic representation of the building-construction knowledge-supporting ontology-based corporate memory system (El-Diraby and Zhang 2006).
- HiOnto: a distributed highway ontology (El-Diraby and Kashif 2005).
- OSPTaxo: an ontolgy for outside plant construction in telecommunication infrastructure (El-Diraby and Briceno 2005).
- S2HOnto: provides ataxonomy for stakeholder management and sustainability in the domain of urban highway construction (El-Diraby and Wang 2005).

All of these ontologies are built based on a fundamental process-modeling ontological concept which is: actors are involved in the processes that are part of a project. Such processes utilize resources according to a mechanism; however, they are constrained by constraints. (El-Diraby et. al 2003)

Another domain which has much in common with industrial construction is manufacturing. Both combine discrete processes updating the status of a product until it satisfies required specifications. Exploring manufacturing ontologies such as Manufacturing Semantically Ontology (MASON) (2006) shows again that the process modeling approach has been used to develop a manufacturing ontology. For instance, MASON ontology follows Martin and Dacunto (2003), who describe the manufacturing domain as the sum of “product, process and resource concepts.”Table 3-1 shows the major concepts used in some construction and manufacturing ontologies.

Table 3-1: Major concepts used in some construction and manufacturing ontologies

Construction Ontology	**Manufacturing Ontology**	**Industrial Construction Ontology**
IC-PRO-Onto (2010)	MASON (2006)	InCon-Onto (2011)
Project Actor Product Process Resource Constraint Mechanism Attribute Modality Family	Entity Operation Resource	Process Product Resource

For InCon-onto, in order to keep the main structure as simple as possible, the main industrial domain concepts have been chosen to be “process, resource and product”. (Figure 3-6) In developing an Industrial Construction Ontology (InCon-Onto), the ontologies which were named in table 3-1 have been studied and the concepts and relationships which seem to suit the industrial construction domain have been adapted to InCon-Onto. As was mentioned, InCon-Onto was developed based on process modeling concepts. In the concepts' classification and decomposition, the previously mentioned process modeling ontologies are followed.

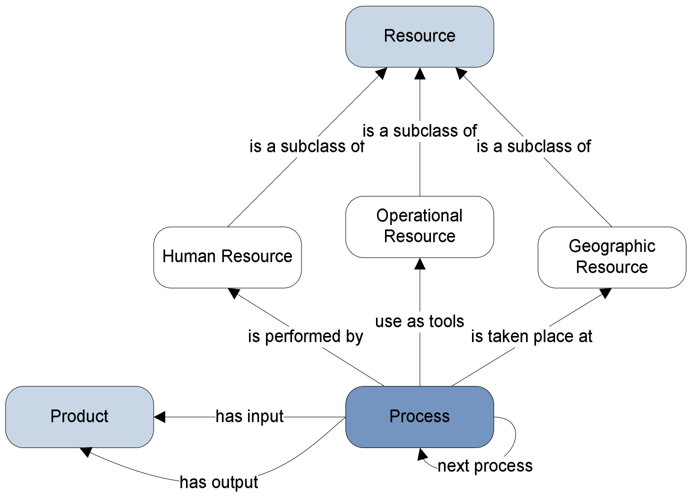


Figure 3-6: InCon-Onto top level concepts and relationships

The main ontological model followed within industrial construction concepts of InCon-Onto is the following: the processes utilize the resource to produce or update a product; the process is performed by a human resource using an operational resource and taking place at a geographic resource, the process takes a product as an input and after updating the product's status delivers it as its output and the output moves to next process. For example a fitting has parts or spool assemblies as input, is performed by a fitter, requires a welding machine as a tool, and takes place at a fitting station.

3-5.3 Industrial construction ontology coding

Ontologies can be encoded using a variety of semantic web languages. The most well-known are RDF and OWL semantic web languages recommended by World Wide Web Consortium (W3C) since 2004.

The evolution of semantic web languages started with the use of XML. XML goal, in contrast to HTML, is to store and carry information. XML is a simple yet flexible markup language which with the use of meaningful tags, it is able to convey more semantics than HTML (W3C 2008).

Within Resource Description Framework (RDF) instead of fixing what data can be captured, the description of data is enriched. RDF makes statements about the resources, in the form of triples, indicating their properties or relationships. Triple expressions are composed of subject-predicate-object. The subject is a resource which is in a relationship with another resource (object) through the predicate. RDF collection is organized through RDF Schema, which is a set of classes with certain properties which provide basic elements to describe ontologies. But RDF Schema does not provide exact semantics for representing complex constraints (W3C 2004).

The W3C has approved OWL as another standard language for encoding ontologies. It incorporates and enhances its predecessors' interoperability features (RDF, RDF-S, DAML, DAML+OIL). Compared to RDF-S, OWL provides more vocabulary for describing classes (e.g., disjointness), properties, and relationships (e.g., symmetry, transitivity) (Figure 3-7) (W3C 2009).

OWL comes in three different expressiveness degrees: OWL Lite, which has expressiveness similar to that of RDF-S; OWL DL, which is based on description logics which are computationally complete and decidable; and OWL Full, which provides additional features but does not guarantee finite computation (McGuinness and Harmelen 2003).

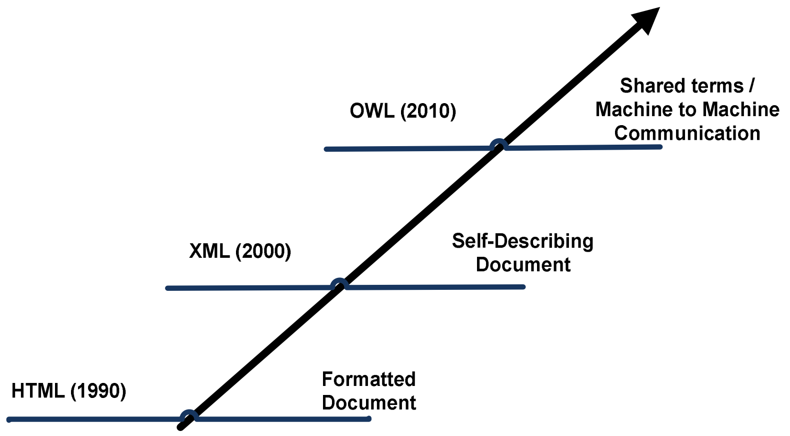


Figure 3-7: Semantic web language evolution

InCon-Onto is encoded in OWL DL and was developed using Protégé 2000 (protege.stanford.edu) and TopBraid Composer, which has its roots in Protégé OWL. (Knublauch 2006). InCon-Onto has been formulated in OWL/RDF bundled with the Protégé platform. The editor comes with different types (e.g. import, export, validation, visualization…) of plug-ins (Storey et. al 2001).As figure 3-8 shows industrial domain ontology includes three representation levels: underlying knowledge representation level, ontology concept level and the instance level. The ontological knowledge level consist of object classes, data properties and axioms. At the ontology concept level all the domain specific concepts, attributes and relationships are defined. The concepts are divided to general process modeling concepts and specific domain concepts. This allows all the mapping rules to be based on general process modeling concepts while at the same time covering specific domain concepts. The concepts are grouped in hierarchies to simplify understanding domain concepts and the relationships define how the concepts become connected.

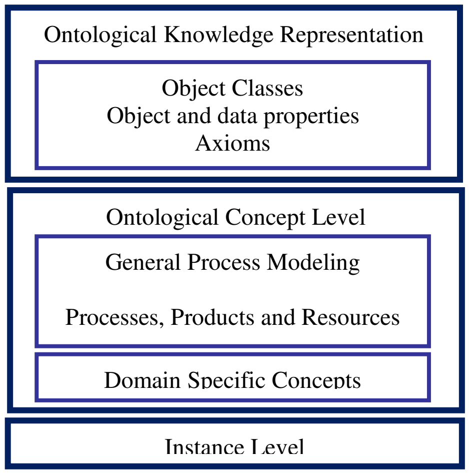

Ontological Knowledge Representation
Object Classes
Object and data properties
Axioms
Ontological Concept Level
General Process Modeling
Processes, Products and Resources
Domain Specific Concepts
Instance Level

Figure 3-8: Different levels of Industrial Construction Ontology

The ontology structure consists of five major components as follows:

1- Classes represent domain concepts arranged in hierarchy
2- Instances or objects belong to classes
3- Properties describe domain attributes
4- Relationships are interrelationships between concepts
5- Axioms specify a term’s definition and the constraints on its interpretation.

Figure 3-9 is a snapshot of InCon-Onto main classes modeled in Protégé using OWL editors. (Appendix I contains RDF/XML source code)

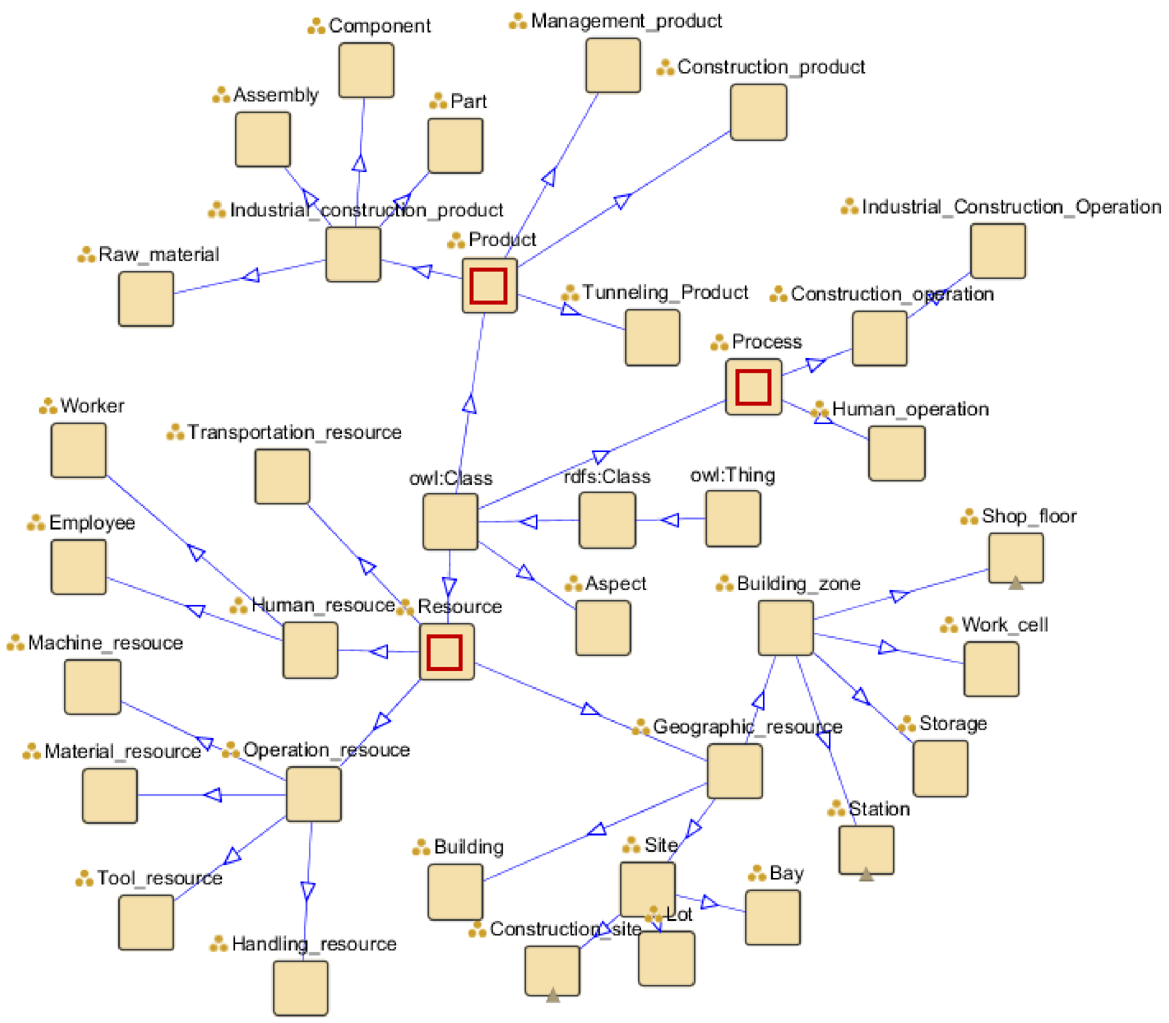


Figure 3-9: InCon-Onto higher level hierarchy

Here is a description of the main concepts, along with figures of their hierarchies and relationships for better understanding.

Processes occur within a time span. In InCon-Onto, the processes are divided into construction processes with the focus on industrial construction and tunneling operations.

Included in InCon-Onto are the hierarchy of industrial construction processes, including shop fabrication, module assembly and site construction, and all the processes involved in them. Figure 3-10 has two parts: the first shows the main hierarchy and the second shows the extended hierarchy. (An abstract of tunneling concepts presented in InCon-Onto is presented in appendix I)

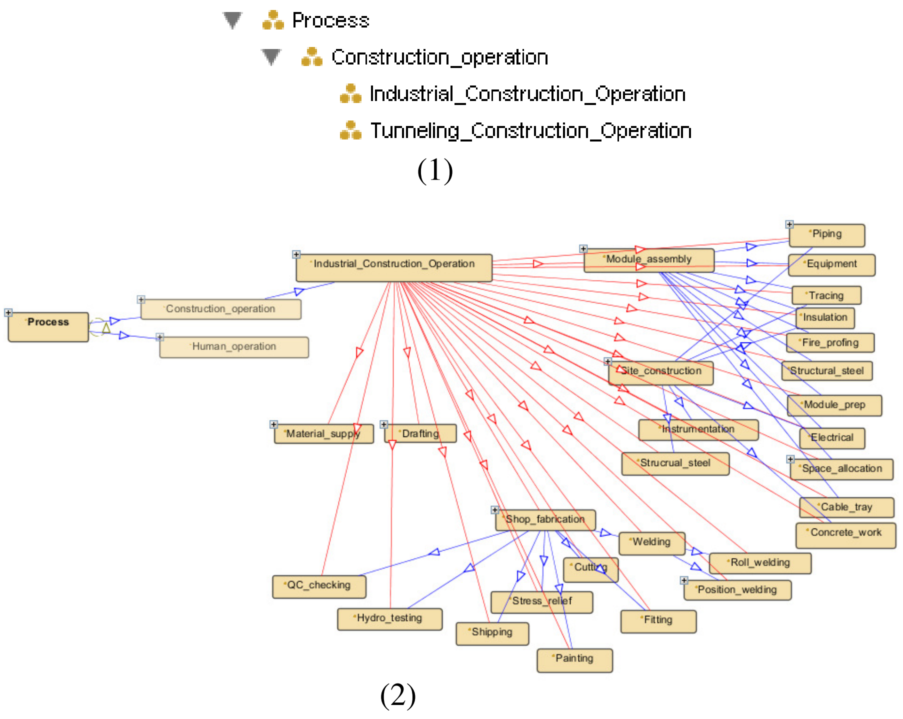
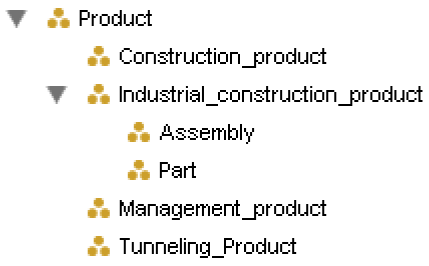


Figure 3-10: Process hierarchy and instances in InCon-Onto

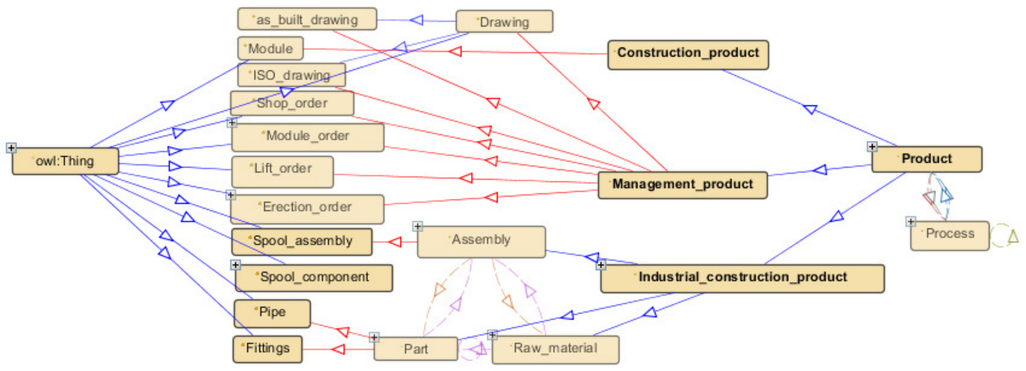
Product: A process produces or updates a product. According to El-Gohary, the products are mainly knowledge or physical products (2010). In InCon-Onto, the products are mainly divided into construction and management products. In the case of industrial construction, the chain of products starts from pipe and fittings which assemble to make spool assemblies, and at the end they turn into spools which are a module assembly component. Management products are included in InCon-Onto too (e.g. shop orders, module orders and erection orders) (Figure 3-11).

Product hierarchy view:



- Product
  - Construction_product
  - Industrial_construction_product
    - Assembly
    - Part
  - Management_product
  - Tunneling_Product

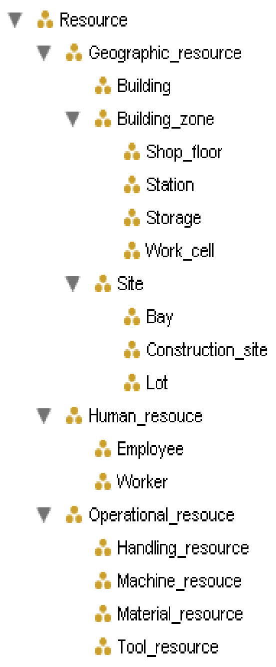
(1)



(2)

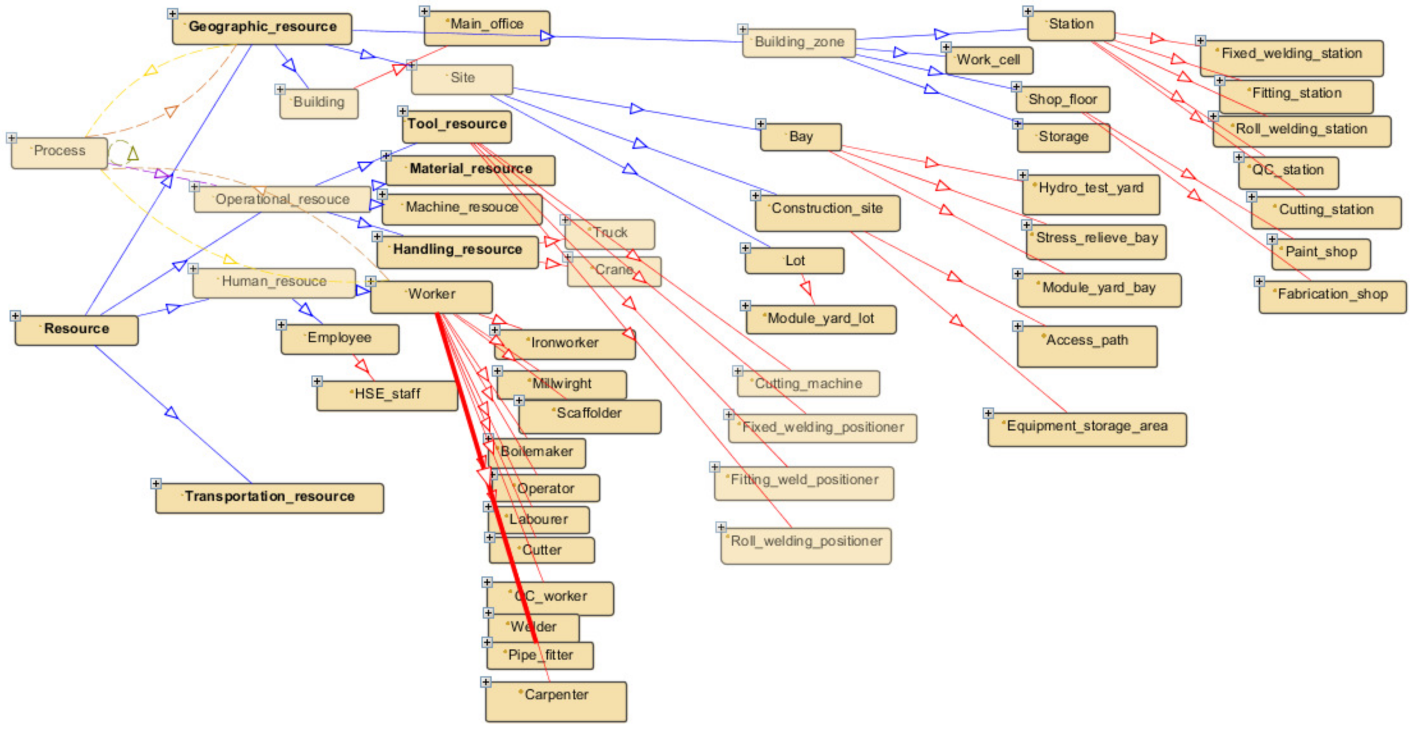
Figure 3-11: Product hierarchy and instances in InCon-Onto

Resources: A process utilizes resources to produce a product. Resources have been divided into sub-categories of geographic, human, and operational resources. The following figure shows the main hierarchy along with the instances related to industrial construction.



- Resource
  - Geographic_resource
    - Building
    - Building_zone
      - Shop_floor
      - Station
      - Storage
      - Work_cell
    - Site
      - Bay
      - Construction_site
      - Lot
  - Human_resouce
    - Employee
    - Worker
  - Operational_resouce
    - Handling_resource
    - Machine_resouce
    - Material_resource
    - Tool_resource

(1)



(2)

Figure 3-12: Resource hierarchy and instances of InCon-Onto

InCon-Onto relationships

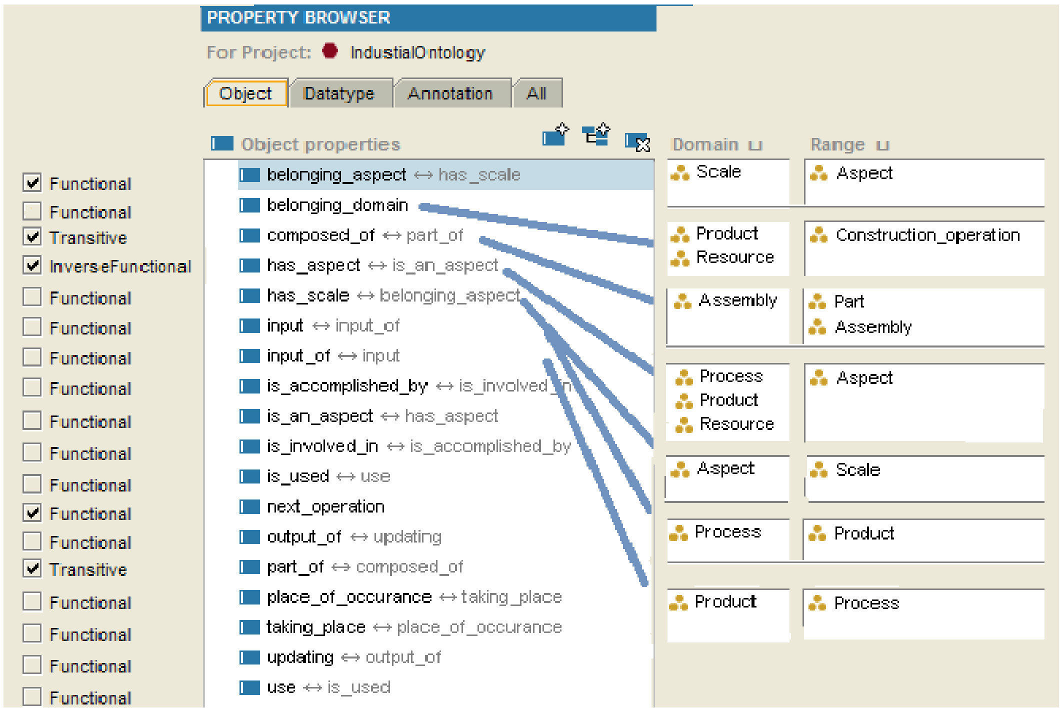
There are two main types of relationships: hierarchical and non-hierarchical. Hierarchical relationships are implicitly expressed through the hierarchies. Those remaining are non-hierarchical. Non-hierarchical relationships are either object properties or data-type properties. Object properties bind two concepts together. Data-type properties link an individual to an XML data-type value. The object-properties link the instances belonging to the domain to instances belonging to the range. The relationships come in four different categories: functional, inverse-functional, symmetric, and transitive (Horridge et al. 2004). InCon-Onto relationships link the main concepts such as product, resource, process, aspect and scale to each other. Table 3-2 list some the relationships between "process" and other concepts in industrial construction ontology.

Table 3-2:Relationships between process and other concepts in InCon-Onto

Domain	Relationship	Range
Process	next_operation	Process
Process	has_aspect	Aspect
Process	has_input	Input
Process	take_place	Resource (geographic)
Process	is_accomplished_by	Resource (human)
Process	uses	Resource (operational)
Process	updating	Product

For each relation its inverse and type of relation (functional, inverse-functional, symmetric, and transitive) is indicated. Within inverse relationship, the domain and range associated with the relation are inversed. If type of relationship is functional, it means that for a given instance there is only one instance in relation with it. As an example in "has aspect" relationship for each scale there is just one instance from aspect. Another type of relationship is transitive; "part of" and “compose of” are both transitive, from a is part of b and b is part of c, it is inferred that a is also part of c. (Figure 3-15)

InCon-Onto relationships are displayed in the first part of figure 3-13. The figure’s second and third parts showcase all the related relationships for the two industrial construction processes.

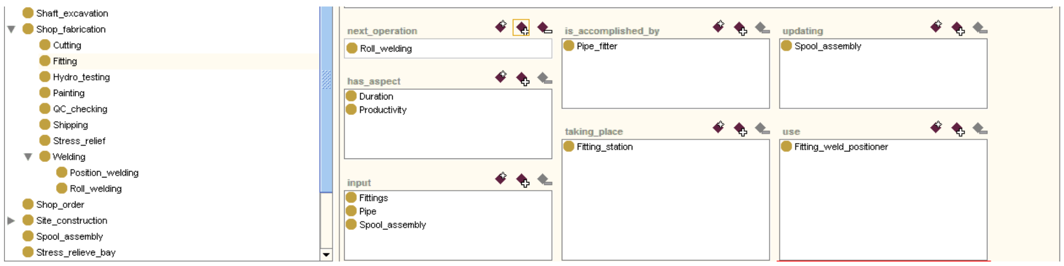

PROPERTY BROWSER
For Project: IndustialOntology
Object | Datatype | Annotation | All

Object properties

✓ Functional	belonging_aspect ↔ has_scale
☐ Functional	belonging_domain
✓ Transitive	composed_of ↔ part_of
✓ InverseFunctional	has_aspect ↔ is_an_aspect
☐ Functional	has_scale ↔ belonging_aspect
☐ Functional	input ↔ input_of
☐ Functional	input_of ↔ input
☐ Functional	is_accomplished_by ↔ is_involved_in
☐ Functional	is_an_aspect ↔ has_aspect
☐ Functional	is_involved_in ↔ is_accomplished_by
☐ Functional	is_used ↔ use
✓ Functional	next_operation
☐ Functional	output_of ↔ updating
✓ Transitive	part_of ↔ composed_of
☐ Functional	place_of_occurance ↔ taking_place
☐ Functional	taking_place ↔ place_of_occurance
☐ Functional	updating ↔ output_of
☐ Functional	use ↔ is_used

Domain ⊔	Range ⊔
Scale	Aspect
Product, Resource	Construction_operation
Assembly	Part, Assembly
Process, Product, Resource	Aspect
Aspect	Scale
Process	Product
Product	Process

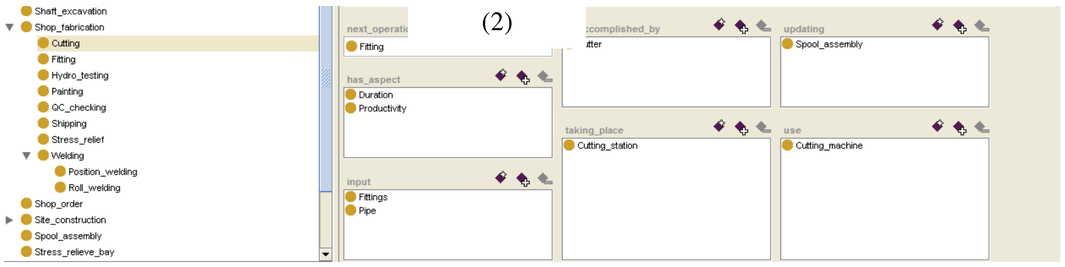
(1)


Shaft_excavation
Shop_fabrication
- Cutting
- Fitting
- Hydro_testing
- Painting
- QC_checking
- Shipping
- Stress_relief
- Welding
  - Position_welding
  - Roll_welding

Shop_order
Site_construction
Spool_assembly
Stress_relieve_bay

next_operation	Roll_welding
has_aspect	Duration, Productivity
input	Fittings, Pipe, Spool_assembly
is_accomplished_by	Pipe_fitter
taking_place	Fitting_station
updating	Spool_assembly
use	Fitting_weld_positioner

(2)


Shaft_excavation
Shop_fabrication
- Cutting
- Fitting
- Hydro_testing
- Painting
- QC_checking
- Shipping
- Stress_relief
- Welding
  - Position_welding
  - Roll_welding

Shop_order
Site_construction
Spool_assembly
Stress_relieve_bay

next_operati	Fitting
has_aspect	Duration, Productivity
input	Fittings, Pipe
ccomplished_by	tter
taking_place	Cutting_station
updating	Spool_assembly
use	Cutting_machine

(3)

Figure 3-13: InCon-Onto relationships

Processes, products, and resources have different aspects such as their physical and configuration properties. These aspects are presented following the manner in which Gellish (i.e. a product modeling language) presents them (Remsen, 2003). All the possible aspects are gathered as instances of the aspect class which has a scale of measurement and value for the particular class they are representing. The instances of product, process, or resource are linked to the proper aspects (Figure 3-14).

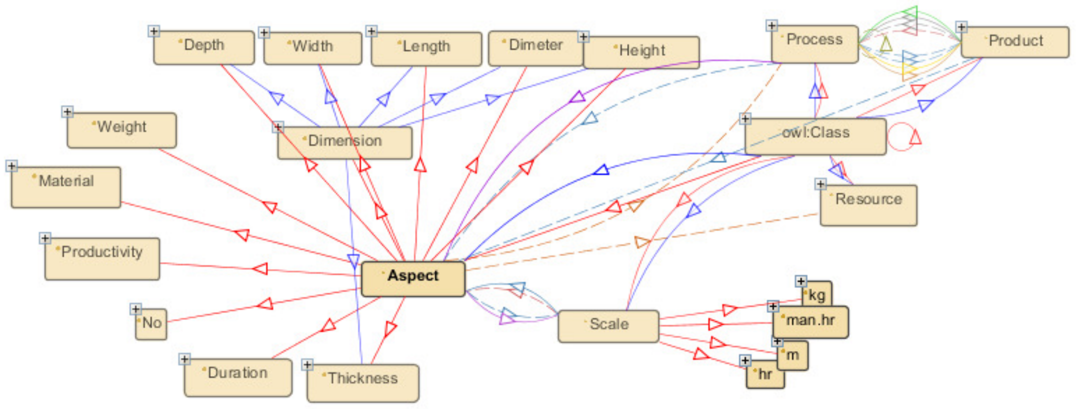
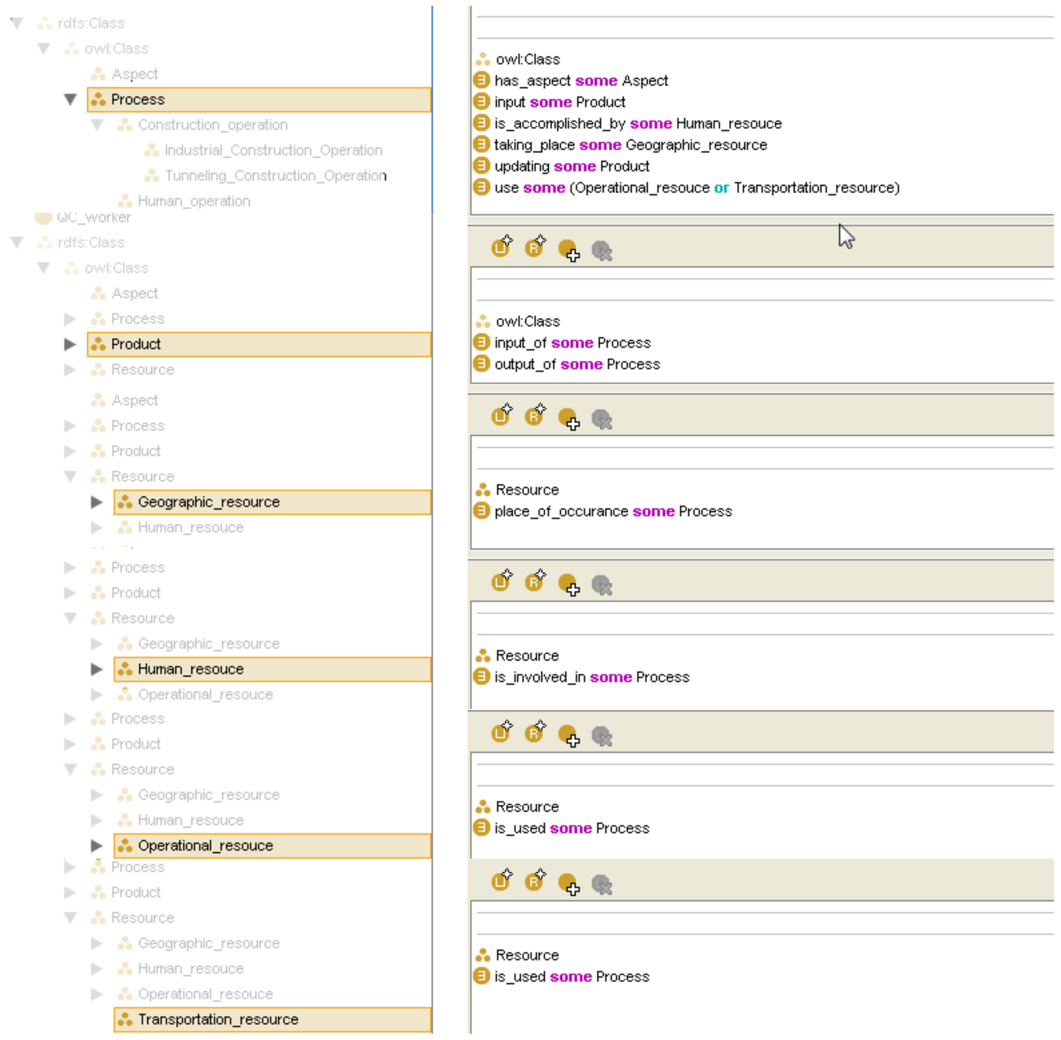


Figure 3-14: Aspects of process, products, and resources in InCon-Onto

Axioms put restrictions on the individuals participating in the relationship and clarify the interpretation (Figure 3-15).



```
owl:Class
has_aspect some Aspect
input some Product
is_accomplished_by some Human_resouce
taking_place some Geographic_resource
updating some Product
use some (Operational_resouce or Transportation_resource)

owl:Class
input_of some Process
output_of some Process

Resource
place_of_occurance some Process

Resource
is_involved_in some Process

Resource
is_used some Process

Resource
is_used some Process
```

Figure 3-15: InCon-Onto axioms

3-5.4 Evaluating the ontology

One way to determine the extent of captured knowledge in an ontology is through competency questions. The competency questions can be imposed on the ontology through ontology query language.

The following table includes some competency questions which can be answered based on the knowledge that exists in the industrial construction domain ontology:

Table 3-3: InCon-Onto competency questions

#	Competency Question	Target
1	What processes are involved in industrial construction?	General
2	What kinds of resources are involved in industrial construction processes?	Resources
3	What kinds of tools are involved in industrial construction?	Resources
4	Where do industrial construction processes occur?	Resources
5	What are the products of industrial construction processes?	Product
6	How are the products measured?	Product
7	What is the purpose of “process A”?	Process
8	To which domain does “process A” belong?	Process
9	To what field does industrial construction “process A” belong?	Process
10	What are the sub-processes of “process A”?	Process
11	Where does “process A” happen?	Process
12	Who is involved in performing “process A”?	Process
13	What are the inputs of “process A”?	Product
14	What are the outputs of “process A”?	Product
15	What tool does “process A” use?	Resource
16	What is the next process after “process A”?	Process
17	What aspect is described for “process A”?	Aspect
18	What is the related aspect of “process A” and what is the scale for measuring the aspect?	Scale
19	What is the productivity of “process A”?	Aspect
20	What kind of operational resources are used in “process A”?	Resource

3-6 Ontology Interoperability

3-6 Ontology Interoperability

The purpose of InCon-Onto is to document the conceptual model of industrial construction processes which can be used for building models in different applications specially simulation modeling application. The domain knowledge that InCon-Onto captures should become accessible for reuse in different applications (Figure 3-16). In this section, sharing and reuse of InCon-Onto knowledge with other ontologies is investigated.

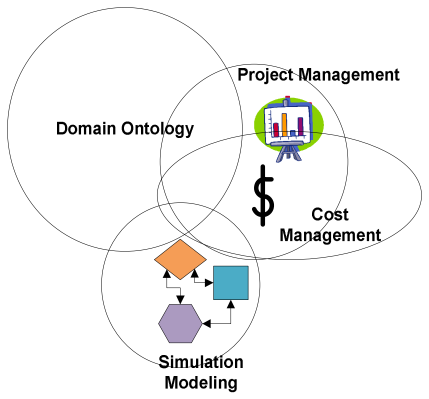


Figure 3-16: Sharing in construction domain

Knowledge representation in ontologies is a tradeoff between several contradictory aspects including usability, reusability, accessibility, interoperability, modularity, and extendibility. According to their scope, ontologies serve a specific domain of interest. On the other hand, they have to be interoperable with other ontolgies. For instance, to serve the industrial construction domain, many other applications such as project management, modeling, and simulation are involved.

It is critical to maintain this interoperability between different ontologies. In building InCon-Onto, two distinctive types of concepts were used: those representing the industrial construction domain, and those which do not physically exist in that domain but are used for abstraction purposes. These types of concepts such as process, product, or resource, usually are called general concepts. Although they do not have a tangible use in the domain, they play a vital role in modeling (i.e. classification), accessing, and reusing the ontologies' content. The concepts can mediate the ontology interoperability. This will be investigated more in the coming sections.

As shown in Figure 3-17, there are four types of ontologies: representation, general, domain, and application (Gomez-Perez et. al, 2004). Here it should be pointed out that this categorization cannot be strictly applied to ontologies, because ontologies usually are a combination of these different types, and drawing a fine line between them is not possible. This type of classification better suits the type of the concepts used in ontologies not the ontologies.

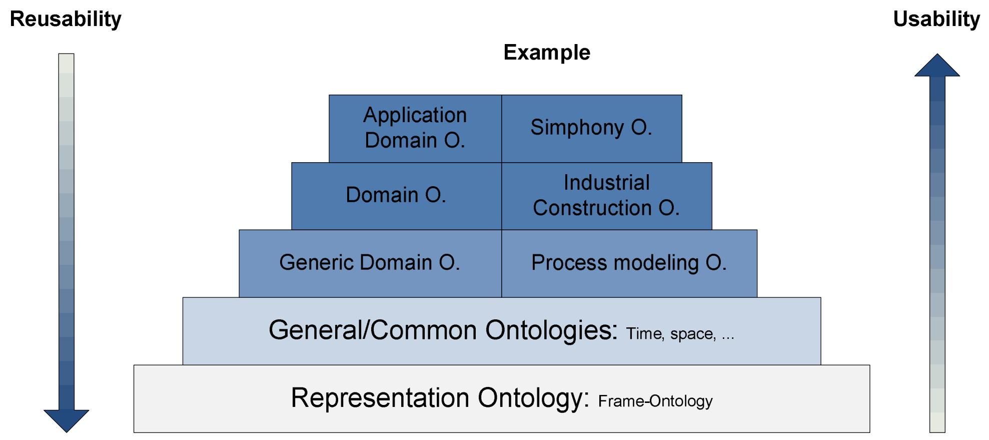

Reusability
Usability
Example
Application Domain O.
Simphony O.
Domain O.
Industrial Construction O.
Generic Domain O.
Process modeling O.
General/Common Ontologies: Time, space, ...
Representation Ontology: Frame-Ontology

Figure 3-17: Types of Ontologies (adapted from Gomez 2004)

General/Common ontologies represent common sense knowledge which is reusable across different domains. These ontologies contain concepts related to things, events, time, space, etc.

General Domain ontologies are reusable in a specific domain such as different fields of engineering.

Domain ontologies contain domain-related concepts in a way that is application-independent and reusable within the domain.

Application ontologies contain all the concepts needed to represent an application.

In order to connect industrial construction ontology to simulation modeling, ontologies of different type are involved: Domain and application ontologies. The following section contains explanations about involved ontologiesand also how they are connected to each other.

3-6.1 Simulation domain ontologies

Simulation application has two components: the simulation world view and simulation interface. The simulation world view represents the way that dynamics of process are presented in a simulation model. The simulation application interface is the simulation environment component that the simulation developer is dealing with in order to develop a model. Somehow the simulation world view bridges the conceptual model to the simulation implementation. The following describes how the formalism of these simulation components through ontologies opens many doors in the world of simulation and modeling with respect to interoperation and knowledge extraction.

The first simulation ontology is Discrete Event Model Ontology (DeMO), which is a comprehensive Discrete Event Simulation (DES) ontology containing templates which capture knowledge of different simulation world views, including activity-oriented, event-oriented, state-oriented and process-oriented (Fishwick and Miller 2004). This ontology is the most suitable resource in order to obtain a comprehensive understanding of DES. DeMO has three top-level classes: DeModel, Model-Component, and Model-Mechanism. Model-Component's subclasses define the DES models' building blocks, such as state, event, activity, and process, while Model Mechanism subclasses define how components work within the model. The DeModel class splits into four first-level subclasses: State-Oriented Model, Event-Oriented Model, Activity-Oriented Model, and Process-Oriented Model. Each of these classes defines a top-level DES formalism, and the subclasses of these classes represent existing modeling techniques.

The Process Interaction Modeling Ontology for Discrete Event Simulations (PIMODES) is another simulation ontology by Lacy (2005b, 2005c), which is built specifically for the process-interaction world view which is a popular paradigm for representing DES. PIMODES includes sets of classes for basic concepts of process interaction such as activity, entity, entity attribute, resource, queue, and location (Figure 3-18).

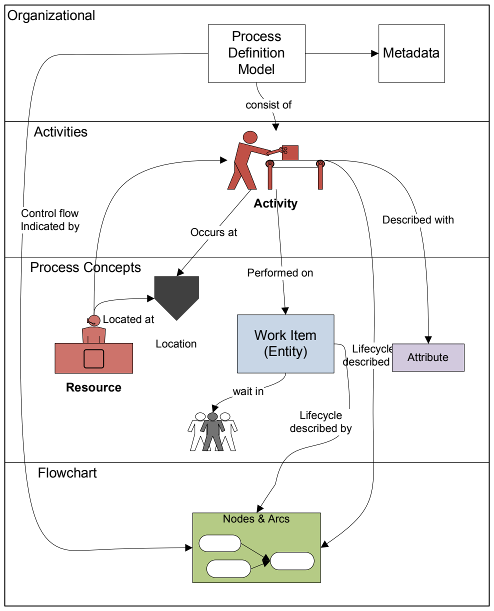


Figure 3-18: PIMODES Structure

Between PIMODES and DeMo, PIMODES has been chosen to present process interaction world view because it is heavily influenced by popular software packages such as Arena, AnyLogic, and ProModel. This makes it easy to connect PIMODES to software packages. PIMODES can be used for an ontology-based representation of models, which facilitates the interchange of simulation models between different simulation packages.

For modeling construction opeartions, process-interaction world view of discrete-event simulation is the dominant simulation world view which has been used and it is fully capable of representing construction operations. The simulation elements used in different simulation software that follow the same world view might not be the same in implementation details, but ultimately they are presenting process-interaction concepts (Silver et al. 2006). That is why PIMODES has been chosen as the simulation world view representation ontology for this research. The first step towards extracting industrial construction process knowledge for a simulation model is connecting the conceptual model concepts to simulation world view concepts. The simulation world view concepts are represented in the simulation application interface.

3-6.2 Simulation application: simphony

The simulation package used in this research following the process interaction world view is Simphony, which is briefly introduced here and fully investigated in following chapters.

Simphony is a special purpose simulation (SPS) tool introduced to the construction domain by Hajjar and AbouRizk (1999). It is a simulation platform for building SPS templates and models competent with process-oriented discrete events simulation modeling. It allows users to implement complex system logic and dynamic interactions among resources and processes within a flexible simulation environment that supports graphical, hierarchical, modular, and integrated modeling (Hajjar and AbouRizk 2002). As with most process simulation tools, Simphony employs a common three-layer architecture. The first layer is the Graphical User Interface (GUI), the second provides process simulation domain objects, and the third provides the simulation services containing the simulation engine, storage, and communication. Figure 3-19 summarizes the model's specifications.

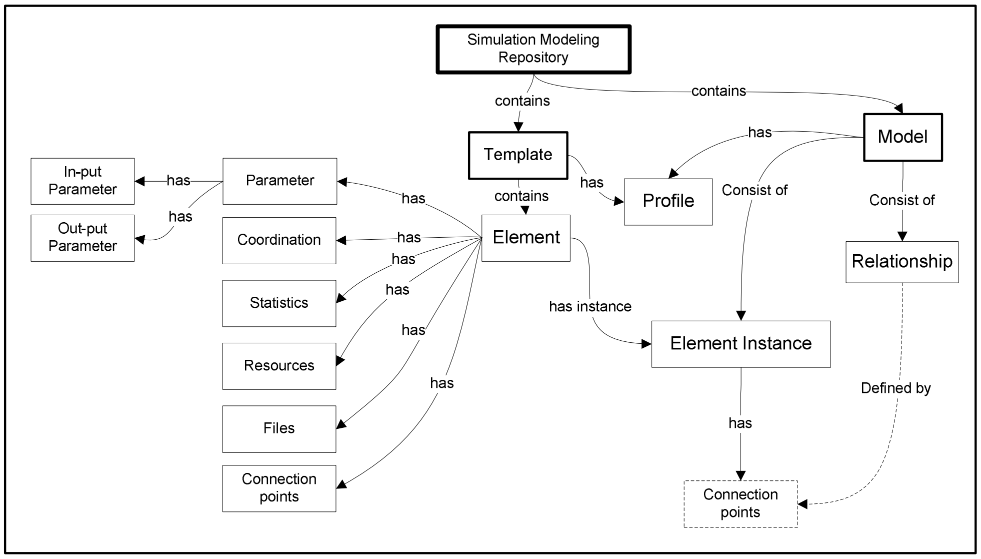


Figure 3-19: Formalized Simphony Structure

The main layer which the simulation developer is dealing with is GUI and the simulation elements. A simulation model built in Simphony is composed of a number of instances of modeling elements that the modeler drags from the modeling element library into the modeling layout and links together in order to build the relationships. Each of these modeling elements reacts in a unique way to different events through input and output variables. A template is a collection of these elements belonging to a particular construction domain. These specifications can be stored in the Simphony legacy form and also the XML format. The XML view of the model provides a neutral and implementation-independent version of the model, which has the potential to be exchanged between applications. Simphony can provide the XML view of the simulation model, and the XML representation has been used as the starting point of developing the Simphony models' formal ontology. More discussion on this matter will be provided in Chapter 4.

3-7 Interoperability between Simulation Ontologies

The following figure 3-20 displays all the involved ontologies in building a simulation model of industrial construction. These ontologies were elaborated on previously. In order to be able to build a simulation model of industrial construction, these ontologies should become connected to each other to make knowledge-sharing and extraction between them possible.

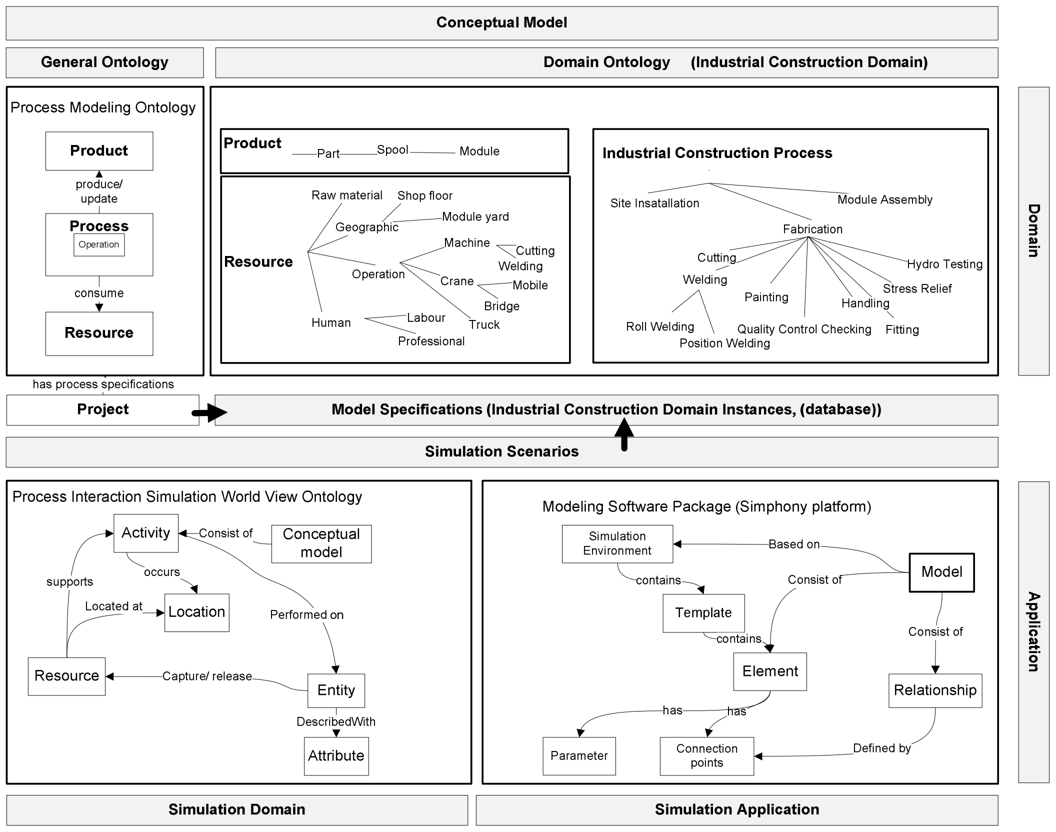


Figure 3-20: Industrial construction simulation framework

The simulation world view connects the conceptual model to simulation implementation. That is why the first step of ontology integration is connecting the conceptual model to the world view presentation of the simulation model through PIMODES.

In order to build the connection between the two ontologies, interoperability approaches within semantic web are investigated. Our suggested approach is presented in the following section.

3-7.1 Ontology interoperability through ontology mapping

3-6.1.1 Mapping between simulation ontologies

Mapping between different ontologies is fundamental for establishing correspondence between ontologies. It provides interoperability and integration means between them. Usually approaches used for ontology mapping are limited to expressing direct correspondence between concepts, which is labor-intensive and prone to error. Most existing mapping tools are based on this approach to support constructing mapping between ontologies; they are based on heuristics to identify structural and naming similarities between models (Noy and Musen 2000; Rahm and Bernstein 2001) or on machine-learning techniques to distinguish the similarities. (Lacher and Groh 2001; Doan et al. 2002). These tools require feedback from users to refine the proposed mapping (Kalfoglou and Scholemmer 2003).

Experimenting with these tools was not that productive, so instead of using them, we have followed an approach not often used by general mapping tools. In this approach, mapping between the two ontologies is established through an intermediate source, so the mapping is done through pair mapping from a third ontology. The third ontology, along with its mappings, is called articulation of two ontologies (Figure 3-21). A few mapping tools follow this approach, among them MAFRA, follows a framework for distributed ontolgies in the semantic web that semantic bridges to connect the ontologies (Maedche and Staab 2000).

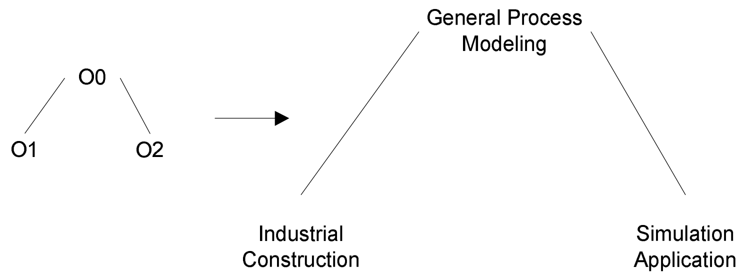


Figure 3-21: Mapping ontologies through a third ontology

In the case of the ontologies we are dealing with, general process modeling concepts are common in both domain (industrial construction) and application (simulation) ontology. The common process modeling concepts play the role of mediator, linking the two ontologies. InCon-Onto is a combination of two types of ontologies: the concepts representing general process modeling ontology and those representing the industrial construction domain. At the same time, the simulation world view ontology, PIMODES, contains process interaction world view concepts which have correspondence with concepts existing in InCon-Onto's process modeling concepts. Table 3-4 shows the existing correspondence between high-level hierarchy classes of two ontolgies.

Table 3-4: Process-oriented concepts used in simulation and industrial construction ontologies

Process Modeling Concept	**Simulation Concepts**	**Discussion**
Product	Entity	The input and outputs for process
Process	Process, Activity	The modeling main concept
Resource	Resource	
Geographic Resource	Location	

Extracting domain knowledge and transferring it to simulation application ontology delivers the components of the implementation independent model, which potentially can be used in any simulation tool following the process-oriented world view. Continuing the mapping process towards the simulation implementation provides the simulation components of the simulation model. The instances of simulation model are presenting the domain concepts which are extracted within two mapping processes (Figure 3-22). Still, the two-stage mapping process is superior to conventional mapping based on concept and structural similarities, because it guarantees full control on the mapping process. Some reasons for the claim are as follows:

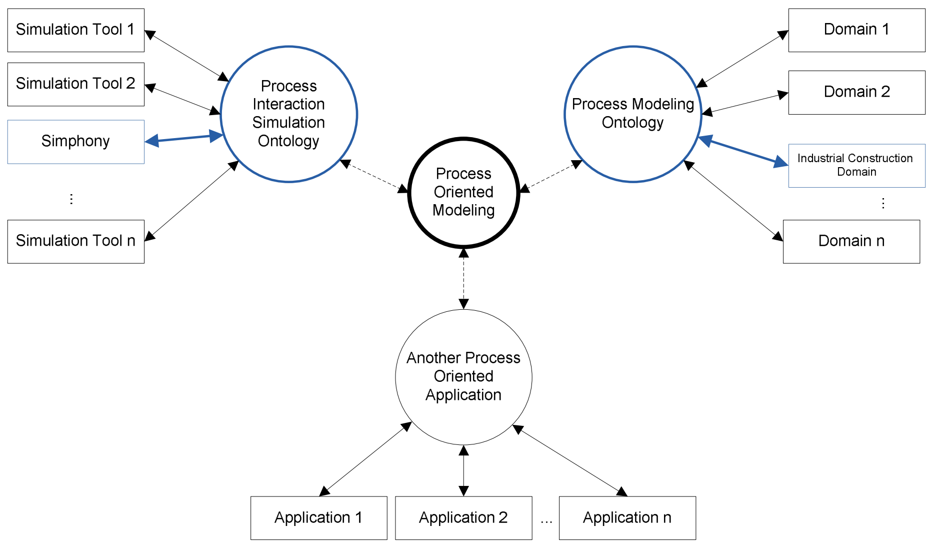

Simulation Tool 1
Simulation Tool 2
Simphony
Simulation Tool n
Process Interaction Simulation Ontology
Process Oriented Modeling
Process Modeling Ontology
Domain 1
Domain 2
Industrial Construction Domain
Domain n
Another Process Oriented Application
Application 1
Application 2
Application n

Figure 3-22: Mapping through process-modeling concepts

1- Process-modeling concepts and relationships are limited and well-known.

2- By using process-oriented concepts, several related concepts in domain and simulation ontologies are acquired at once in an aggregated manner.

3- Mapping and coordination between ontologies is simplified because the process ontologies are simple and contain a limited number of concepts.

4- Within a non-complex and totally controlled mapping process, a connection is made between two entirely different worlds of industrial construction and simulation with numerous concepts and relationships.

5- Following the process-oriented presentation of domains makes it easier to add other domains' ontologies and applications to the mapping network. More important, as long as the different domains share a process-modeling language, they do not need in-depth knowledge about each other's ontology contents to foster their communication.

6- As the concepts are mapped based on their role in the process, mapping needs be established just once. From that point it can be maintained and used.

7- This is the main difference between this work and the other work on ontology-driven models. In the other work, model development exclusive mapping has to be rebuilt each time; however, in the current work, using process-oriented general ontologies in the different domains simplifies the entire process of mapping and model derivations.

The linkage between process-oriented simulation domain ontology and process-modeling ontology for industrial construction is connecting end-point industrial domain concepts to their most usual roles in the simulation domain. It should be mentioned that mapping follows the most common interpretation of the concepts. For example, a truck in most models is simulated as a resource; however, within a creative simulation modeling approach, it might be modeled as a flowing entity in the simulation model.

The model derived at this stage allows the model developer to see the composition of the simulation model, the model which is semantically meaningful but still very easily understood and less bogged down with low-level implementation details. Also, it is still easy to get connected to the simulation scenario and build a detailed scenario-based model rather than just the conceptual model.

3-7.1.2 Ontology mapping through SPARQL

3-4.4.1 SPARQL (SPARQL Protocol and RDF Query Language) queries for knowledge retrieval

The interaction with ontolgies is a two-way interaction; the first one is infusing new knowledge into ontologies and the other one is acquiring knowledge from it. Knowledge inquiry is done through posing queries on ontologies. According to W3C, SPARQL is a query language for ontologies (Prud'hommeaux et. al 2008).

SPARQL has rich built-in functions that can be used to query the ontologies stored as RDF or viewed as RDF through middleware.

When the ontologies come from different categories, the mapping purpose can be different than just finding taxonomical similarities. When one ontology comes from the domain category and another from the application category, the domain ontology is the knowledge source. As a result, it has to provide the instances for the application ontology through mapping. SPARQL (SPARQL Protocol and RDF Query Language) is an expressive yet simple language that has been used to formulate mapping relationships between concepts from different ontologies. SPARQL mapping rules can be executed through inference engines in order to perform information exchange between the ontologies. In this case, transformation mostly includes instance transference between mapped classes (Makris et. al 2009) (Figure 3-23).

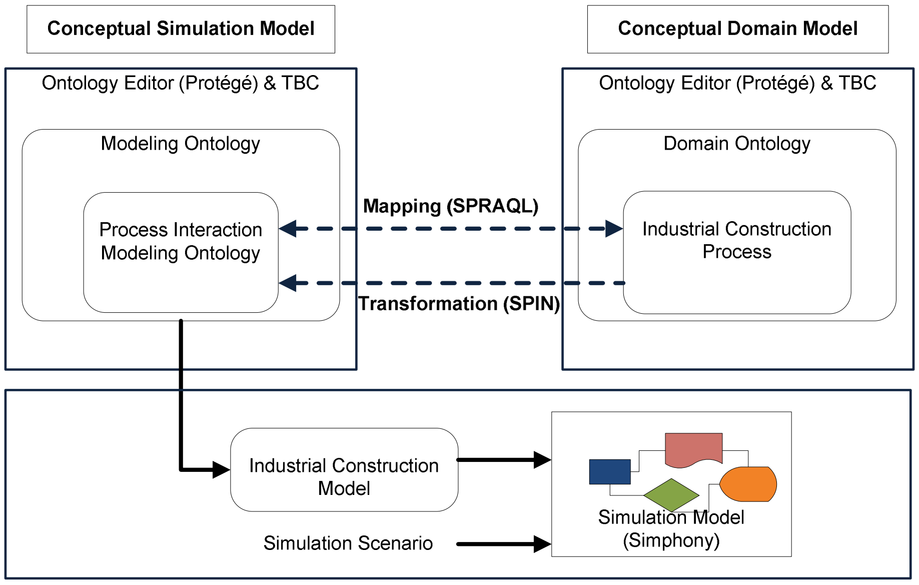

Conceptual Simulation Model
Conceptual Domain Model
Ontology Editor (Protégé) & TBC
Ontology Editor (Protégé) & TBC
Modeling Ontology
Domain Ontology
Mapping (SPRAQL)
Process Interaction Modeling Ontology
Industrial Construction Process
Transformation (SPIN)
Industrial Construction Model
Simulation Scenario
Simulation Model (Simphony)

Figure 3-23: Mapping Process

In the case of connecting construction domain ontology to the simulation domain, the aim of mapping is to establish the correspondence between the ontologies and then transfer the concept instances from the source ontology to the target. Another crucial reason for using SPARQL as a mapping language is that SPARQL easily allows for data integration, which down the road is very important for developing scenario-based simulation models.

The following figure describes the SPARQL mapping implementation between InCon-Onto and simulation application in the TopBraid Composer environment (2010). SPIN (SPARQL Inferencing Notation) is a framework which utilizes SPARQL. Its inference engine takes the RDF/OWL model and derives new information from it based on existing logical rules such as mapping rules (Furber and Hepp 2010).

In the following, some of possible correspondence between the two ontologies' concepts is shown in Figure 3-24. As shown in the graph, all the involved ontologies are connected through their common ground of process-modeling concepts. The simulation modeling world view connects the simulation application to the industrial construction domain.

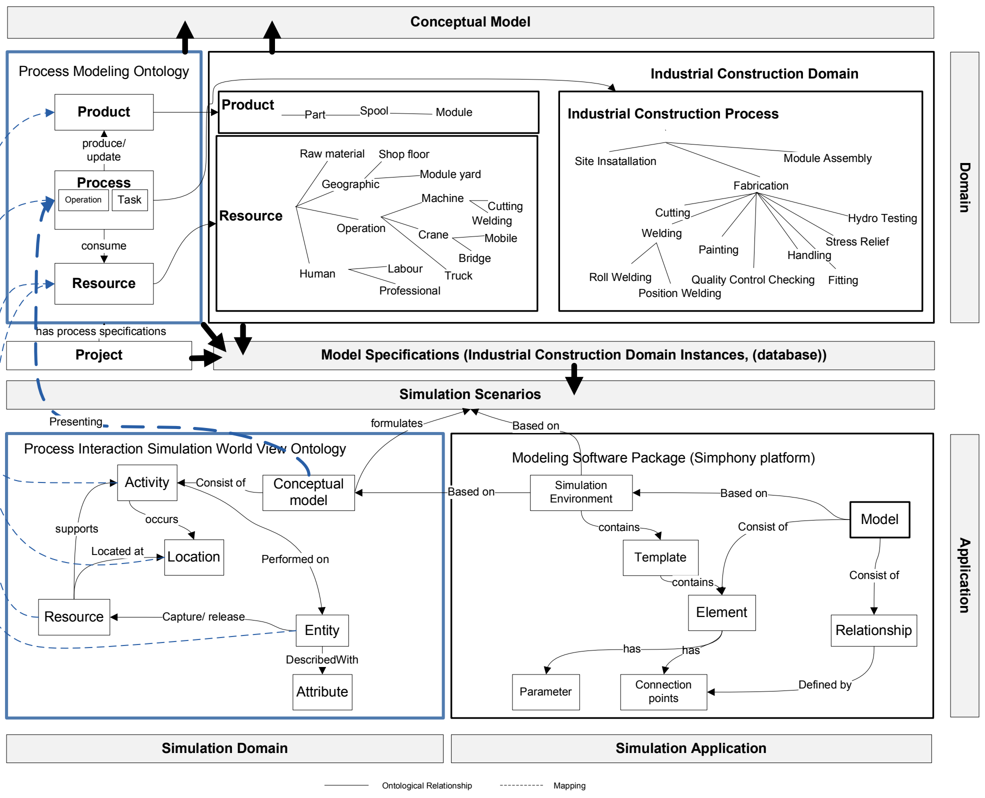
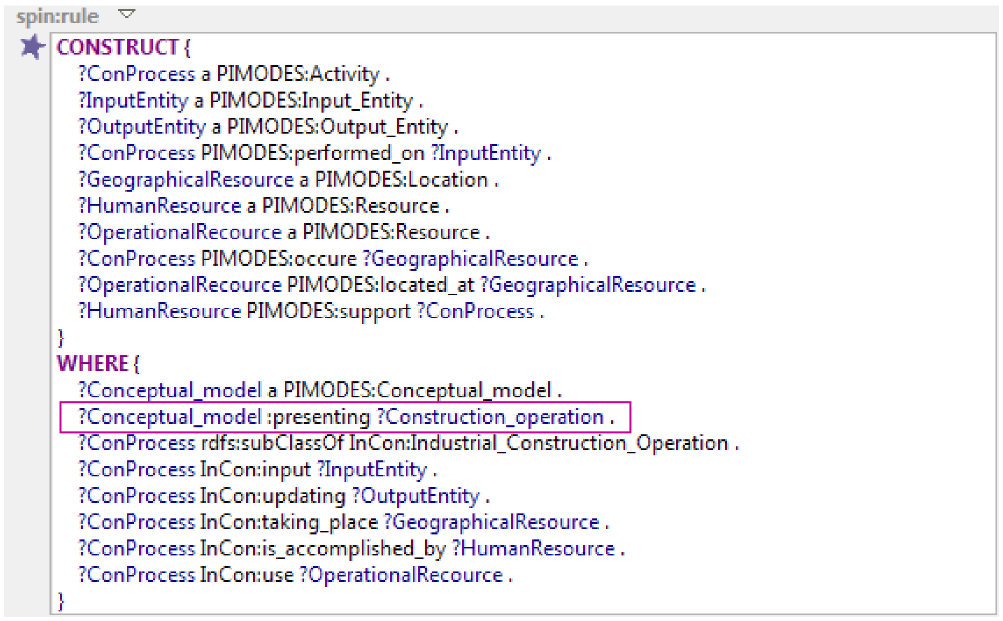


Figure 3-24: Ontological construction simulation framework

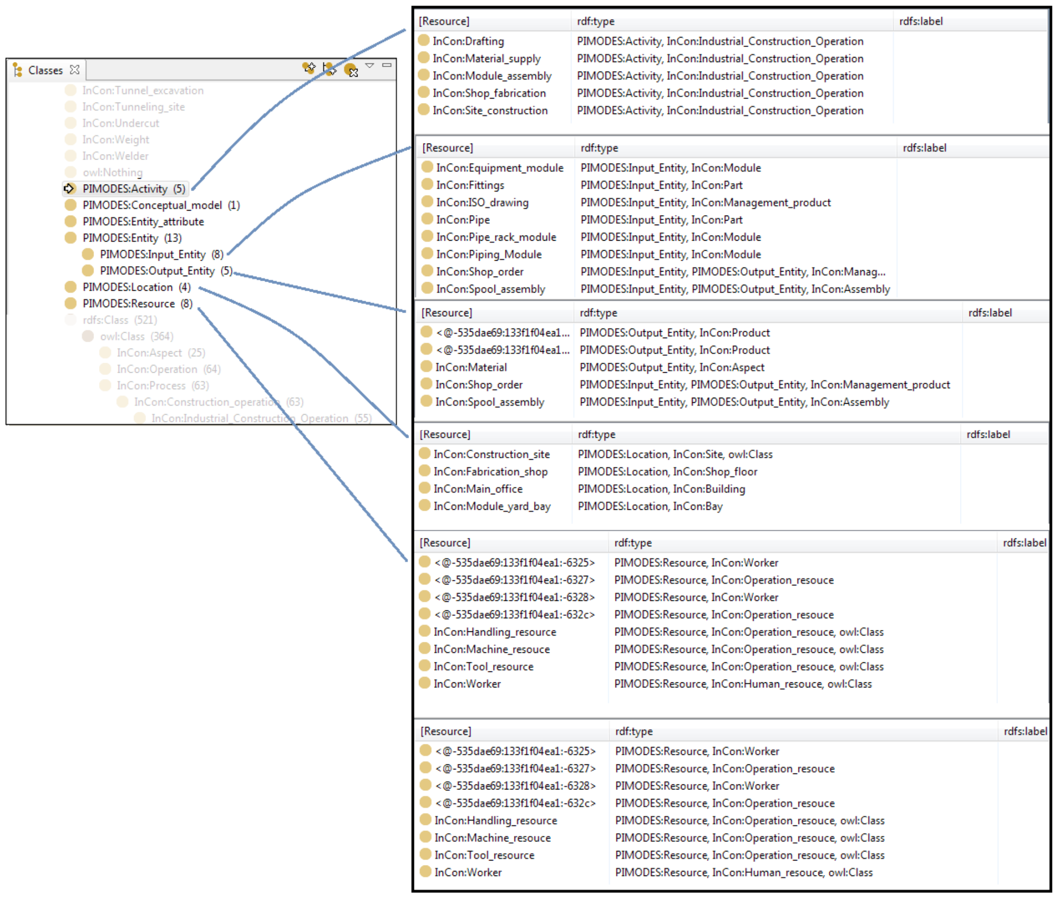
The mapping expressions are formulated through SPARQL query language. SPARQL was originally used for querying RDF data on the web; it has a similar notation to SQL for querying: SELECT, FROM, WHERE. And supporting functions such filter, union, and disjunction allow for more sophisticated queries. Query reformulation through the CONSTRUCT and RULE statements gives SAPAQL mapping the capacity to pose a query over another ontology for mapping purposes. The execution of the CONSTRUCT statement in the target ontology would yield to the transformation of ontology instances in the simulation ontology. SPIN, the inference engine, can support saving and reusing SPARQL queries within its resources for inferring mapping rules.

Below is an example of a SPARQL query which maps InCon-Onto to PIMODES. The PIMODES ontology concepts and relationships are linked to their corresponding concepts and relationships in the InCon-Onto. All of the mapping can be done through one single query containing all the mapping expressions. The chosen processes, along with their different involved resources and products, are mapped to equivalent concepts in simulation ontology. Performing the mapping process, all of PIMODES ontology concepts are instantiated with the industrial domain ontology instances. (Figures 3-25 and 3-26)


spin:rule

```
CONSTRUCT {
  ?ConProcess a PIMODES:Activity .
  ?InputEntity a PIMODES:Input_Entity .
  ?OutputEntity a PIMODES:Output_Entity .
  ?ConProcess PIMODES:performed_on ?InputEntity .
  ?GeographicalResource a PIMODES:Location .
  ?HumanResource a PIMODES:Resource .
  ?OperationalRecource a PIMODES:Resource .
  ?ConProcess PIMODES:occure ?GeographicalResource .
  ?OperationalRecource PIMODES:located_at ?GeographicalResource .
  ?HumanResource PIMODES:support ?ConProcess .
}
WHERE {
  ?Conceptual_model a PIMODES:Conceptual_model .
  ?Conceptual_model :presenting ?Construction_operation .
  ?ConProcess rdfs:subClassOf InCon:Industrial_Construction_Operation .
  ?ConProcess InCon:input ?InputEntity .
  ?ConProcess InCon:updating ?OutputEntity .
  ?ConProcess InCon:taking_place ?GeographicalResource .
  ?ConProcess InCon:is_accomplished_by ?HumanResource .
  ?ConProcess InCon:use ?OperationalRecource .
}
```

Figure 3-25: Mapping through SPARQL query



```
Classes
    InCon:Tunnel_excavation
    InCon:Tunneling_site
    InCon:Undercut
    InCon:Weight
    InCon:Welder
    owl:Nothing
    PIMODES:Activity  (5)
    PIMODES:Conceptual_model  (1)
    PIMODES:Entity_attribute
    PIMODES:Entity  (13)
        PIMODES:Input_Entity  (8)
        PIMODES:Output_Entity  (5)
    PIMODES:Location  (4)
    PIMODES:Resource  (8)
    rdfs:Class  (521)
        owl:Class  (364)
            InCon:Aspect  (25)
            InCon:Operation  (64)
            InCon:Process  (63)
                InCon:Construction_operation  (63)
                    InCon:Industrial_Construction_Operation  (55)
```

[Resource]	rdf:type	rdfs:label
InCon:Drafting	PIMODES:Activity, InCon:Industrial_Construction_Operation	
InCon:Material_supply	PIMODES:Activity, InCon:Industrial_Construction_Operation	
InCon:Module_assembly	PIMODES:Activity, InCon:Industrial_Construction_Operation	
InCon:Shop_fabrication	PIMODES:Activity, InCon:Industrial_Construction_Operation	
InCon:Site_construction	PIMODES:Activity, InCon:Industrial_Construction_Operation	

[Resource]	rdf:type	rdfs:label
InCon:Equipment_module	PIMODES:Input_Entity, InCon:Module	
InCon:Fittings	PIMODES:Input_Entity, InCon:Part	
InCon:ISO_drawing	PIMODES:Input_Entity, InCon:Management_product	
InCon:Pipe	PIMODES:Input_Entity, InCon:Part	
InCon:Pipe_rack_module	PIMODES:Input_Entity, InCon:Module	
InCon:Piping_Module	PIMODES:Input_Entity, InCon:Module	
InCon:Shop_order	PIMODES:Input_Entity, PIMODES:Output_Entity, InCon:Manag...	
InCon:Spool_assembly	PIMODES:Input_Entity, PIMODES:Output_Entity, InCon:Assembly	

[Resource]	rdf:type	rdfs:label
<@-535dae69:133f1f04ea1...	PIMODES:Output_Entity, InCon:Product	
<@-535dae69:133f1f04ea1...	PIMODES:Output_Entity, InCon:Product	
InCon:Material	PIMODES:Output_Entity, InCon:Aspect	
InCon:Shop_order	PIMODES:Input_Entity, PIMODES:Output_Entity, InCon:Management_product	
InCon:Spool_assembly	PIMODES:Input_Entity, PIMODES:Output_Entity, InCon:Assembly	

[Resource]	rdf:type	rdfs:label
InCon:Construction_site	PIMODES:Location, InCon:Site, owl:Class	
InCon:Fabrication_shop	PIMODES:Location, InCon:Shop_floor	
InCon:Main_office	PIMODES:Location, InCon:Building	
InCon:Module_yard_bay	PIMODES:Location, InCon:Bay	

[Resource]	rdf:type	rdfs:label
<@-535dae69:133f1f04ea1:-6325>	PIMODES:Resource, InCon:Worker	
<@-535dae69:133f1f04ea1:-6327>	PIMODES:Resource, InCon:Operation_resouce	
<@-535dae69:133f1f04ea1:-6328>	PIMODES:Resource, InCon:Worker	
<@-535dae69:133f1f04ea1:-632c>	PIMODES:Resource, InCon:Operation_resouce	
InCon:Handling_resource	PIMODES:Resource, InCon:Operation_resouce, owl:Class	
InCon:Machine_resouce	PIMODES:Resource, InCon:Operation_resouce, owl:Class	
InCon:Tool_resource	PIMODES:Resource, InCon:Operation_resouce, owl:Class	
InCon:Worker	PIMODES:Resource, InCon:Human_resouce, owl:Class	

[Resource]	rdf:type	rdfs:label
<@-535dae69:133f1f04ea1:-6325>	PIMODES:Resource, InCon:Worker	
<@-535dae69:133f1f04ea1:-6327>	PIMODES:Resource, InCon:Operation_resouce	
<@-535dae69:133f1f04ea1:-6328>	PIMODES:Resource, InCon:Worker	
<@-535dae69:133f1f04ea1:-632c>	PIMODES:Resource, InCon:Operation_resouce	
InCon:Handling_resource	PIMODES:Resource, InCon:Operation_resouce, owl:Class	
InCon:Machine_resouce	PIMODES:Resource, InCon:Operation_resouce, owl:Class	
InCon:Tool_resource	PIMODES:Resource, InCon:Operation_resouce, owl:Class	
InCon:Worker	PIMODES:Resource, InCon:Human_resouce, owl:Class	

Figure 3-26: Mapping inference results

Conceptual model extraction can happen at any level of abstraction of construction processes.

3-8 Summary and Conclusion

The current simulation modeling in construction pays the least attention to the conceptual modeling process; however it plays an important role in the reusability and composability of simulation models. In this chapter, the conceptual model of industrial construction was ontologically modeled with an attempt to bridge reuse and composability gaps. The industrial construction ontology has a modular structure based on the process-modeling ontology. Taking this approach for developing InCon-Onto has been particularly effective in dealing with the interoperability challenges of construction simulation models. Through the mapping process, an ontological framework of all the involved simulation components is built and interoperability between the components is facilitated. Instead of using existing tools, SPARQL, which is a query language, has been used to formulize the articulation of mapping rules. The inference of mapping rules results in sharing the knowledge content of the industrial construction ontology with simulation application ontology, and carries the conceptual model forward to the implementation phase. In the coming chapter, we investigate reusability challenges through the development process, especially for distributed simulation.

3-9 References

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Chapter 4

Enhancing Reusability in HLA-based Distributed Simulation Modeling of Industrial Construction Processes

4-1 Introduction

The Construction Synthetic Environment (COSYE), which is a High Level Architecture (HLA)-based distributed simulation environment, has been developed by AbouRizk (AbouRizk et al. 2006). COSYE has already been utilized to model various large-scale construction and industrial construction projects. In the second chapter, two examples of distributed simulation models were presented. The models were integrated from independently developed components by different simulation developers. However reuse, composability, and interoperability of these simulation components are stated as HLA goals; still, it is difficult to fulfil these goals in implementation (Radeski et al. 2002). The necessary requirement for reaching reusability and interoperability is that unambiguous and structured formalization of information must be shared and exchanged between distributed simulation modeling components (Tolk and Turnitsa 2007). Ontological means have been taken in this research to link and drive information between heterogeneous knowledge sources and illustrate how knowledge integration leads to increased reusability and interoperability in distributed simulation modeling.

4-2 Distributed Simulation Modeling Challenges

As was mentioned before, the key motivation for using distributed simulation modeling in construction management is the decomposition of large-scale construction models into smaller and more manageable components called federates, so that the development efforts are distributed between different development groups. Once the federates have been developed independently, they should be assembled together in order to build the entire model. This cannot happen without consensus between all the involved collaborator parties about the knowledge that they are sharing. All the parties have to take a harmonized approach towards all core aspects of simulation modeling. Having a common understanding about the simulation modeling problem, simulation modeling world view, and simulation modeling environment is the first step towards successfully developing a distributed simulation modeling.

The approach taken in this research is based on ontological modeling of all different aspects involved in a distributed simulation modeling. The approach uses semantic web technologies to automate sharing and reusing knowledge within these different ontologies to overcome current challenges facing the construction industry as it develops distributed simulation models.

In the following section some of the challenges related to modeling construction processes in a distributed simulation modeling environment based on HLA are investigated more specifically. Subsequently the ontological modeling framework, including all the involved components, is elaborately discussed. There is also a description of two specific cases that use the ontological approach.

4-2.1 Reuse and interoperability challenges within distributed simulation modeling

For the distributed simulation modeling components (federates) to be able to communicate with each other, they should comply with a common representation for the exchangeable information through shared federation object model (FOM) object classes and interactions (IEEE 2000. Std 1516.2 2000). Developing an FOM, which all the collaborates agrees on, takes lots of time and effort. On the other hand, communication dependency on FOM highly restricts the federates' reusability as any changes in FOM lead to lots of code updates and modifications in the corresponding federates (Rathnam and Paredis 2004). That is why the Federation Development and Execution Process (FEDEP) (Defense Modeling and Simulation Office 1999) recommends reusing existing FOMs. In order to develop FOMs which facilitate reusability, the industry should take a common approach towards FOM development. In this chapter, ontologies provide the agreed-upon common and shared understanding of the domain and simulation knowledge.

Another issue which is to be addressed by using ontolgies is the reusability spectrum in the distributed simulation modeling environments. Reusability within HLA is focused on reusing federates. The federates are treated as atomic simulation components, and reusing even a portion of the code within them is almost impossible. The narrow reusability scope within distributed simulation modeling often makes the development process complex and effort intensive (Radeski et al. 2002). The steep learning curve and complexity associated with HLA rules and standards are a part of development complexities. Developing simulation federates from reusable elements, such as what exists in stand-alone construction simulation modeling environments, reduces development efforts and therefore speeds up the development process of simulation models (AbouRizk and Mohamed 2000). In this chapter, in order to apply an element-based approach for distributed simulation modeling of construction operations, breakdown of elements and their characteristics are identified and developed serving process interaction concepts while providing HLA communication services.

4-3 Ontology-Driven Framework for Construction Simulation Modeling

4-3.1 Overview on ontological framework

In chapter 2 we presented the ontological framework of the involved simulation components modeled and linked together. As was discussed before, the framework (Figure 4-1) consists of two parts: industrial domain and simulation domain. Industrial construction processes are modeled through process-modeling concepts within Industrial Construction Ontology (InCon-Onto).

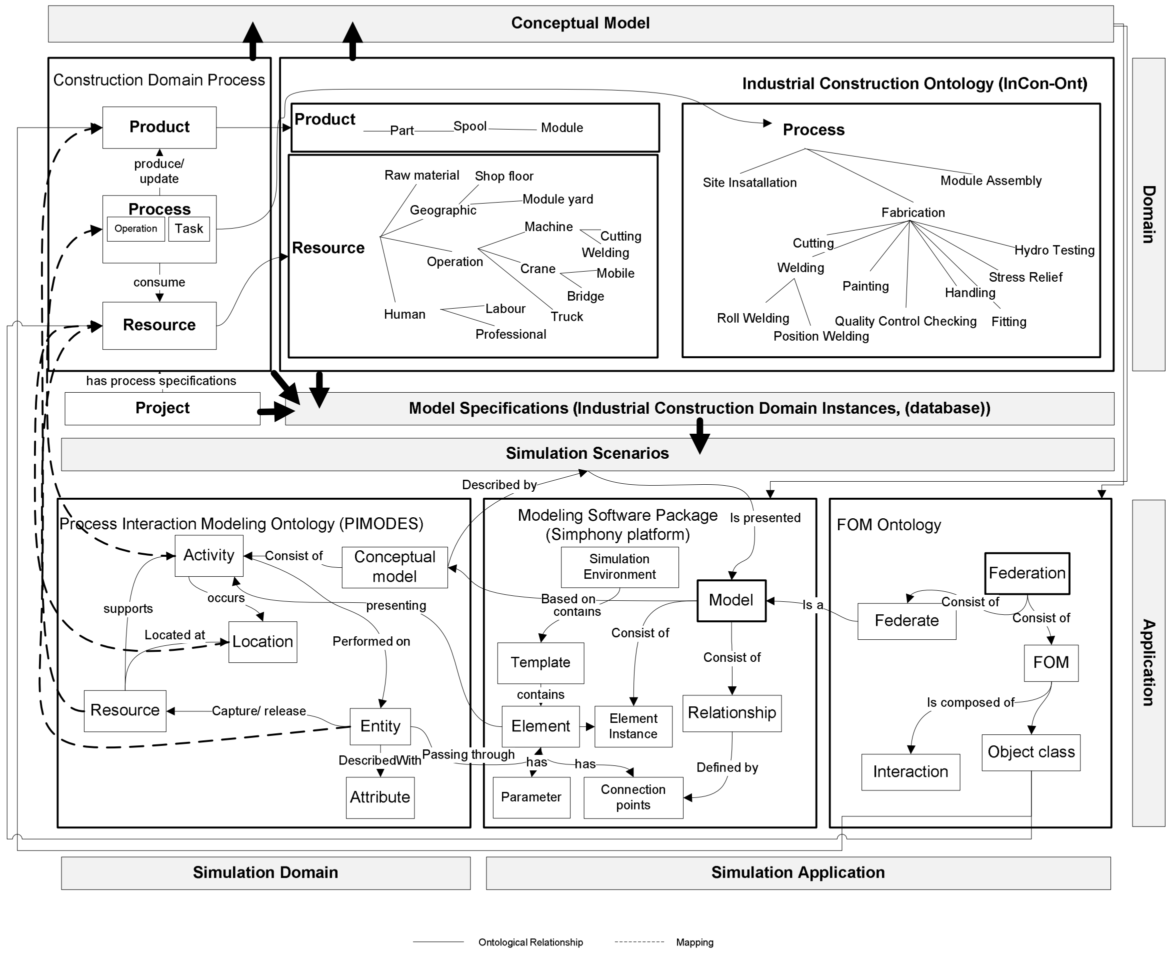


Figure 4-1: The ontological framework of construction simulation components

The simulation domain itself has two parts: simulation world view and simulation application. The modeling representation follows a process-oriented world view ontology presented in POMIDES ontology developed by Lacy (2005). The simulation application is an element-based presentation of distributed simulation modeling consisting of federates, focusing on modeling the dynamics of processes. FOM, representing products and resources dealing with processes, is also captured within ontologies. All ontological components were explained in Chapter 2. The only component which is discussed further is the simulation application component.

4-3.2 Simulation application ontologies

The ontology of the simulation interface formalizes the software interface with which the simulation developer is dealing. In this research, as was stated before, the distributed simulation model is developed in an element-based environment of a Special Purpose Simulation (SPS) tool called Simphony. FOM provides the federate's communications means with other federates, which might be developed using different applications. Therefore the simulation application ontology has two components: Simphony, which was explained previously, and FOM.

FOM Ontology: This specifies the major components of FOM, which are composed of object classes, attributes, interactions, and parameters which are going to be shared and exchanged within federates. The entire framework is encoded using OWL/RDF semantic languages as was explained previously.

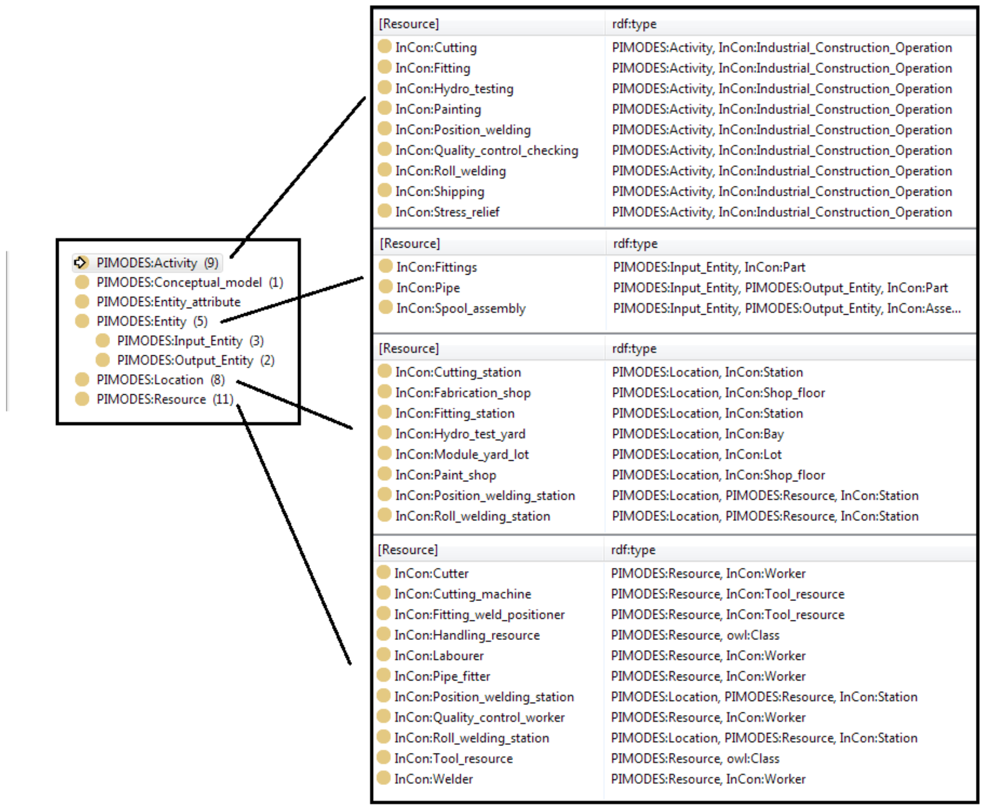
4-4 Ontology-Driven Applications

4-4.1 Role of industrial construction ontology in modeling industrial construction processes at multiple levels of abstraction

Modeling industrial construction processes in the COSYE environment allows for the overall system to decompose into multiple components, which means that models are developed at different levels of abstraction. At low resolution of a large-scale model, all parties involved in developing the simulation model have to reach consensus so that the simulation components will be able to communicate with each other. At lower resolution, few objects or processes can be aggregated into one object. Successful implementation of models at different levels of abstraction requires a decomposition strategy which can keep up with consistency of information at different levels for later integration of simulation components (Benjamin et al. 1998, 2006). Ontology-driven modeling of large industrial processes provides a reference for decomposing the process while preserving consistency and connection between the components. The breakdown of processes in InCon-Onto follows the real-world implementation of the processes. Each main component is managed separately from others and has its own domain expertise and final users.

The ontological-driven approach is fast yet reliable. Within this approach, the level of abstraction is chosen and then all the related resources and products of those processes can be queried from the domain ontology. The extraction queries are imposed upon InCon-Onto through process interaction ontology (PIMODES; Lacy, 2006) which consists of components of the industrial construction ontological framework. As an example, querying the InCon-Onto at high level industrial construction can provide the breakdown of industrial construction processes as different federates (Figure 4-2) (The query is almost similar to Figure 2-31). As shown in figure the industrial construction federates can be the following: drafting, material supply, module assembly, shop fabrication, and site construction. All involved objects at this level are shown as products or resources forming the federation object model of the federation. It should be noted that domain ontologies are helpful in developing domain-dependent federates. Domain-independent federates, such as the calendar federate, weather federate, site condition, and resource allocation federate, are commonly used in different construction domain federations. The federates and federation model objects should be considered and included separately.

In order to step into lower levels of abstraction, we can query the lower layers of industrial construction processes as shown in the following figure (Figure 4-2).



- PIMODES:Activity (9)
- PIMODES:Conceptual_model (1)
- PIMODES:Entity_attribute
- PIMODES:Entity (5)
  - PIMODES:Input_Entity (3)
  - PIMODES:Output_Entity (2)
- PIMODES:Location (8)
- PIMODES:Resource (11)

[Resource]	rdf:type
InCon:Cutting	PIMODES:Activity, InCon:Industrial_Construction_Operation
InCon:Fitting	PIMODES:Activity, InCon:Industrial_Construction_Operation
InCon:Hydro_testing	PIMODES:Activity, InCon:Industrial_Construction_Operation
InCon:Painting	PIMODES:Activity, InCon:Industrial_Construction_Operation
InCon:Position_welding	PIMODES:Activity, InCon:Industrial_Construction_Operation
InCon:Quality_control_checking	PIMODES:Activity, InCon:Industrial_Construction_Operation
InCon:Roll_welding	PIMODES:Activity, InCon:Industrial_Construction_Operation
InCon:Shipping	PIMODES:Activity, InCon:Industrial_Construction_Operation
InCon:Stress_relief	PIMODES:Activity, InCon:Industrial_Construction_Operation

[Resource]	rdf:type
InCon:Fittings	PIMODES:Input_Entity, InCon:Part
InCon:Pipe	PIMODES:Input_Entity, PIMODES:Output_Entity, InCon:Part
InCon:Spool_assembly	PIMODES:Input_Entity, PIMODES:Output_Entity, InCon:Asse...

[Resource]	rdf:type
InCon:Cutting_station	PIMODES:Location, InCon:Station
InCon:Fabrication_shop	PIMODES:Location, InCon:Shop_floor
InCon:Fitting_station	PIMODES:Location, InCon:Station
InCon:Hydro_test_yard	PIMODES:Location, InCon:Bay
InCon:Module_yard_lot	PIMODES:Location, InCon:Lot
InCon:Paint_shop	PIMODES:Location, InCon:Shop_floor
InCon:Position_welding_station	PIMODES:Location, PIMODES:Resource, InCon:Station
InCon:Roll_welding_station	PIMODES:Location, PIMODES:Resource, InCon:Station

[Resource]	rdf:type
InCon:Cutter	PIMODES:Resource, InCon:Worker
InCon:Cutting_machine	PIMODES:Resource, InCon:Tool_resource
InCon:Fitting_weld_positioner	PIMODES:Resource, InCon:Tool_resource
InCon:Handling_resource	PIMODES:Resource, owl:Class
InCon:Labourer	PIMODES:Resource, InCon:Worker
InCon:Pipe_fitter	PIMODES:Resource, InCon:Worker
InCon:Position_welding_station	PIMODES:Location, PIMODES:Resource, InCon:Station
InCon:Quality_control_worker	PIMODES:Resource, InCon:Worker
InCon:Roll_welding_station	PIMODES:Location, PIMODES:Resource, InCon:Station
InCon:Tool_resource	PIMODES:Resource, owl:Class
InCon:Welder	PIMODES:Resource, InCon:Worker

Figure 4-2: The ontological driven simulation components

Ontological-driven modeling guarantees that model behaviour will be consistent at different levels of abstraction. But the benefits of the ontological modeling framework are not limited to this. With the help of ontologies, maintaining object consistency is automatic. The following section discusses extracting the federation's FOM from InCon-Onto.

4-4.2 FOM extraction from industrial construction ontology

FOM specifies a common representation for all the shared objects and interactions between all the federates.

Object Model Template (OMT) is the meta-data and contains the structure of objects, attributes, interactions, and parameters.

As discussed in the previous section, the simulation platform contains multiple heterogeneous ontologies but they have to become linked together to build an industrial construction simulation model. In order to build the connection between modeling representation components with real-world representation, components' semantic roles should be considered (Benjamin et al. 2005). Industrial construction processes are the dynamic core of the model. The federation's object model mainly represents the products and resources whose status is shared and updated by interested federates. InCon-Onto components are linked to their counterparts in FOM ontology (Table 4-1).

Table 4-1: Linking InCon-Onto concepts to FOM components

InCon-Onto Concept	**FOM Corresponding**
Product	Object Class
Resource	Object Class
Product Data-type	Attribute
Resource Data-type	Attribute

Mapping the two ontologies builds a bridge for information transformation from InCon-Onto to the FOM. The transformation mechanism between the two ontologies is built using SPARQL (SPARQL Protocol and RDF Query Language) queries (Scharffe and Fensel 2008).

The main objective is instance transformation for different FOM components, so that a set of instances referring to the source ontology (in this case, InCon-Onto) is transferred into instances belonging to the target ontology (in this case, ontology). In the following example, product instances are transformed to object class instances within the following SPARQL construct statement:

```
CONSTRUCT
 {
? X rdf:type FOM:object Class.
WHERE
?X rdf:type InCon-Onto:Product.
}
```

Adding other SPARQL constructs such as FILTER and UNION allows for more sophisticated queries for information transformation. For instance, we could just include products which belong to a certain process, i.e., only module assembly process products. The mapping outcome is an enriched FOM ontology with related instances from InCon-Onto. As FOM is originally an XML document, the final step would be mapping the FOM Ontology to the FOM XML schema. Figure 4-3 summarizes the entire object instances transformation process.

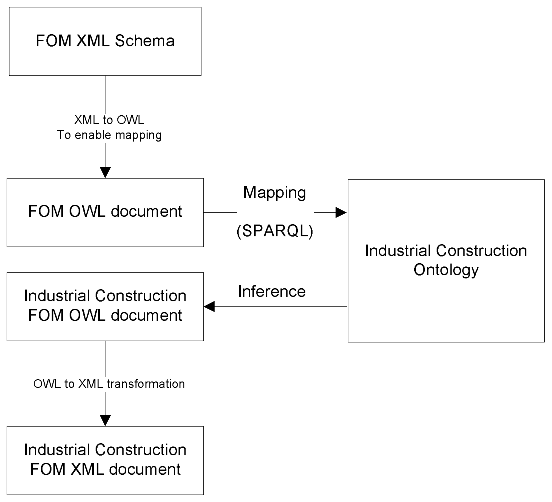

FOM XML Schema
XML to OWL
To enable mapping
FOM OWL document
Mapping
(SPARQL)
Industrial Construction Ontology
Inference
Industrial Construction FOM OWL document
OWL to XML transformation
Industrial Construction FOM XML document

Figure 4-3: Object instances transformation from InCon-Onto to FOM

The discussed method is able to extract all the objects involved in the FOM in the form of queries' results. In order to have the final FOM, the queries' results should be simply put together. But still, that does not mean that the outcome can be used as FOM, as it has no manual interventions, especially regarding data-types. The current adapted OMT in COSYE has a very complicated structure which makes it a challenge to apply it to the FOM ontology. Another part of the FOM which is not covered through this method is that of interactions and parameters. Using interactions has not been popular in the related FOM of different construction federations developed at the University of Alberta Construction Engineering and Management (CEM) group. Table 4-2 shows the statistics of different FOM components in four different federations.

The result of ontology extraction includes all the involved objects and their related attributes, but does not cover the interaction and parameters involved in the FOM.

Table 4-2: The statistics of different FOM components in different federations

Federation	Object/Attribute (1st level)	Object/Attribute (2nd level)	Object/Attribute (3rd level)	Object/Attribute (4th level)	Interaction/ parameter
Industrial construction 1	4/34	4/32	3/8	4/9	4/9
Industrial construction 2	5/34	0/0	0/0	0/0	1/1
Tunnelling	12/34	17/127	15/69	0/0	1/3
Structural steel	5/44	0/0	0/0	0/0	0/0

4-4.3 Developing ontology-based process interaction elements

Regardless of the simulation environment, when the world view is the same, the same concepts are used to represent the models. The same applies to the distributed environment; however, process-interaction code implementations are coupled with communication service constructs, so that they can satisfy distributed and parallel simulation modeling requirements. These federate developments are ad-hoc implementations without a standard framework for facilitating packaging and deployment for reusable piece parts. In the current study we have tried to come up with packaging these piece parts according to the available process interaction ontology introduced before. Table 4-3 shows the formal concepts of process-interaction from PIMODES and the equivalent concepts used in stand-alone simulation software (Simphony) and the construction distributed simulation modeling environment (COSYE).

Table 4-3: Modeling environment process interaction concepts mapping

Organizational Concept	**POMIDES (DES Ontology)**	**Simphony**	**COSYE (newly defined elements)**
Activity Concepts	Creation Activity	New Entity	Register
	Assignment Activity	Set Attribute	Update
	Resource Interaction Activity (Seize/Release)	Capture/Release	Capture/Release
	Delay Activity	Task	Delay
	Branch Activity	Probability Branch	Filter
		Conditional Branch	
	Queue Activity	Waiting file	Waiting file
	Disposition Activity	Delete Entity	Delete
Process Concepts	Entity Type	-	-
	Entity	Entity	Proxy Entity
	Location	Resource	Resource
	Variable	Variable	Variable
	Resource	Resource	Resource
	Entity Attribute	Entity Attribute	Entity Attribute

When a federate presents a model through the process-interaction world view, the model is composed of process interaction concepts coupled with HLA communication and sharing requirements, although not necessarily in the organized way presented in Table 4-3. For instance, for capturing or releasing a resource, the simulation federate not only needs to employ simulation services in order to capture the resource, but before that it should request the resource object instance ownership and then go through the simulation process and at the end divest the object instance ownership so that the object instance can be seized by other components. Reviewing different simulation federates helps to find the set of modeling constructs corresponding to each process interaction concept and find out and document their common description, properties, conditions, and exceptions. This experiment was performed on developed federations. The inclusive code was packaged within elements to be used in federates developed in a visual environment such as Simphony. The following are the set of COSYE elements which have been programmed to serve, at the same time, the process interaction simulation elements and communication requirements of distributed simulation.

4-4.3.1 Description of COSYE-compliant elements

Register: The “Register” element notifies Run Time Infrastructure (RTI) about the “quantity number,” which is the number of object instances (proxy entities) that has been created, and passes it along to the destination element. For the “initial quantity” of entities, the instances of the object class are registered before simulation starts.

Update: The “Update” element is a combination of the update attribute event and delay function; it notifies RTI that the attribute value of an associated object instance has been updated after a delay time.

Reflect: The “Reflect” element is used when other simulation federates need to know the attribute value of an object instance. When the attribute that the federate has subscribed to changes, the RTI sends a notification to the interested federates.

Filter: After receiving the attribute value of an object instance via the "Reflect" element, the modeller is usually interested in a particular attribute value, and the elements with different attribute values will be filtered.

4-5 Distributed Simulation Model of Industrial Construction Processes

The entire process of industrial construction has been modeled as a large-scale and distributed simulation model (AbouRizk et al. 2010). The present model is an enhancement of previous development, with the same model decomposition (Figure 4-4) accompanied by the extracted FOM XML document from FOM Ontology, containing the object classes and attributes shared between simulation federates. The major difference in the federation happened with the spool fabrication federate, which was replaced with the newly developed element-based federate in a visual environment. The new model is built from COSYE-aware elements, customized for the shop fabrication domain. The fabrication shop federate's simulation behaviour is explained in the following section.

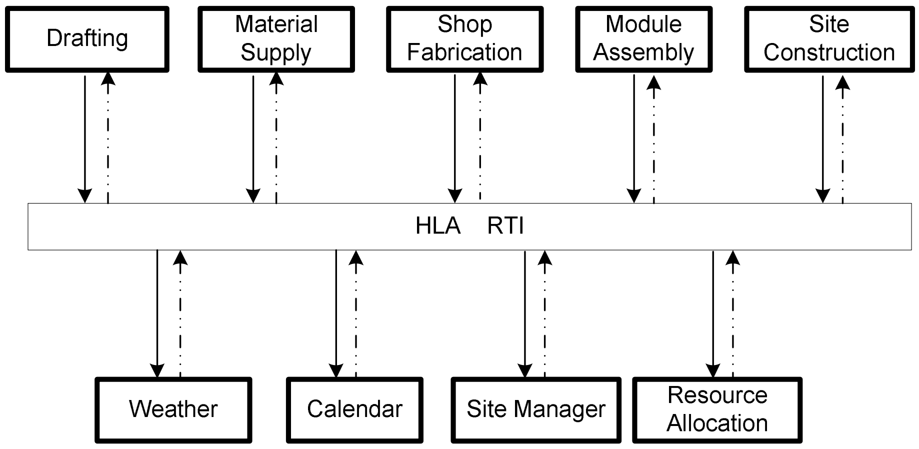


Figure 4-4: Industrial construction federation (AbouRizk et al. 2010)

4- 5.1 Element-based spool fabrication federate

The typical operations of pipe-spool fabrication include cutting, fitting, welding, quality control, stress relief, hydro testing, painting, and other surface finishing. Each spool travels through the entire process changing from raw material to spool components and finally a complete spool. Each spool, with its unique product features, should be traced through the entire process. The complexity of the product/process model can be captured within a Special Purpose Simulation (SPS) modeling environment such as Simphony (AbouRizk and Mohamed 2000). Two such instances of using Simphony are Wang et al.'s use of simulation to support implementation of lean techniques in spool fabrication (Wang et al. 2009) and Sadeghi and Fayek's development of a modeling structure that uses a work breakdown structure of a product model to model the assembly process and predict the potential design bottlenecks (Sadeghi and Fayek 2008).

The fabrication shop federate is based on the production chain as shown in Figure 4-5. A real-world fabrication shop receives the raw material and fittings and fabricates them into spools. The spools are then shipped to a module yard, assembled into modules, and shipped to the construction site for final installation.

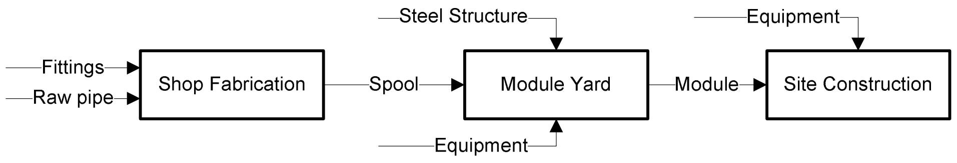


Figure 4-5: Production chain within the industrial construction federation

The industrial construction federation is broken down into federates in such a way that each federate contains the largest possible number of interdependent processes, with minimal dependence on other federates. The spool fabrication federate and module assembly federate are coupled together through messages from module object instances. In order to give the module instances, the ability to flow as a regular simulation entity, and also an object instance, a module carries two identities at the same time: (1) it is a proxy entity that can be transferred to other traditional simulation elements and (2) it is an object instance that can be communicated between different federates. When all the spools belonging to a particular module have been fabricated, they are shipped to the module yard. When other necessary resources are available, module assembly can start. What happens within and between federates is shown in Figure 4-6.

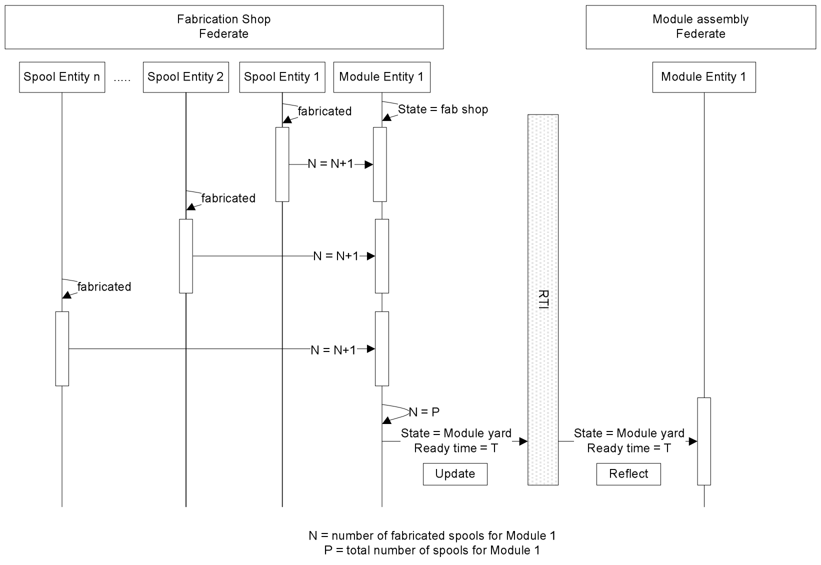


Figure 4-6: Unified Modeling Language (UML) description federates' interaction

The COSYE modeling elements described before feature the most common functions needed to develop a distributed-simulation model within the process-interaction world view. These elements are customized to better serve the simulation of the industrial construction domain by adding additional behaviours. In the following, the fabrication process elements are explained and a spool fabrication federate is developed utilizing these elements. The federate models a scenario of pipe spool fabrication processes (Figure 4-7). The elements' detailed description and their code is attached in Appendix III.

Register Modules by Interval: The Register element registers a quantity number of module entities and passes them along to the destination element. (Module entities are module object instances; the module object class and its attributes are shared between the fabrication shop federate and module assembly federate through the industrial construction FOM.) The first module object instance is registered at time zero, and the subsequent object instance will be registered at a specified time interval.

Update Module Attributes: Through the Update element, the attribute values of module object instances are initialized. In this element, the initial attribute values are assigned to each module object instance. Attributes are as follows:

- Total number of spools (the attribute value is a sample of a triangular distribution).
- Total number of fabricated spools (equal to zero at the start of the simulation process).
- State of module instance (fabrication shop at the start, then module yard followed by site construction).
- Component ready time (the time at which all the spools of a module instance have been fabricated and the module is ready to be assembled).
- Modules assembly priority is used for the fabrication process. All of these attributes can be communicated to other federates that require the information.

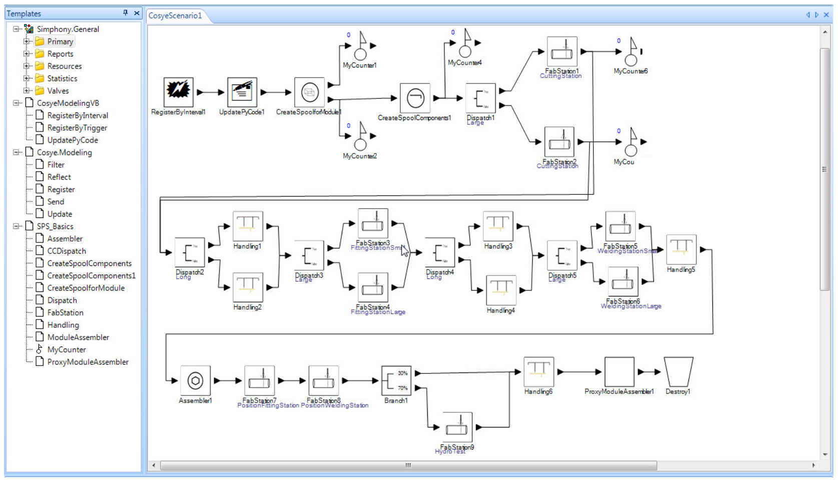


Figure 4-7: Fabrication shop federate developed in Simphony environment using COSYE elements

Reflect: Due to changes in module assembly or field construction, the order of module installation and subsequently the priority of assembling a module might change. In these cases the initial priority is updated in the module assembly federate, which will be updated in the fabrication federate through the Reflect element.

Create Spool for Module, **Create Spool Components**: This element receives the module entity, and for each module creates a corresponding number of spools, including their physical configurations and attributes.

Dispatch: This element sends the entities to the appropriate destination element, based on the entity's properties.

Fabrication Station: This represents any type of work station that material or spool components go through during the fabrication process. The processes are cutting, roll and position fitting, roll and fixed welding, and quality control and hydro test. Entities are sent to different stations based on their properties, even when the process is the same. For instance, spool components with a different diameter size (small, intermediate, large) will each go to a different fitting station.

Handling: This element models the handling process in fabrication, either between work stations and lie-down areas or out of the fabrication shop. The element supports two types of handling: manual or crane.

Assembler: This element keeps track of spool components; it collects from one spool all the components that have gone through roll fitting and welding and sends the spool to the final stage of assembly.

Modules Assembler: The function of this element is similar to the assembler element, but operates for spools that belong to the same module. When all the spools of one module are available, this element updates and sends the module attributes to the RTI for the module assembly federate to use.

From composition of instances of these elements, spool fabrication federate is built. The federate serves as one of the simulation federates of the entire industrial construction federation.

4-6 Discussion on Component-based Industrial Construction Distributed model

Assembling simulation models from reusable elements brings more flexibility, ease and, more importantly, reusability to developing large-scale distributed simulation models. Here are more specific outcomes of this approach:

Component-based simulation modeling has generally known advantages. Such as:

- It allows for building a complex simulation model from aggregating reusable elements.
- It makes understanding a model easier, even for non-modellers
- It facilitates verification and validation of the model through element unit testing

Increased reusability scope in the distributed simulation modeling environments: At the simulation level, traditionally each federate is regarded as an atomic object and its reuse within the federates is not taken into consideration. Within our approach federates are built from reusable components which speeds up their development and makes it more structured.

4-7 Summary and Conclusion

This chapter described an ontology-driven framework for developing distributed simulation modeling of construction processes. The use of an ontological modeling framework has been shown through mapping different ontological components with process modeling concepts, which provide effective yet simple rules for sharing information between simulation ontological components. This technique is used to extract the needed information from the construction process ontology into simulation representation components. Another use of ontologies is discussed through element identification for an element-based environment within a distributed environment. In both of these cases, reusing existing information and modeling elements within the distributed simulation modeling environment leads to enhanced reusability, which results in a more efficient development process and provides a more sustainable mechanism for developing distributed construction simulation models.

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Chapter 5

A Semantic Approach to Representation, Sharing and Discovery of Construction Simulation Models

1 Parts of Chapter 5 has been submitted to Construction 2012 Research Congress

5-1 Introduction

Simulation modeling is an effective tool for analyzing construction operations and supporting the decision-making process (Halpin et al. 2003). Simulation model development consumes lots of time and resources. The models are the result of extensive knowledge acquisition in different domains: knowledge of construction, and simulation modeling techniques and tools. When the model is used for its initial intention, its reuse is not straightforward, mostly because the process of finding the appropriate modelling components for reuse has not yet been addressed (Aronson and Bose 1999, Chreyh and Wainer 2009). This problem can be traced back to the accessibility and availability of models and their content (e.g., simulation components and their behaviour) for simulation, which so far has not been addressed, especially in the construction domain.

With internet technology advances, simulation models can be shared in repositories and distributed over the web, while with efficient web discovery services, the knowledge residing within them can be extracted. This advancement has not yet been introduced to the construction industry. In order to share construction simulation models and facilitate meaningful discovery on the Web, simulation models including model features and model behaviour must be represented in an appropriate format, one that the semantic web can process. Sharing and discovering simulation models is richer when the models are properly linked to other useful and relevant sources of information (e.g., maps, different documents and spread sheets, drawings, images, video and audio files).

The innovative architecture presented in this chapter blends semantic web technologies and construction simulation models presented in machine interpretable metadata for storing, sharing, and discovering construction simulation models and properly linking them to their related information sources. This environment utilizes semantic web technology which has been used for resolving similar challenges such as reusability, composability, and interoperability of resources within the WWW. The goal is to adapt such techniques into the construction simulation world.

The next section presents a brief background about the use of semantic web and its use in simulation. This is followed by our methodology to apply semantic web techniques and technology in construction simulation modeling. Afterwards, the main research efforts are presented, including a semantic representation of simulation models with the aim of easy discovery and reuse of simulation model components. We also introduce a semantic web-based environment which supports storage of simulation models and knowledge extraction and discovery. Then the prototype is presented and, finally, the summary and future works are discussed.

5-2 Semantic Web

The semantic web is revolutionizing the World Wide Web. It describes methods and technologies to allow machines to understand the meaning or "semantics" of information on the WWW. The traditional web is just about displaying information. It lacks the semantics underpinning for meaningful sharing and discovery of resources. Data, information, and knowledge-sharing are more prolific on the semantic web because they can be linked to relevant sources across the web.

The semantic web is a network of data described and linked in ways to establish content or semantics, which enables machines to be able to interpret the data and act upon the web content. This enables more efficient searching, sharing, and information combinations.

The semantic web consists of different types of statements that allow for the formation of rich expressions, and also for simplified integration and sharing, enabling inference, and extraction of meaningful information. The semantic web content is made up of resources which are linked through relationships.

The languages and technologies that comprise the semantic web are shown in semantic web stack (Figure 5-1). The bottom layer contains foundation technologies of the hypertext web, which are also the basis for the semantic web; Unicode, Uniform Resource Identifier (URI), and XML are technologies used for character encoding, resource indexing, and syntax for data serialization. RDF, RDF Schema (RDF-S), OWL, SPARQL, and Semantic Web Rule Language (SWRL) are standardized technologies used for enabling semantic web applications, including functions for description, rule setting, and querying.

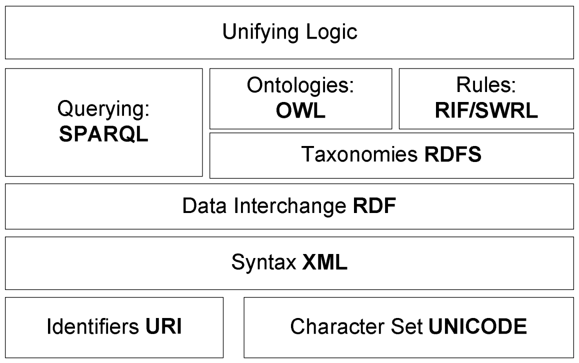


Figure 5-1: Semantic Web Stack (adapted from w3.org)

5-2.1 Semantic web languages: XML

Unlike standard text files or HTML web pages, eXtensible Markup Language (XML) is not only about a form of display, it also contains content representation encoding.

XML is a simple but flexible mark-up language. An XML document contains mark-up and content, where mark-up is the means to add structure and syntax to the data by allowing users to create their own tags. Within XML, elements are data containers which may contain nested elements. Furthermore, elements can include an attribute, which is an explanation about the element content.

The fact that the user is able to create her own data structure makes the language flexible, but the structure is still not machine interpretable and is easily prone to errors. That is solved by another document called schema, which is the description of the XML structure within a set of rules to which an XML document must conform in order to be considered valid according to that schema.

The structured data through XML tags can be employed to exchange data across information systems that may had been built upon different platforms.

5-2.2 Semantic web languages: RDF

XML is used for structuring information, while RDF is used for conceptually describing or modeling the information. RDF (Resource Description Framework) accepted by World Wide Web Consortium (W3C) to standardize information stored on the Web. RDF uses a labelled graph data format for representing information on the Web.

The RDF statements, consisting of triples (subject, predicate, object), form graphs and the nodes, represent either the subject, object, or predicate. Where the subject refers to the resource and can be represented by a Uniform Resource Identifier (URI), the predicate refers to the resource's features or characteristics and expresses the relationship between the resource and the object. Finally, the object is a resource or a string.

RDF-S is an extension to RDF to support the expression of structured information. It provides an ontology representation language which has been widely used.

5-2.3 Semantic web languages: OWL

OWL builds upon RDF-S and provides greater expressivity in the description of concepts and relationships. The OWL expressiveness allows different domain knowledge modeling, (i.e., ontologies). Ontologies provide formal methods for describing the concepts, categories, and relationships within a domain (McGuinness and Harmelen 2004). OWL supports expressing cardinalities, hierarchical properties, and capabilities of properties (e.g., transitive, symmetric). It has three versions with different expressivity: OWL-Lite, OWL-DL and OWL-Full.

5-2.4 Semantic web languages: RDF Query Language (SPARQL)

SPARQL is a declarative language that the W3C recommends for extracting information from RDF graphs using queries across diverse data sources.

SPARQL has four query forms: SELECT, CONSTRUCT, ASK, and DESCRIBE. These query forms use pattern matching to form result sets or RDF graphs. SELECT returns matching triples with the query. CONSTRUCT returns an RDF graph. ASK returns a Boolean indicating whether a query pattern matches or not, and DESCRIBE returns an RDF graph that describes the found resources. Result sets can also be serialized into either XML or RDF.

5-3 Related Work

The semantic web brings with it new ways of thinking about modeling and new methods and tools (Taylor 2011). The following are some of the instances of use of semantic web techniques and technologies in simulation and modeling.

Ontologies have been proposed to represent knowledge about simulation modeling domains. The first simulation ontology is Discrete Event Model Ontology (DeMO) which is a comprehensive Discrete Event Simulation (DES) ontology containing templates which capture knowledge of different simulation world views such as activity-oriented, event-oriented, state-oriented and process-oriented (Fishwick and Miller 2004). This ontology is a suitable resource for obtaining a comprehensive understanding of DES.

The Process Interaction Modeling Ontology for Discrete Event Simulations (PIMODES) is another simulation ontology by Lacy (2005b, 2005c), which is built specifically for the process interaction world view, a popular paradigm for representing DES. PIMODES is heavily influenced by popular software packages such as Arena, AnyLogic, and ProModel. This makes it easy to connect PIMODES to software packages. PIMODES can be used for an ontology-based representation of models which facilitates the interchange of simulation models between different simulation packages. Sliver et. al (2007) suggested a technique to establish links between domain ontologies and simulation ontologies and use these relationships to instantiate a simulation model. Lozano et. al (2009) presented a semantic approach to simulation component identification and discovery. They used Simulation Reference Mark-up Language (SRML) documents to search through a simulation repository of Base Object Models (BOM). BOM is a Simulation Interoperability Standards Organization (SISO) standard for conceptual modeling documentation. It provides a formal way to capture and share conceptual simulation documentation (Gustavson 1998). Moradi et al. have investigated ontological BOM discovery and composition for building new models (Moradi et al. 2007). Fishwick recently proposed hypermodeling, the general theory and practice of linking system models and their components (2011).

One of few efforts in the construction domain towards using web services has been made by Halpin et. al (2003). They have used web-based simulation modeling for simplified access to a construction simulation modeling tool, providing different levels of interface for people at different levels of simulation and domain knowledge. However, this work certainly does not seek to take advantage of the semantic web.

Within this chapter, the goal is to borrow semantic web techniques and technology and apply them to construction simulation modeling. Within this adaptation, a new representation is given to simulation models through the use of semantic mark-up languages. Using query capabilities of semantic mark-up languages, the knowledge and information within simulation models can be retrieved and processed. Within the proposed representation, the simulation models and their components can become connected to relevant and useful sources of data and information on the web. The semantic web technology brings other advantages regarding reusability, composability, and interoperability to construction simulation models, which are discussed later in the chapter.

5-4 Adaptation of Semantic Web into Construction Simulation Modeling

Adapting semantic web techniques and technologies has significant effects on modeling, discovery, composition, interoperability and reuse of simulation models. In order to be able to apply these techniques to existing construction engineering simulation models developed in conventional construction simulation modeling tools, some pre-work on models is needed, as follows:

1- Model representation: Any storing, sharing, and discovery in the semantic web is highly dependent on the model's structure and encoding. As mentioned before, information encoded within semantic mark-up languages such as XML, RDF, or OWL is semantic web readable. The coming section explains how the XML text view of models developed in Simphony (A special purpose simulation modeling tool) is used as the basis for the semantic representation of simulation models of construction operations.
2- Model content: The acquired models need enhancement both in representation and content. The XML text view of models contains a full description of the modeling elements and their input and output properties, along with the relationships within the elements. But it does not provide essential big picture information about the model. This information is important for sharing and discovery purposes and is added to the model through a separate section in the XML model description, the model "profile."
3- Linking the relevant sources of data and information: An important aspect of the semantic web is proper linking to relevant information. Simulation models are always built based on vast amounts of knowledge coming from conceptual models and documents containing input data. The sources are included in the repository through linking them to the model. The linking is cited in the added "profile" section.
4- Outcomes of semantic web adaptation in construction simulation modeling encompass a wide range of enhancement in reusability, composability, and interoperability. Tangible examples of knowledge extraction through SPARQL queries are discussed later.

5-4.1 Simulation modeling representation

Documenting simulation models with the aim of easy discovery and reuse requires well-arranged structured and formalized simulation model representation. Three simulation views are available for a simulation model:

- Graphical view, which is generated by a Graphical User Interface (GUI) and is the most convenient view for the end user.
- Code view: The behaviour of simulation elements is customized through writing code in visual basic or C#.
- XML text view: Provides the experimental frame of the model, including textual description of elements along with input and output results in Extensible Mark-up Language (XML). This view has been provided to facilitate data-storage in simulation modeling tools and at the same time it provides a human-legible format of data and meta-data of simulation models.

None of these views has been formatted towards proper sharing and discovery of knowledge about models and their components. Considering that our primary goal is to use existing resources instead of creating and suggesting a completely new model representation for the purpose of proper sharing and discovery, the XML view has been the best candidate for semantic representation of simulation models. It can be used as the starting point and enhanced to a higher level for richer semantic representation.

The approach taken in this chapter is to use the existing textual XML format, which is easily storable and readable, and with minor changes and add-ons show its potential for the purpose of meaningful sharing and model discovery. Hence, the changes should be applied towards the simulation document's content and format.

At first general information about model, which are missing but are vital for discovery, should be added to the model, this part is done through different profiles. Moreover meaningful tags and relationships should be added to the models and their syntax should be transformed XML to more sophisticated semantic web languages such as RDF and OWL, which are used for semantic web development.

In the following Simphony (Hajjar and AbouRizk 1999), the used simulation modeling tool, with emphasis on its XML representation is introduced. Then the suggested semantic enrichment and formatting changes are discussed in order to prepare the representation for sharing and discovery purposes. Finally, the discovery process is presented.

5-4.1.1 Simphony

Simphony is a simulation platform for building construction domain templates and models. Similar to most of process simulation tools, Simphony employs a common three layer architecture. The first layer is the Graphical User Interface (GUI), the second provides process simulation domain objects, and the third provides the simulation services containing the simulation engine, storage, and communication.

The main layer which the simulation developer is dealing with contains GUI and the simulation elements. A simulation model built in Simphony is composed of a number of instances of modeling elements that tbe modeller drags from the modeling element library into the modeling layout. The modeller then links them together in order to build the relationships. Each of these modeling elements has its own behaviour that produces different events through input and output and statistics variables. The elements are members of templates which are collections of elements serving the same construction domain. The model XML document contains brief information about the model and the templates used in building the model. Then it contains the list of elements <Elements> taking part in the simulation model along with their attributes and graphical representation information. At the end, it provides information about the interconnection between the elements <Relationship>. Figure 5-2 summarizes the model's specifications. These specifications can be stored in XML format. The XML view of the model provides a neutral and implementation-independent version of the model in human and machine readable format, which has the potential to be exchanged between applications. Simphony can provide the XML view of the simulation model; however the schema has not been developed with interoperability purposes in mind. But still, the XML representation has been used as the starting point of developing the formal ontology of Simphony models with some modifications and add-ons to the document.

The first stage of modifications is minor document clean up, because the model's XML document is the result of model execution; it contains details which are least important for knowledge search and discovery within models.

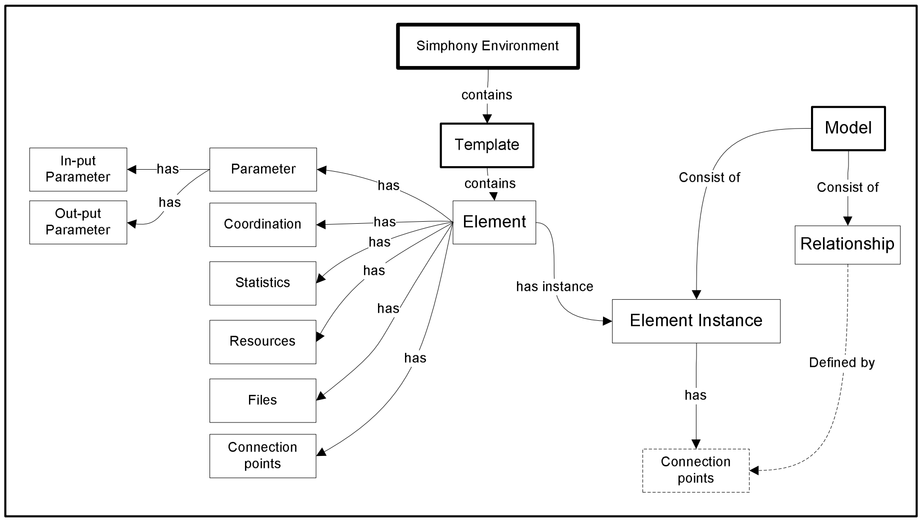


Figure 5-2: Simphony Model Representation

General and specific information about the model should be added to simulation models, mainly because the information provides a unique description for each simulation model. This distinguishes them from other simulation models and also more semantic weight to simulation models.

In the following section, the suggested semantic enrichment of the simulation document is explained.

5-4.2 Semantic enrichment of construction simulation models (modeling content and proper linking)

BOMs are the only form of structured modeling documentation developed by the military simulation community. Modeling documentation has been investigated in the military domain more than in any other domains, because military simulations are often large-scale models and this makes structured documentation more crucial (Robinson 2006).

As the only reference for modeling documentation, the BOM documentation process has been investigated. BOM documentation is used for conceptual modeling documentation. It is carried forward as simulation components through the development process. The first step is discovering the patterns within the processes and leveraging them into BOM meta-data. The events and entities are mapped to the interface describing the specific class structures (Gustavson and Chase 2007). The meta-data consist of the identification model, conceptual model definition, modeling mapping, and object modeling definition. General information about each component is stored in model identification and the rest of model is conceptual model representation through capturing the patterns of interplay within the domain. In construction modeling, the pattern of process is usually expressed through process modeling (Figure 5-3).

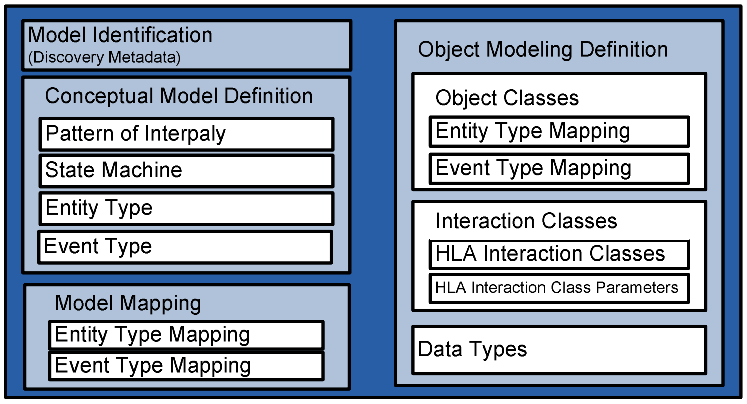


Figure 5-3: The BOM structure (adapted from BOM standard, 2006)

Within our approach we have tried to enhance the existing simulation textual documentation with insight from BOMs without discarding the existing Simphony documentation. The XML text view of models heavily documents the graphical representation of model and also modeling elements and their input and output parameters and relationships, but nothing about their simulation role. For instance, in a simulation document through the XML tag, a particular simulation component is identified as a simulation element but there are no tags regarding the content of the element if the element is presenting a process, resource or product. That is because the simulation application has another component which has remained untouched in the current simulation documentation. This part is the simulation world view which provides the means to model the domain knowledge within process-oriented concepts. The current research tries to briefly introduce this component to simulation documentation.

In the construction, application processes are usually modeled based on the process-oriented world view. Through many developed models that world view has demonstrated that it is capable of representing construction operations (Figure 5-4).

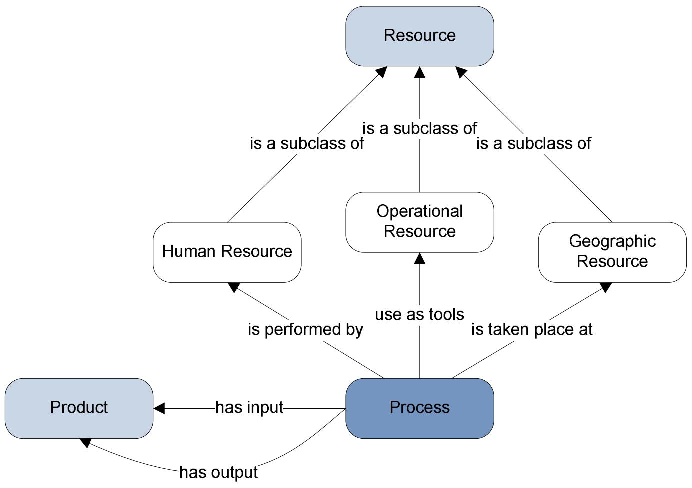


Figure 5-4: Process Modeling of Construction Processes

As an initial attempt to add semantic content to the model, the main process-oriented concepts including Process, Product, and Resource (PPR tagging) are added to the model. The tags give more expressiveness to the model and they can simply get linked to other process-oriented applications. More importantly, the model can be compared to ontologies of the domain-conceptual model. Linkage to conceptual models can bring to model composition and interoperability new opportunities, such as comparison and verification with other sources. These are discussed later.

5-4.2.1 Adding new content to simulation models through model profiles

According to standard modeling documentation, model identification is an essential component. The information includes what the modeling component simulates, how it has been used, and descriptions aiming towards helping users to find and reuse the model. Other information such as intended application domain, the component's purpose, use history, and use limitation are parts of the meta-data. The profile also includes references to other documents (e.g., an OWL document).

The current Simphony documentation has a few components such as the name of the simulation model and the required templates in the model. But following BOM, more profile information is indispensable for sharing and efficient search and discovery.

A Profile is a descriptor of the simulation model which gives the simulation model's brief individual identity and facilitates model discovery. The simulation profile has three main categories: General profile, Descriptive Profile and Implementation Profile (Table 5-1).

Table 5-1: Profile of Simulation Model Documentation

Profile	**Purpose**
General Profile	Basic identification information
Descriptive Profile	More specific information
Implementation profile	Related to implementation of the model

The "General Profile" components capture basic identification information about a simulation model, including the name which is assigned to the model, the model developer's name, and the simulation model's modification date and version (Table 5- 2).

Table 5-2: General Profile Descriptors

Profile component	Profile component	Description
General Profile	Name of Model	Name assigned to the model
	Model Developer	Name of developer & contact information
	Modification Date	Date of modification
	Version	Version of the model

The "Descriptive Profile" component provides more specific information about the simulation model. The model's application domain is specified and more detailed specifications, such as the client or modeling case, are provided. Finally, the ontologies related to the model are stated (Table 5- 3).

Table 5-3: Descriptive Profile Descriptors

Profile component	Profile component	Description
Descriptive Profile	Application Domain	Which construction operation the model is presenting, for example spool fabrication.
	Description	A brief description of modeling purpose.
	Ontologies	Ontolgies related to the model.

The "Implementation Profile" component provides information related to implementing the simulation model. A few components are about the version of the simulation tool (Simphony) and the rest present the simulation model or XML document URI and the model's location. In Simphony, multiple templates can be used for developing one model. The required template component provides the link to those sources. Another thing is that in most simulation models, the data comes from a database. In document dependencies, the location of those documents is provided. Finally, if there are any software dependencies for model implementation is specified at the end (Table 5- 4).

Table 5-4: Implementation Profile Descriptors

Profile component	Profile component	Description
	About Simulation tool	Software version and built.
	Security classification	Simulation content restrictions (0-5 rating).
	URIs	The URI where simulation model XML document can be located for use.

Implementation Profile	Location of the source model	Name of developer & contact information
	Required templates	The templates which the model is dependent on.
	Document dependencies	The documents which the simulation model is dependent for execution.
	Software dependencies	The software dependencies.

5-4.3 XML to RDF/OWL transformation

The XML to OWL transformation is implemented to make the simulation models processable by semantic web tools and techniques. This is done through a basic mapping between simulation models meta-data to the model ontology. As shown in the following Table 5-5, the XML element is mapped to OWL class, XML attributes to RDF/OWL data-type property, element instance to instance of the created class and the only relationship expressed in XML is parent-child relationship is mapped to an object property.

Table 5-5: XML Document Transformation into RDF/OWL

XML model representation	**Model ontology representation**
Element/tag name	OWL class
Attribute	OWL data-type property
Element instance	Instance of created class
Parent-child relationship	OWL Object property

After the XML to OWL transformation, simulation models and templates are imported to the repository as RDF/OWL files. Owl:import is the basic primitive for reusing ontologies. The imported ontology is not a "copy-and-paste" of the original ontology and any changes in the import environment are reflected into the original one and vice-versa. An Example these models, is presented in Appendix IV.

5-4.4 Repository of models

The construction modeling repository mainly contains simulation templates and models and other relevant sources (Figure 5-5). Simulation templates contain a collection of elements

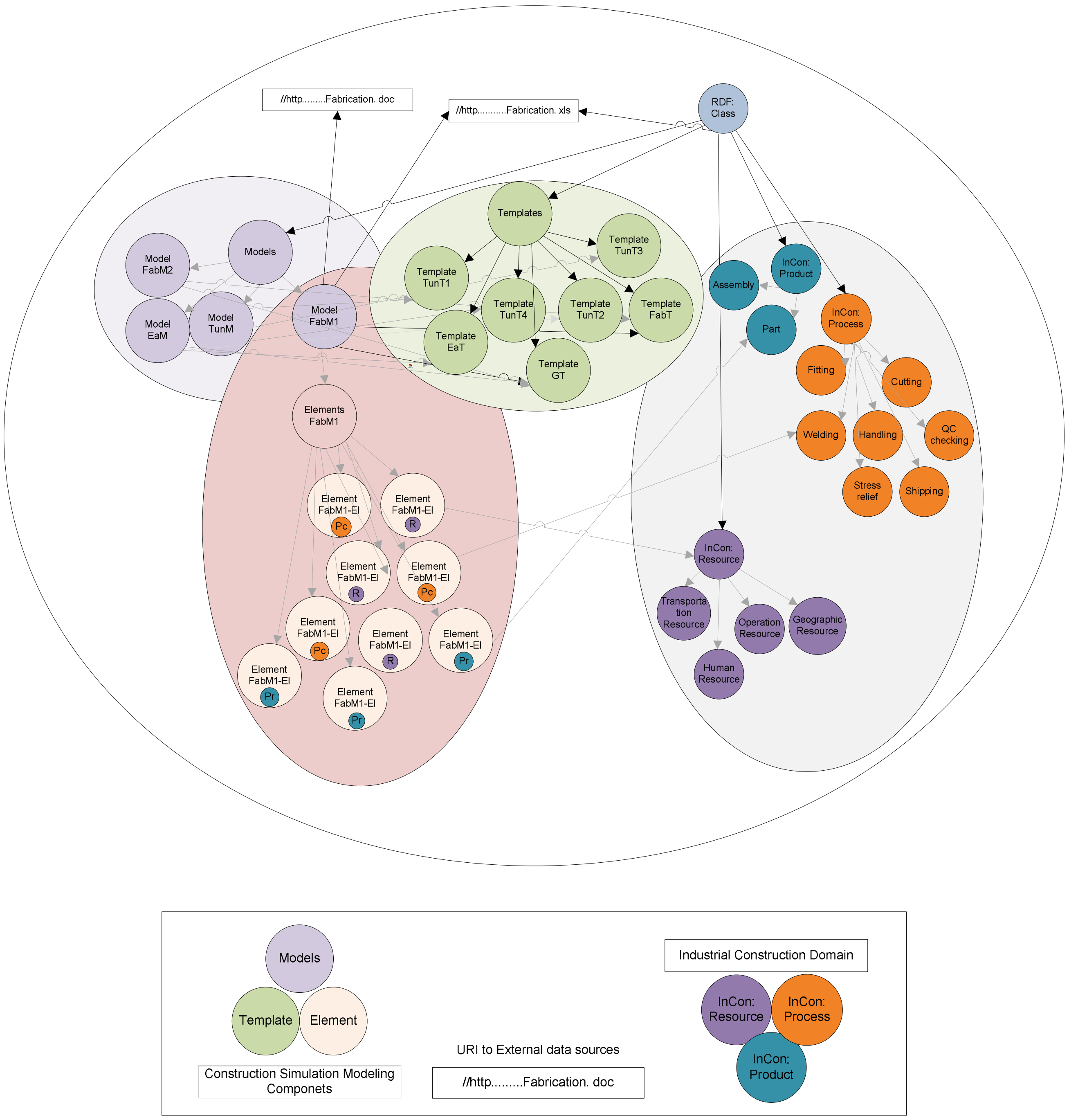


Figure 5-5: Linking between simulation model components and other relevant sources

serving a particular construction simulation domain. The simulation templates' description consists of two parts: the template profile and belonging elements. Simulation models, on other hand, are composed of modeling element instances which can be created from different templates. Their description contains three parts: model profile; participating elements along with their different parameters such as input and output parameter, and statistics and their corresponding values; and the relationships between the elements. All these components reside in the repository. Sharing and integrating them makes it possible to infer and extract meaningful information through structuring queries. The discovery process focuses on three main areas:

1- Content of simulation models: Accessing the simulation models and their content is inevitably important regarding both the use and reuse of models. The modeling content, such as simulation components and their properties and relationships taking place in the simulation model, can be dug out through the semantic web without the need for any other application. The queries can be quantitative or qualitative.

2- Related sources of information: inquiring about other sources of information (e.g., domain ontologies, documents, spread sheet, videos) is possible through the cited links within the simulation models.

3- Model interoperability with other sources: Accessing other sources is not just limited to their URI, but can be extended to their content. This opens up new means for model comparison and verification. For example, the semantics of the model can be verified with the domain ontologies' content.

Figure 5-6 summarizes the entire process of semantic representation and discovery of simulation models.

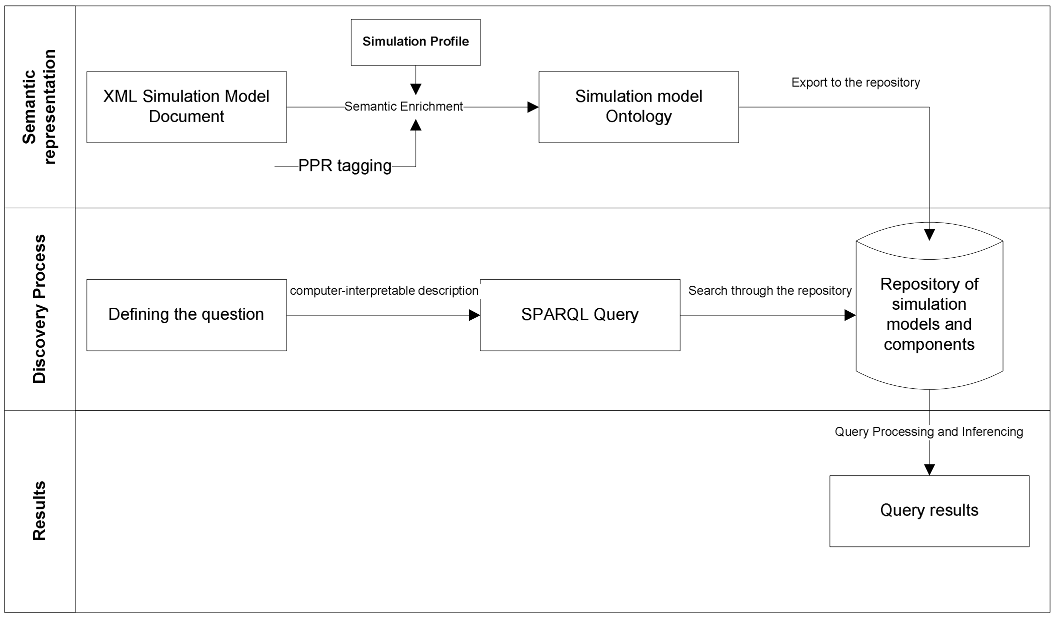

Semantic representation
Simulation Profile
XML Simulation Model Document
Semantic Enrichment
Simulation model Ontology
Export to the repository
PPR tagging
Discovery Process
Defining the question
computer-interpretable description
SPARQL Query
Search through the repository
Repository of simulation models and components
Query Processing and Inferencing
Results
Query results

Figure 5-6: Representation and discovery process of simulation models

5-4.5 Semantic repository for construction operations simulation modeling

The prototype repository of construction simulation models has been developed in order to evaluate the discovery environment's usability and performance. The simulation models are stored within ontologies using RDF and OWL syntax and accessed through SPARQL queries. The prototype repository, as shown in the following figures, contains 7 templates and 4 models.. The repository has been built using TopBraid Composer (TBC) (2010) and Protégé (2006) tools. Figure 5-7 to 5-10 represent different repository members in TBC.

Figure 5-7 shows different templates which are imported to the repository, Figure 5-8 depicts different components of a simulation element (PipeWorkStation) from an instance of spool fabrication model built from spool fabrication template. As it is shown the PipeWorlStation element is an instance of class element and has related inputs, outputs, files and statistics.

Figure 5-9 shows different elements of earth moving template. Figure 5-10 shows the repository before and after importing a model into it. In 5-10-1 different modeling classes are shown and in 5-10-2 different modeling classes are instantiated with tunneling model components.

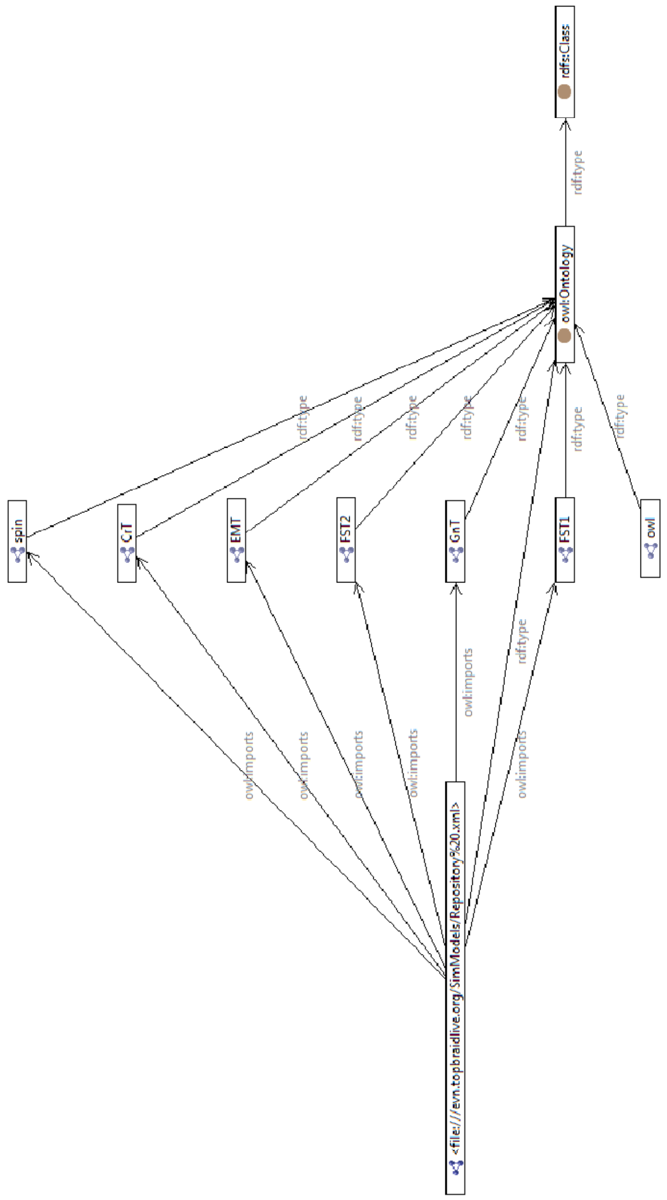


Figure 5-7: RDF graph representing the templates in the repository

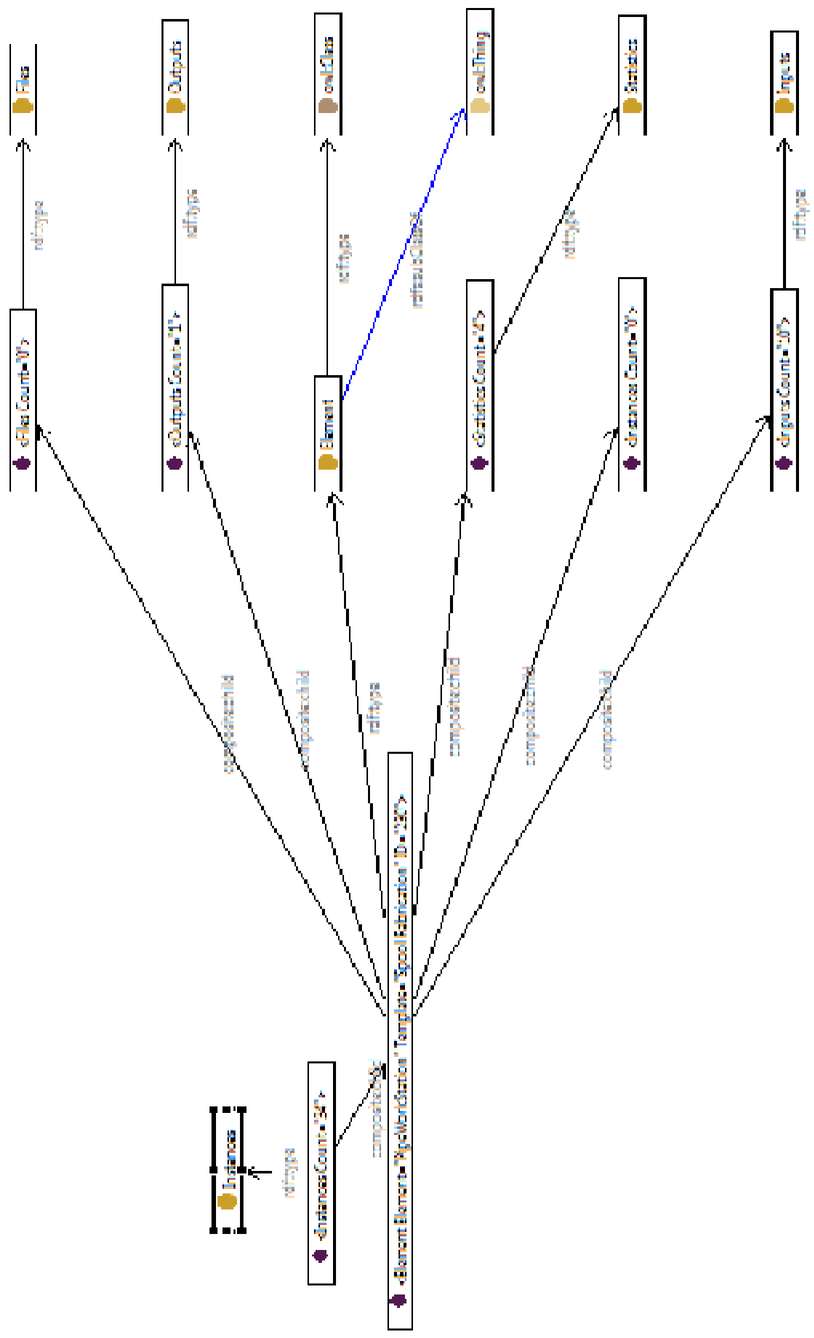


Figure 5-8: RDF graph of spool fabrication model components

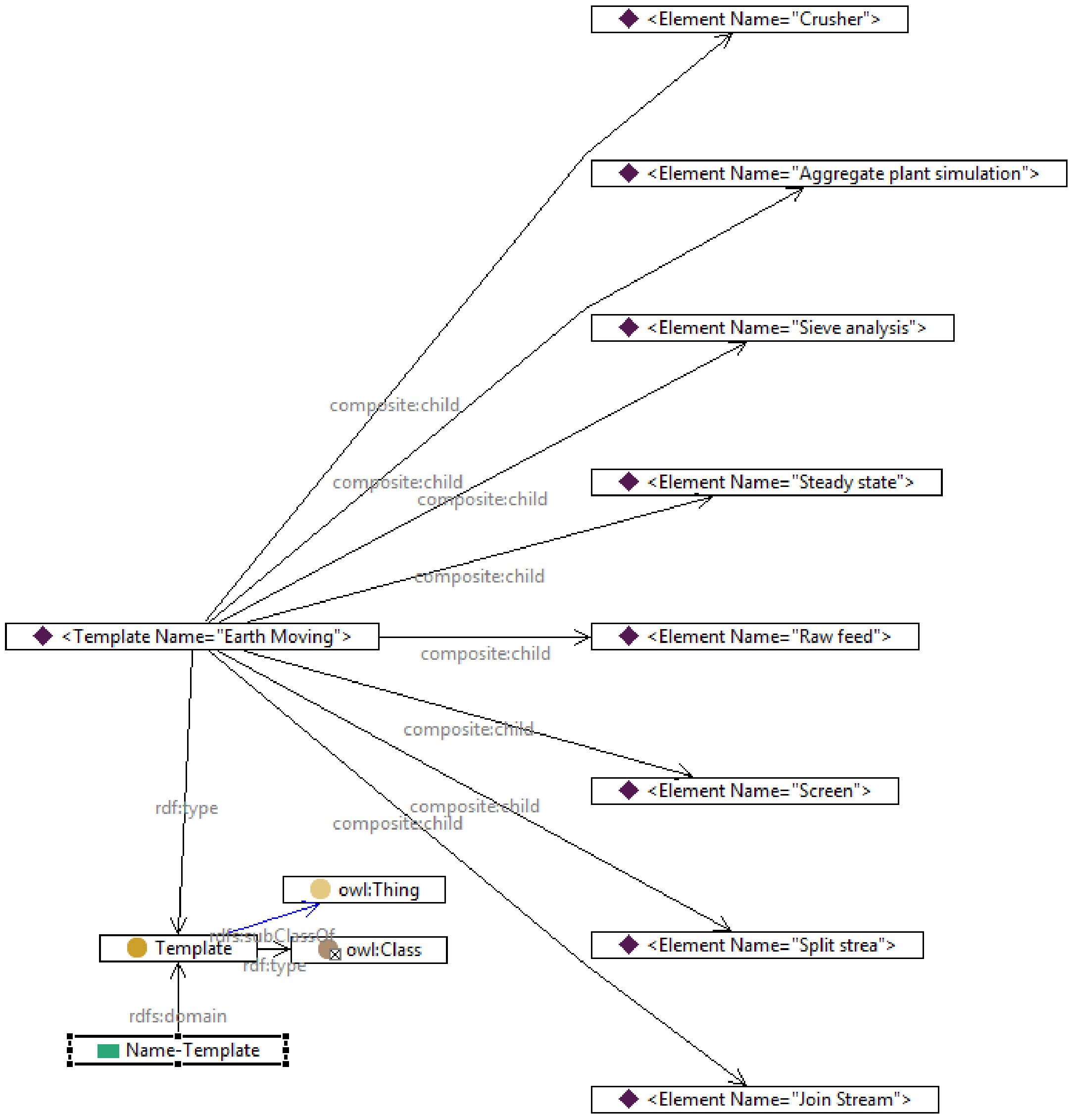
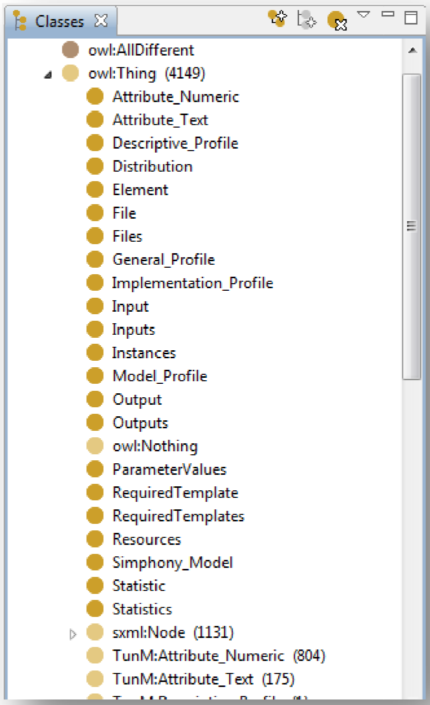
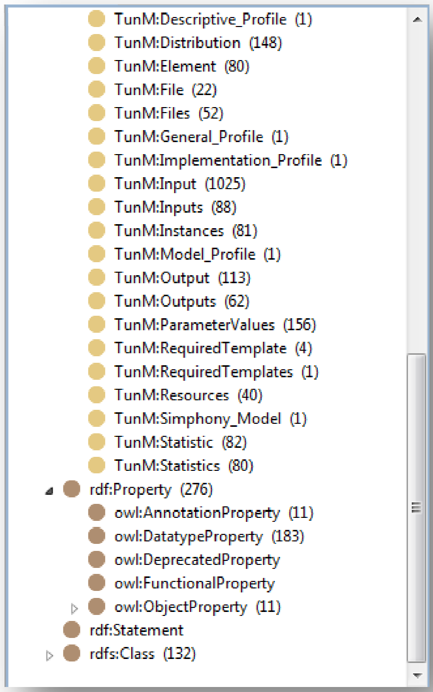

<Element Name="Crusher">
<Element Name="Aggregate plant simulation">
<Element Name="Sieve analysis">
<Element Name="Steady state">
<Template Name="Earth Moving">
<Element Name="Raw feed">
<Element Name="Screen">
<Element Name="Split strea">
<Element Name="Join Stream">
composite:child
rdf:type
owl:Thing
Template
owl:Class
rdfs:subClassOf
rdfs:domain
Name-Template

Figure 5-9: RDF graph of earth moving elements



```
   owl:AllDifferent
◢  owl:Thing  (4149)
     Attribute_Numeric
     Attribute_Text
     Descriptive_Profile
     Distribution
     Element
     File
     Files
     General_Profile
     Implementation_Profile
     Input
     Inputs
     Instances
     Model_Profile
     Output
     Outputs
     owl:Nothing
     ParameterValues
     RequiredTemplate
     RequiredTemplates
     Resources
     Simphony_Model
     Statistic
     Statistics
  ▷  sxml:Node  (1131)
     TunM:Attribute_Numeric  (804)
     TunM:Attribute_Text  (175)
```

(1)Modeling Class

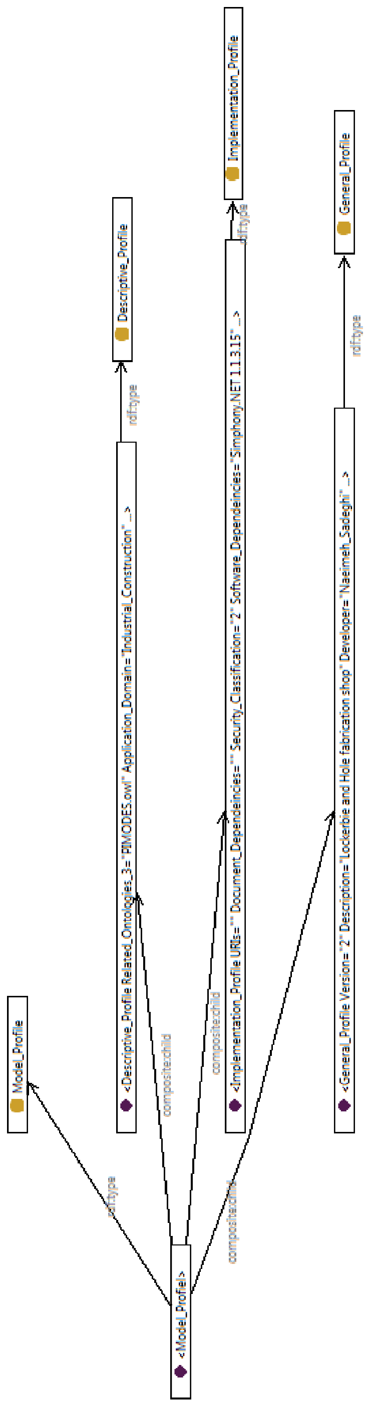


```
     TunM:Descriptive_Profile  (1)
     TunM:Distribution  (148)
     TunM:Element  (80)
     TunM:File  (22)
     TunM:Files  (52)
     TunM:General_Profile  (1)
     TunM:Implementation_Profile  (1)
     TunM:Input  (1025)
     TunM:Inputs  (88)
     TunM:Instances  (81)
     TunM:Model_Profile  (1)
     TunM:Output  (113)
     TunM:Outputs  (62)
     TunM:ParameterValues  (156)
     TunM:RequiredTemplate  (4)
     TunM:RequiredTemplates  (1)
     TunM:Resources  (40)
     TunM:Simphony_Model  (1)
     TunM:Statistic  (82)
     TunM:Statistics  (80)
◢  rdf:Property  (276)
     owl:AnnotationProperty  (11)
     owl:DatatypeProperty  (183)
     owl:DeprecatedProperty
     owl:FunctionalProperty
  ▷  owl:ObjectProperty  (11)
   rdf:Statement
▷  rdfs:Class  (132)
```

(2)Class instances for tunneling model

Figure 5-10: Snapshot of repository

Figure 5-11 presents the RDF graph for spool fabrication model profile. As it is shown it contains different components of model profile such as general, descriptive and implementation profile and the values for the specific example.



<Model_Profile>
rdf:type
Model_Profile
composite:child
<Descriptive_Profile Related_Ontologies_3="PIMODES.owl" Application_Domain="Industrial_Construction" ...>
rdf:type
Descriptive_Profile
composite:child
<Implementation_Profile URIs="" Document_Dependeincies="" Security_Classification="2" Software_Dependeincies="Simphony.NET 1.1.3.15" ...>
rdf:type
Implementation_Profile
composite:child
<General_Profile Version="2" Description="Lockerbie and Hole fabrication shop" Developer="Naeimeh_Sadeghi" ...>
rdf:type
General_Profile

Figure 5-11: RDF graph of Models' profile

Table 5-6 contains some statistics on the repository and its different components. The repository contains 7 templates and 4 models with the total number of 7995 RDF resources.

Table 5- 6: Construction Repository Statistics

Item Number	Name of Resource	Type of resource (model or template)	Namespace	Total number of resources (rdfs:Resource)	Number of (owl:thing)	Number of (owl:DatatypeProperty)
	Repository			7995	7042	327
1	Tunnelling_Model	Model	TunM	4457	4148	101
2	Tunnelling_Template_ Shaft_Construction	Template	TunT1	297	68	30
3	Tunnelling_Template _Support	Template	TunT2	305	74	31
4	Tunnelling_Template_ Tunnel	Template	TunT3	481	244	38
5	Tunnelling_Template_Weather_Generation	Template	TunT4	261	32	30
6	Earthmoving_Model	Model	EaM	356	109	41
7	Earthmoving_Template	Template	EaT	317	93	26
8	General_Template	Template	GT	447	212	32
9	Spool_Fabrication_Template	Template	FabT	321	95	27
10	Spool_Fabrication_Model_M1	Model	FabM1	1378	1125	43
11	Spool_Fabrication_Model_M2	Model	FabM2	1155	902	43
12	Related Documents	Documents	-	5	-	-

In order to write queries, it is beneficial to be aware of the overall meta-data of the ontology; however, despite regular query languages the queries could be written meta-data oblivious. In this type of query, multiple variables are allowed in one query and the returned results are based on the restrictions specified in the query. The logic behind this is that SPARQL is an RDF query language. RDF documents are constructed based on triples. As long as the variables are linked with each other through the triples, the unknown can be found through the known components.

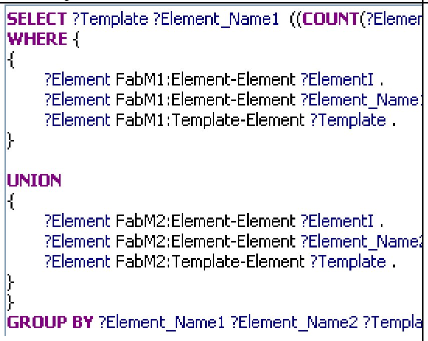
Table 5-7 contains sample queries expressed in SPARQL. The results are the matching simulation components retrieved from the modeling repository. Table 5-8 shows Q6 query syntax and results displayed in TBC. The rest of queries can be found in Appendix V.

Table 5-7: Queries for Knowledge Retrieval from the Repository

#	Query	Explanation
Q1	What are the models and templates in the repository and which domain do they belong to?	Repository content
Q2	What are "Descriptive Profile" properties and what are the properties' values for the "Spool Fabrication" Model?	Profile of a model
Q3	Find the simulation component which has the "Resource" role in the "Spool Fabrication" model. And also "objects" in industrial construction domain ontology under "resource"	Semantic role of simulation components and comparison with linked data
Q4	Find simulation elements with "process" role which contain inputs regarding "resources" in the "spool fabrication" model.	Semantic role of simulation components
Q5	What are required templates for developing a model of "Tunnelling operations"?	The query returns the URI of the supporting documents.
Q6	What are the differences between two models of "Spool Fabrication Shops"?	Comparing two ontologies through querying two ontolgies at the same time through linking resources.
Q7	In the properties of "tunnelling" profile and search if there is any "document" related properties and if there is what's the document URI?	The result is the URIs of related documents.
Q8	Which models consider work shifts in their simulation components?	Investigative queries to get to know the simulation content.
Q9	Find the Simulation element instances in the "Tunnelling model" which their output is involved with Cost>30000.	Investigative queries to get to know the simulation content.
Q10	Find the Simulation "work station" instances in Spool fabrication which are operating with more than 2 workers.	Investigative queries to get to know the simulation content.

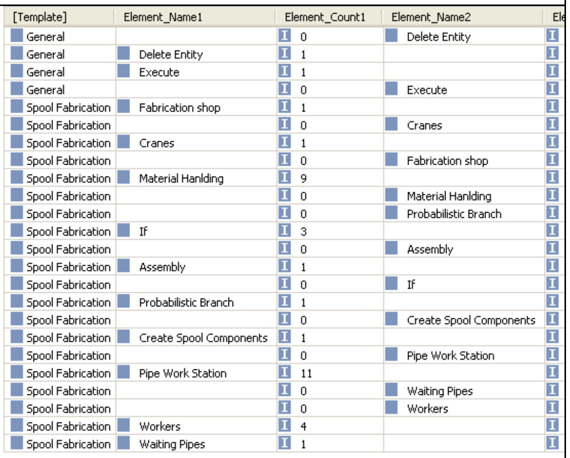
Table 5-8: Sample Query and Results in TBC

#	Query	Result
Q6	(query below)	(result below)



```
SELECT ?Template ?Element_Name1  ((COUNT(?Elemen
WHERE {
{
      ?Element FabM1:Element-Element ?ElementI .
      ?Element FabM1:Element-Element ?Element_Name1
      ?Element FabM1:Template-Element ?Template .
}

UNION
{
      ?Element FabM2:Element-Element ?ElementI .
      ?Element FabM2:Element-Element ?Element_Name2
      ?Element FabM2:Template-Element ?Template .
}
}
GROUP BY ?Element_Name1 ?Element_Name2 ?Templa
```



[Template]	Element_Name1	Element_Count1	Element_Name2	Ele
General		0	Delete Entity	
General	Delete Entity	1		
General	Execute	1		
General		0	Execute	
Spool Fabrication	Fabrication shop	1		
Spool Fabrication		0	Cranes	
Spool Fabrication	Cranes	1		
Spool Fabrication		0	Fabrication shop	
Spool Fabrication	Material Hanlding	9		
Spool Fabrication		0	Material Hanlding	
Spool Fabrication		0	Probabilistic Branch	
Spool Fabrication	If	3		
Spool Fabrication		0	Assembly	
Spool Fabrication	Assembly	1		
Spool Fabrication		0	If	
Spool Fabrication	Probabilistic Branch	1		
Spool Fabrication		0	Create Spool Components	
Spool Fabrication	Create Spool Components	1		
Spool Fabrication		0	Pipe Work Station	
Spool Fabrication	Pipe Work Station	11		
Spool Fabrication		0	Waiting Pipes	
Spool Fabrication		0	Workers	
Spool Fabrication	Workers	4		
Spool Fabrication	Waiting Pipes	1		

5-5 Summary

The innovative approach presented in this chapter blends semantic web technologies and construction simulation models for meaningful storage, sharing, and discovery of construction simulation models. It also properly links the models to their related information sources. The repository of simulation models contains three main components: composed models of construction processes, templates containing simulation components, and related data and information sources. Model discovery is achieved by the web service semantic search. Merging the semantic web into the construction simulation modeling some of its outcomes are: i) easy storage and accessibility of models, ii) knowledge extraction from simulation model content iii) access to data and knowledge sources. The benefits of the semantic web have been briefly investigated; there can be many other advantages to simulation model reuse, composability, and interoperability.

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Chapter 6

Conclusion

The research described in the thesis was motivated by a lack of reuse and interoperability of construction simulation models. Construction simulation models are knowledge intensive and are built up on construction domain knowledge and simulation modeling knowledge. The objective of this research was to capitalize on this embedded knowledge and effectively share and reuse it. The research focuses on two main areas: capture and representation of construction processes and simulation modeling, and simulation and modeling knowledge retrieval.

The study began by determining different simulation aspects in which modeling sharing and reuse could be enhanced. The first was conceptual modelling, which is the representation means of the acquired industrial construction knowledge. The second was the modeling development process, while utilizing HLA-based distributed simulation modeling environment. The third was reuse of the models that already are developed. Chapters 3, 4 and 5 consequently presented these areas.

Chapter 2 presented the industrial construction domain and the models addressing the challenges of the domain. In Chapter 3 the conceptual model of the industrial construction domain is captured and formalized through its ontological model containing concepts' hierarchies and relationships between them for further extraction and reuse in the simulation development process. Chapter 3 investigated reusability challenges through the modeling process, especially for the HLA-based distributed simulation modeling environments. In Chapter 5, the focus was on facilitating the reuse of models by introducing a new means for accessing, sharing, presenting, and discovering simulation models in a domain.

Thesis contributions:

1- Studying reuse through the entire simulation life cycle

This study for the first time utilized semantic web technology and techniques through the entire life cycle of simulation modeling. It is expected that this research will initiate more implementation of ontologies in the construction industry.

2- First attempt to formalize the industrial construction domain through ontologies.

The study introduced formalizing and structuring of the industrial construction domain knowledge.

3- Sharing and reusing the captured domain knowledge within industrial construction ontology for the use of applications.

This has been done through mapping related concepts to each other and ultimately connecting industrial construction domain instances to simulation modeling element instances.

4- Ontological approach towards facilitating reuse within distributed simulation modeling.

An ontological framework was utilized to facilitate a collaborative environment. An example of this is shown for developing a federation object model, which is shared between all the simulation modeling components (federates). Moreover, an element-based development approach is employed for the distributed simulation model components, to facilitate reuse through the development process.

5- Using the semantic web for storing, sharing, and reuse and discovery of developed construction models.

The innovative architecture blends semantic web technologies and construction simulation models presented in a machine-interpretable metadata for storing, sharing, and discovering construction simulation models and properly linking them to their related information sources.

6-1 Recommendations for future work:

1- This research also provides a knowledge-based foundation through the entire life-cycle of construction simulation modeling. Also, it is applicable for any knowledge-intensive application.

2- In order to evaluate the industrial domain ontology, it should be put into use. The ontology can be modified and extended according to new needs. The best practice for accomplishing this is to provide the ontology of domain knowledge as a wiki for interested parties. A wiki is a collaborative website designed to enable domain exports to access and contribute or modify the website's content. Important parts which have to be added to the ontology are domain projects and lessons learnt in different areas. This will lead to an invaluable source of knowledge for the construction industry.

3- The semantic web offers an important opportunity to compose simulation models from existing simulation components. The simulation components stored in simulation repositories can be discovered based on a specific simulation scenario and glued to each other to build a simulation model. This is an interesting area to be investigated.

4- Linking models to related sources can be extended without limitations. Moreover the access to these sources can easily exceed from their URLs to their contents. Shifting from a document to its content brings powerful features for model interoperability, discovery and simulation models' knowledge extraction process.

Appendix I

XML/RDF Source Code of InCon-Onto

```
<?xml version="1.0"?>


<!DOCTYPE rdf:RDF [
   <!ENTITY owl "http://www.w3.org/2002/07/owl#" >
   <!ENTITY swrl "http://www.w3.org/2003/11/swrl#" >
   <!ENTITY swrlb "http://www.w3.org/2003/11/swrlb#" >
   <!ENTITY xsd "http://www.w3.org/2001/XMLSchema#" >
   <!ENTITY rdfs "http://www.w3.org/2000/01/rdf-schema#" >
   <!ENTITY rdf "http://www.w3.org/1999/02/22-rdf-syntax-ns#" >
   <!ENTITY protege "http://protege.stanford.edu/plugins/owl/protege#" >
   <!ENTITY xsp "http://www.owl-ontologies.com/2005/08/07/xsp.owl#" >
   <!ENTITY InCon "http://www.owl-ontologies.com/Ontology1291499709.owl#" >
]>


<rdf:RDF xmlns="http://www.owl-ontologies.com/Ontology1291499710.owl#"
     xml:base="http://www.owl-ontologies.com/Ontology1291499710.owl"
     xmlns:rdfs="http://www.w3.org/2000/01/rdf-schema#"
     xmlns:swrl="http://www.w3.org/2003/11/swrl#"
     xmlns:protege="http://protege.stanford.edu/plugins/owl/protege#"
     xmlns:InCon="http://www.owl-ontologies.com/Ontology1291499709.owl#"
     xmlns:xsp="http://www.owl-ontologies.com/2005/08/07/xsp.owl#"
     xmlns:owl="http://www.w3.org/2002/07/owl#"
     xmlns:xsd="http://www.w3.org/2001/XMLSchema#"
     xmlns:swrlb="http://www.w3.org/2003/11/swrlb#"
     xmlns:rdf="http://www.w3.org/1999/02/22-rdf-syntax-ns#">
   <owl:Ontology rdf:about=""/>
   <InCon:Construction_site rdf:about="&InCon;Access_path">
      <InCon:belonging_domain rdf:resource="&InCon;Tunneling_Construction_Operation"/>
   </InCon:Construction_site>
   <InCon:Management_product rdf:about="&InCon;As_built_drawing">
      <rdfs:subClassOf rdf:resource="&InCon;Drawing"/>
      <InCon:belonging_domain rdf:resource="&InCon;Construction_operation"/>
   </InCon:Management_product>
   <owl:Class rdf:about="&InCon;Aspect">
```

```
    <rdfs:subClassOf rdf:resource="&owl;Class"/>
    <rdfs:subClassOf>
        <owl:Restriction>
            <owl:onProperty rdf:resource="&InCon;is_an_aspect"/>
            <owl:someValuesFrom>
                <owl:Class>
                    <owl:unionOf rdf:parseType="Collection">
                        <owl:Class rdf:about="&InCon;Process"/>
                        <owl:Class rdf:about="&InCon;Product"/>
                    </owl:unionOf>
                </owl:Class>
            </owl:someValuesFrom>
        </owl:Restriction>
    </rdfs:subClassOf>
    <rdfs:subClassOf>
        <owl:Restriction>
            <owl:onProperty rdf:resource="&InCon;has_scale"/>
            <owl:someValuesFrom rdf:resource="&InCon;Scale"/>
        </owl:Restriction>
    </rdfs:subClassOf>
</owl:Class>
<owl:Class rdf:about="&InCon;Assembly">
    <rdfs:subClassOf>
        <owl:Restriction>
            <owl:onProperty rdf:resource="&InCon;composed_of"/>
            <owl:someValuesFrom>
                <owl:Class>
                    <owl:unionOf rdf:parseType="Collection">
                        <owl:Class rdf:about="&InCon;Assembly"/>
                        <owl:Class rdf:about="&InCon;Part"/>
                    </owl:unionOf>
                </owl:Class>
            </owl:someValuesFrom>
        </owl:Restriction>
    </rdfs:subClassOf>
    <rdfs:subClassOf rdf:resource="&InCon;Industrial_construction_product"/>
    <rdfs:subClassOf>
        <owl:Restriction>
            <owl:onProperty rdf:resource="&InCon;is_accomplished_by"/>
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        </owl:Restriction>
    </rdfs:subClassOf>
</owl:Class>
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    <InCon:belonging_domain rdf:resource="&InCon;Tunneling_Construction_Operation"/>
</InCon:Machine_resouce>
<owl:Class rdf:about="&InCon;Bay">
    <rdfs:subClassOf rdf:resource="&InCon;Site"/>
</owl:Class>
<owl:ObjectProperty rdf:about="&InCon;belonging_aspect">
    <rdf:type rdf:resource="&owl;FunctionalProperty"/>
    <rdfs:domain rdf:resource="&InCon;Scale"/>
    <owl:inverseOf rdf:resource="&InCon;has_scale"/>
    <rdfs:range rdf:resource="&InCon;Aspect"/>
</owl:ObjectProperty>
```

```
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      <owl:unionOf rdf:parseType="Collection">
        <owl:Class rdf:about="&InCon;Product"/>
        <owl:Class rdf:about="&InCon;Resource"/>
      </owl:unionOf>
    </owl:Class>
  </rdfs:domain>
  <rdfs:range rdf:resource="&InCon;Construction_operation"/>
</owl:ObjectProperty>
<InCon:Worker rdf:about="&InCon;Boilemaker">
  <InCon:belonging_domain rdf:resource="&InCon;Industrial_Construction_Operation"/>
</InCon:Worker>
<owl:Class rdf:about="&InCon;Building">
  <rdfs:subClassOf rdf:resource="&InCon;Geographic_resource"/>
</owl:Class>
<owl:Class rdf:about="&InCon;Building_zone">
  <rdfs:subClassOf rdf:resource="&InCon;Geographic_resource"/>
</owl:Class>
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  <rdfs:subClassOf rdf:resource="&InCon;Module_assembly"/>
</InCon:Industrial_Construction_Operation>
<InCon:Worker rdf:about="&InCon;Carpenter">
  <InCon:belonging_domain rdf:resource="&InCon;Industrial_Construction_Operation"/>
</InCon:Worker>
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        <owl:Class rdf:about="&InCon;Assembly"/>
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  </rdfs:range>
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  <rdfs:subClassOf rdf:resource="&InCon;Process"/>
</owl:Class>
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  <rdfs:subClassOf rdf:resource="&InCon;Product"/>
</owl:Class>
<owl:Class rdf:about="&InCon;Construction_site">
  <rdfs:subClassOf rdf:resource="&InCon;Site"/>
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```

```
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  </InCon:Worker>
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    <InCon:has_aspect rdf:resource="&InCon;Productivity"/>
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    <InCon:input rdf:resource="&InCon;Pipe"/>
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    <InCon:next_operation rdf:resource="&InCon;Fitting"/>
    <InCon:taking_place rdf:resource="&InCon;Cutting_station"/>
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  </InCon:Aspect>
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```
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   <InCon:next_operation rdf:resource="&InCon;Roll_welding"/>
   <InCon:taking_place rdf:resource="&InCon;Fitting_station"/>
   <InCon:updating rdf:resource="&InCon;Spool_assembly"/>
   <InCon:use rdf:resource="&InCon;Fitting_weld_positioner"/>
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   <InCon:place_of_occurance rdf:resource="&InCon;Fitting"/>
</InCon:Station>
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   <InCon:belonging_domain rdf:resource="&InCon;Industrial_Construction_Operation"/>
</InCon:Tool_resource>
<InCon:Part rdf:about="&InCon;Fittings">
   <InCon:belonging_domain rdf:resource="&InCon;Industrial_Construction_Operation"/>
   <InCon:input_of rdf:resource="&InCon;Cutting"/>
   <InCon:input_of rdf:resource="&InCon;Fitting"/>
   <InCon:part_of rdf:resource="&InCon;Spool_assembly"/>
</InCon:Part>
<InCon:Tool_resource rdf:about="&InCon;Fixed_welding_positioner">
```

```
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  <rdfs:subClassOf>
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      <owl:someValuesFrom rdf:resource="&InCon;Process"/>
    </owl:Restriction>
  </rdfs:subClassOf>
</owl:Class>
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  <rdfs:subClassOf rdf:resource="&InCon;Operational_resouce"/>
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  <rdfs:domain>
    <owl:Class>
      <owl:unionOf rdf:parseType="Collection">
        <owl:Class rdf:about="&InCon;Process"/>
        <owl:Class rdf:about="&InCon;Product"/>
        <owl:Class rdf:about="&InCon;Resource"/>
      </owl:unionOf>
    </owl:Class>
  </rdfs:domain>
  <owl:inverseOf rdf:resource="&InCon;is_an_aspect"/>
  <rdfs:range rdf:resource="&InCon;Aspect"/>
</owl:ObjectProperty>
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  <InCon:input rdf:resource="&InCon;Spool_assembly"/>
  <InCon:is_accomplished_by rdf:resource="&InCon;Quality_control_worker"/>
  <InCon:next_operation rdf:resource="&InCon;Painting"/>
  <InCon:taking_place rdf:resource="&InCon;Hydro_test_yard"/>
  <InCon:updating rdf:resource="&InCon;Spool_assembly"/>
</InCon:Industrial_Construction_Operation>
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  <InCon:next_operation rdf:resource="&InCon;Mechanical_equipment"/>
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    <InCon:is_involved_in rdf:resource="&InCon;Shipping"/>
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    <rdfs:subClassOf rdf:resource="&InCon;Operational_resouce"/>
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  </owl:Class>
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    <InCon:updating rdf:resource="&InCon;Material"/>
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    <InCon:next_operation rdf:resource="&InCon;Insulation"/>
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    <rdfs:range rdf:resource="&InCon;Process"/>
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    <InCon:has_aspect rdf:resource="&InCon;Productivity"/>
    <InCon:input rdf:resource="&InCon;Spool_assembly"/>
    <InCon:is_accomplished_by rdf:resource="&InCon;Labourer"/>
    <InCon:next_operation rdf:resource="&InCon;Shipping"/>
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  <InCon:part_of rdf:resource="&InCon;Spool_assembly"/>
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  <rdfs:range rdf:resource="&InCon;Process"/>
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  <InCon:next_operation rdf:resource="&InCon;Quality_control_checking"/>
  <InCon:taking_place rdf:resource="&InCon;Position_welding_station"/>
  <InCon:updating rdf:resource="&InCon;Spool_assembly"/>
  <InCon:use rdf:resource="&InCon;Position_welding_station"/>
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    <InCon:updating rdf:resource="&InCon;Spool_assembly"/>
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    <InCon:place_of_occurance rdf:resource="&InCon;Roll_welding"/>
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</owl:Class>
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  <InCon:updating rdf:resource="&InCon;Shaft"/>
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  <InCon:input rdf:resource="&InCon;Fittings"/>
  <InCon:input rdf:resource="&InCon;Pipe"/>
  <InCon:next_operation rdf:resource="&InCon;Module_assembly"/>
  <InCon:taking_place rdf:resource="&InCon;Fabrication_shop"/>
  <InCon:updating rdf:resource="&InCon;Spool_assembly"/>
</InCon:Industrial_Construction_Operation>
<owl:Class rdf:about="&InCon;Shop_floor">
  <rdfs:subClassOf rdf:resource="&InCon;Building_zone"/>
</owl:Class>
<InCon:Management_product rdf:about="&InCon;Shop_order">
  <InCon:belonging_domain rdf:resource="&InCon;Industrial_Construction_Operation"/>
  <InCon:output_of rdf:resource="&InCon;Drafting"/>
</InCon:Management_product>
<owl:Class rdf:about="&InCon;Site">
  <rdfs:subClassOf rdf:resource="&InCon;Geographic_resource"/>
</owl:Class>
<InCon:Industrial_Construction_Operation rdf:about="&InCon;Site_construction"/>
<InCon:Industrial_Construction_Operation rdf:about="&InCon;Space_allocation">
  <rdfs:subClassOf rdf:resource="&InCon;Module_assembly"/>
  <InCon:next_operation rdf:resource="&InCon;Structural_steel"/>
</InCon:Industrial_Construction_Operation>
<InCon:Assembly rdf:about="&InCon;Spool_assembly">
  <rdfs:subClassOf rdf:resource="&owl;Thing"/>
  <rdfs:subClassOf>
    <owl:Restriction>
      <owl:onProperty rdf:resource="&InCon;composed_of"/>
      <owl:someValuesFrom>
        <owl:Class>
          <owl:unionOf rdf:parseType="Collection">
            <owl:Class rdf:about="&InCon;Fittings"/>
            <owl:Class rdf:about="&InCon;Pipe"/>
            <owl:Class rdf:about="&InCon;Spool_assembly"/>
          </owl:unionOf>
        </owl:Class>
      </owl:someValuesFrom>
    </owl:Restriction>
  </rdfs:subClassOf>
  <InCon:belonging_domain rdf:resource="&InCon;Industrial_Construction_Operation"/>
  <InCon:composed_of rdf:resource="&InCon;Fittings"/>
  <InCon:composed_of rdf:resource="&InCon;Pipe"/>
  <InCon:composed_of rdf:resource="&InCon;Spool_assembly"/>
  <InCon:input_of rdf:resource="&InCon;Fitting"/>
  <InCon:input_of rdf:resource="&InCon;Hydro_testing"/>
  <InCon:input_of rdf:resource="&InCon;Position_welding"/>
  <InCon:input_of rdf:resource="&InCon;Quality_control_checking"/>
  <InCon:input_of rdf:resource="&InCon;Roll_welding"/>
  <InCon:input_of rdf:resource="&InCon;Stress_relief"/>
  <InCon:output_of rdf:resource="&InCon;Cutting"/>
  <InCon:output_of rdf:resource="&InCon;Fitting"/>
  <InCon:output_of rdf:resource="&InCon;Hydro_testing"/>
  <InCon:output_of rdf:resource="&InCon;Painting"/>
  <InCon:output_of rdf:resource="&InCon;Position_welding"/>
  <InCon:output_of rdf:resource="&InCon;Quality_control_checking"/>
  <InCon:output_of rdf:resource="&InCon;Roll_welding"/>
  <InCon:output_of rdf:resource="&InCon;Shipping"/>
  <InCon:output_of rdf:resource="&InCon;Shop_fabrication"/>
  <InCon:output_of rdf:resource="&InCon;Stress_relief"/>
  <owl:disjointWith rdf:resource="&InCon;Part"/>
  <rdfs:comment rdf:datatype="&xsd;string">Spool_assembly</rdfs:comment>
</InCon:Assembly>
<owl:Class rdf:about="&InCon;Station">
  <rdfs:subClassOf rdf:resource="&InCon;Building_zone"/>
</owl:Class>
<owl:Class rdf:about="&InCon;Storage">
  <rdfs:subClassOf rdf:resource="&InCon;Building_zone"/>
</owl:Class>
<InCon:Industrial_Construction_Operation rdf:about="&InCon;Stress_relief">
  <rdfs:subClassOf rdf:resource="&InCon;Shop_fabrication"/>
  <InCon:has_aspect rdf:resource="&InCon;Duration"/>
  <InCon:has_aspect rdf:resource="&InCon;Productivity"/>
  <InCon:input rdf:resource="&InCon;Spool_assembly"/>
  <InCon:is_accomplished_by rdf:resource="&InCon;Labourer"/>
  <InCon:next_operation rdf:resource="&InCon;Hydro_testing"/>
  <InCon:taking_place rdf:resource="&InCon;Fabrication_shop"/>
  <InCon:updating rdf:resource="&InCon;Spool_assembly"/>
</InCon:Industrial_Construction_Operation>
<InCon:Bay rdf:about="&InCon;Stress_relieve_bay">
  <InCon:belonging_domain rdf:resource="&InCon;Industrial_Construction_Operation"/>
</InCon:Bay>
<InCon:Industrial_Construction_Operation rdf:about="&InCon;Structural_steel">
  <rdfs:subClassOf rdf:resource="&InCon;Site_construction"/>
  <rdfs:subClassOf rdf:resource="&InCon;Module_assembly"/>
  <InCon:next_operation rdf:resource="&InCon;Equipment"/>
</InCon:Industrial_Construction_Operation>
<InCon:Tunneling_Product rdf:about="&InCon;Tail_tunnel">
  <InCon:belonging_domain rdf:resource="&InCon;Tunneling_Construction_Operation"/>
  <InCon:output_of rdf:resource="&InCon;Tunnel_excavation"/>
</InCon:Tunneling_Product>
<owl:ObjectProperty rdf:about="&InCon;taking_place">
  <rdfs:domain rdf:resource="&InCon;Process"/>
<owl:inverseOf rdf:resource="&InCon;place_of_occurance"/>
<rdfs:range rdf:resource="&InCon;Geographic_resource"/>
</owl:ObjectProperty>
<InCon:Machine_resouce rdf:about="&InCon;TBM">
<InCon:belonging_domain rdf:resource="&InCon;Tunneling_Construction_Operation"/>
</InCon:Machine_resouce>
<InCon:Aspect rdf:about="&InCon;Thickness">
<rdfs:subClassOf rdf:resource="&InCon;Dimension"/>
</InCon:Aspect>
<owl:Class rdf:about="&InCon;Tool_resource">
<rdfs:subClassOf rdf:resource="&InCon;Operational_resouce"/>
</owl:Class>
<InCon:Industrial_Construction_Operation rdf:about="&InCon;Tracing">
<rdfs:subClassOf rdf:resource="&InCon;Module_assembly"/>
<rdfs:subClassOf rdf:resource="&InCon;Site_construction"/>
<InCon:next_operation rdf:resource="&InCon;Insulation"/>
</InCon:Industrial_Construction_Operation>
<InCon:Machine_resouce rdf:about="&InCon;Train">
<InCon:belonging_domain rdf:resource="&InCon;Tunneling_Construction_Operation"/>
</InCon:Machine_resouce>
<owl:Class rdf:about="&InCon;Transportation_resource">
<rdfs:subClassOf rdf:resource="&InCon;Resource"/>
<rdfs:subClassOf>
  <owl:Restriction>
    <owl:onProperty rdf:resource="&InCon;is_used"/>
    <owl:someValuesFrom rdf:resource="&InCon;Process"/>
  </owl:Restriction>
</rdfs:subClassOf>
</owl:Class>
<InCon:Transportation_resource rdf:about="&InCon;Truck"/>
<InCon:Tunneling_Product rdf:about="&InCon;Tunnel">
<InCon:belonging_domain rdf:resource="&InCon;Tunneling_Construction_Operation"/>
<InCon:output_of rdf:resource="&InCon;Tunnel_excavation"/>
</InCon:Tunneling_Product>
<InCon:Tunneling_Construction_Operation rdf:about="&InCon;Tunnel_excavation">
<InCon:next_operation rdf:resource="&InCon;Lining"/>
<InCon:updating rdf:resource="&InCon;Tail_tunnel"/>
<InCon:updating rdf:resource="&InCon;Tunnel"/>
</InCon:Tunneling_Construction_Operation>
<owl:Class rdf:about="&InCon;Tunneling_Construction_Operation">
<rdfs:subClassOf rdf:resource="&InCon;Construction_operation"/>
</owl:Class>
<owl:Class rdf:about="&InCon;Tunneling_Product">
<rdfs:subClassOf rdf:resource="&InCon;Product"/>
</owl:Class>
<InCon:Construction_site rdf:about="&InCon;Tunneling_site">
<InCon:belonging_domain rdf:resource="&InCon;Tunneling_Construction_Operation"/>
</InCon:Construction_site>
<InCon:Tunneling_Product rdf:about="&InCon;Undercut">
<InCon:belonging_domain rdf:resource="&InCon;Tunneling_Construction_Operation"/>
<InCon:output_of rdf:resource="&InCon;Lining"/>
</InCon:Tunneling_Product>
<owl:ObjectProperty rdf:about="&InCon;updating">
<rdfs:domain rdf:resource="&InCon;Process"/>
<owl:inverseOf rdf:resource="&InCon;output_of"/>
```

```
        <rdfs:comment rdf:datatype="&xsd;string">updating</rdfs:comment>
        <rdfs:range rdf:resource="&InCon;Product"/>
    </owl:ObjectProperty>
    <owl:ObjectProperty rdf:about="&InCon;use">
        <rdfs:domain rdf:resource="&InCon;Process"/>
        <owl:inverseOf rdf:resource="&InCon;is_used"/>
        <rdfs:range rdf:resource="&InCon;Operational_resouce"/>
    </owl:ObjectProperty>
    <InCon:Aspect rdf:about="&InCon;Weight"/>
    <InCon:Worker rdf:about="&InCon;Welder">
        <InCon:belonging_domain rdf:resource="&InCon;Industrial_Construction_Operation"/>
        <InCon:is_involved_in rdf:resource="&InCon;Position_welding"/>
        <InCon:is_involved_in rdf:resource="&InCon;Roll_welding"/>
    </InCon:Worker>
    <InCon:Aspect rdf:about="&InCon;Width">
        <rdfs:subClassOf rdf:resource="&InCon;Dimension"/>
    </InCon:Aspect>
    <owl:Class rdf:about="&InCon;Work_cell">
        <rdfs:subClassOf rdf:resource="&InCon;Building_zone"/>
    </owl:Class>
    <owl:Class rdf:about="&InCon;Worker">
        <rdfs:subClassOf rdf:resource="&InCon;Human_resouce"/>
    </owl:Class>
</rdf:RDF>
```

Appendix II

Tunneling Ontology

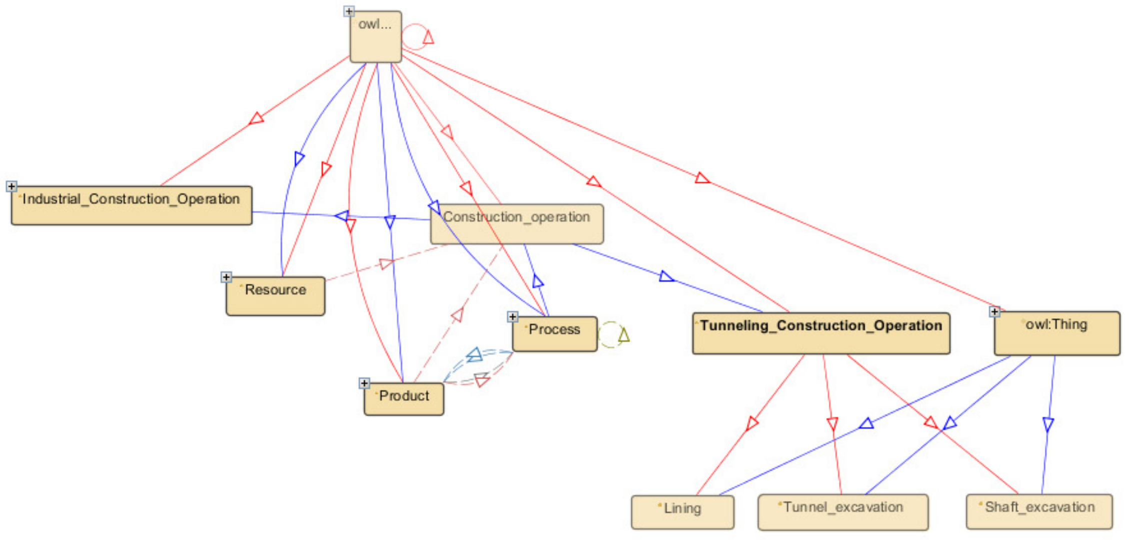


Figure A-I-1: Tunneling processes as a part of construction processes

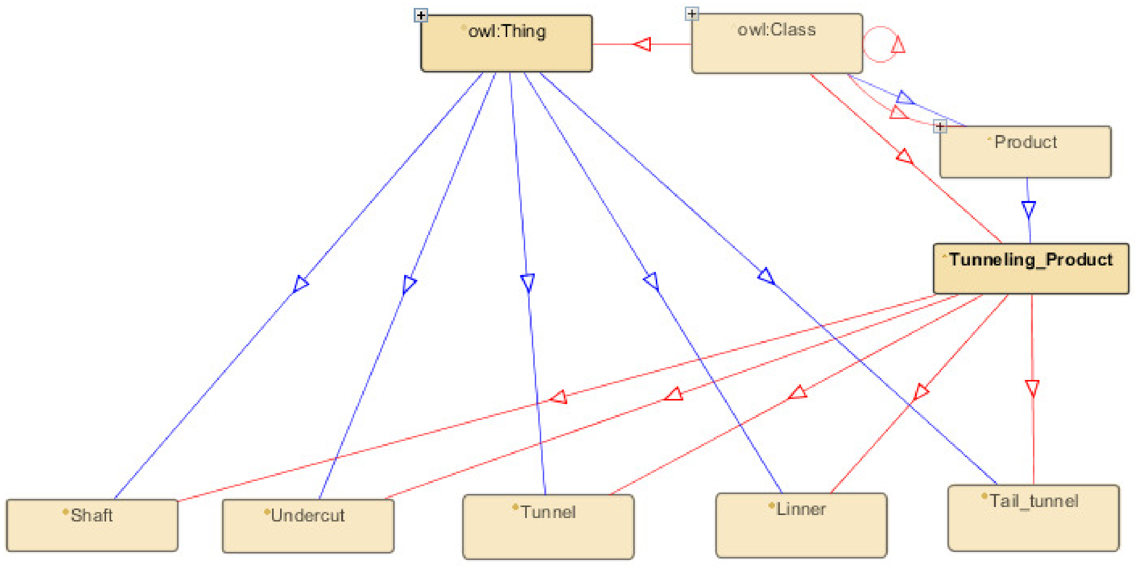


Figure A-I-2: Tunneling products

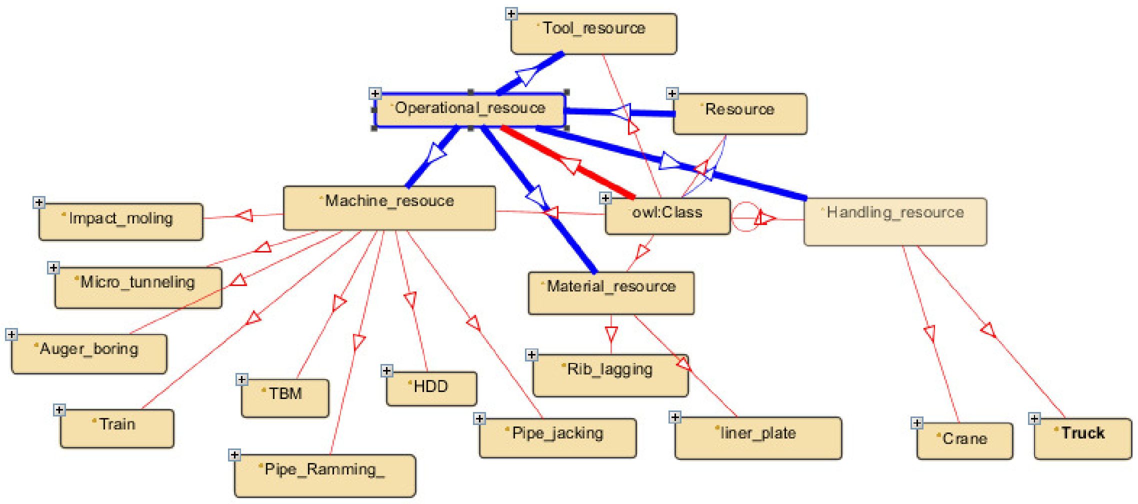


Figure A-I-3: Tunneling resources

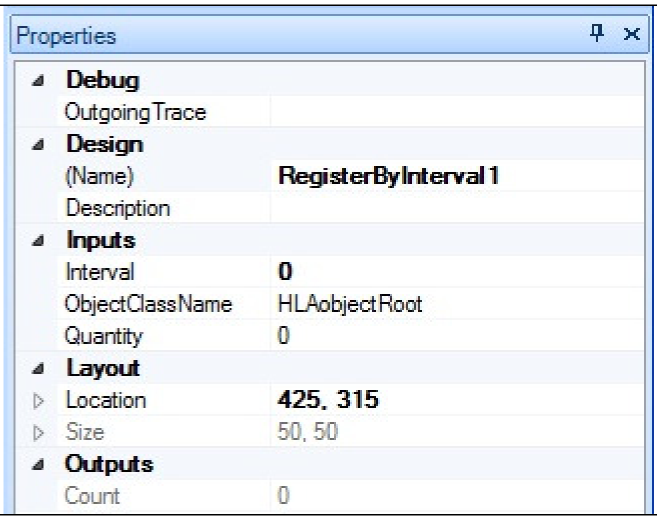
Appendix III

COSYE Fabrication Shop Modeling Elements

Fabrication Shop Modeling Elements:

Element	Template	Description
Register Module	CosyeModeling	Register module by interval
Update Module Attributes	CosyeModeling	The attribute values are initialized
Module Entity	Fabrication	Module Class
Spool Entity	Fabrication	Spool Class
Create Spool for Module	Fabrication	Creating module's belonging spools
Create Spool Components	Fabrication	Creating spool's belonging components
Fab Station	Fabrication	Different types of work stations: cutting, fitting, welding,...
Worker	Fabrication	Different trades of worker: cutter, fitter, welder,...
Handiling	Fabrication	Manual or crane handling
Dispatch	Fabrication	Sending products to appropriate station
Assembler	Fabrication	Keeping track of spool components
Proxy Module Assembler		Updating module attributes

Element: Register Module	Properties


Properties

Debug	
OutgoingTrace	
Design	
(Name)	**RegisterByInterval1**
Description	
Inputs	
Interval	**0**
ObjectClassName	HLAobjectRoot
Quantity	0
Layout	
Location	**425, 315**
Size	50, 50
Outputs	
Count	0

Code:

```
Imports System
Imports System.Collections.Generic
Imports System.ComponentModel
Imports System.Drawing
Imports System.Linq
Imports System.Xml
Imports Cosye.Hla.Rti
Imports Cosye.Modeling
Imports Simphony
Imports Simphony.ComponentModel
Imports Simphony.Modeling
Imports Simphony.Simulation

Namespace CosyeModelingVB
    ''' <summary>
    ''' A modeling element that registers object instances.
    ''' </summary>
    <Description("Generates object instances.")> _
    Public Class RegisterByInterval
        Inherits OutputElement(Of ProxyEntity)
        Implements IObjectClassSpecifier
        Implements ICosyeElement

        Private Const QuantityDefault As Integer = 0
        Private Const ObjectClassNameDefault As String = "HLAobjectRoot"

        Private theClass As ObjectClassHandle
        Private rtiAmb As IRTIambassador
        Private proxies As IProxyProvider
        Private countValue As Integer
        Private quantityValue As Integer = QuantityDefault
        Private objectClassNameValue As String = ObjectClassNameDefault
        Private intervalValue As Double

        <InputsCategory()> _
        <DefaultValue(QuantityDefault)> _
        <Description("The number of entities to register.")> _
        Public Property Quantity() As Integer
            Get
                Return quantityValue
            End Get
            Set(ByVal value As Integer)
                quantityValue = value
            End Set
        End Property

        <InputsCategory()> _
        <DefaultValue(QuantityDefault)> _
        <Description("The number of entities to register during federation startup.")> _
        Public Property Interval() As Double
            Get
                Return intervalValue
            End Get
            Set(ByVal value As Double)
                intervalValue = value
            End Set
        End Property

        <InputsCategory()> _
        <DefaultValue(ObjectClassNameDefault)> _
        <Description("The object class the register element should register.")> _
        <TypeConverter(GetType(ObjectClassNameConverter))> _
        Public Property ObjectClassName() As String
            Get
                Return objectClassNameValue
            End Get
            Set(ByVal value As String)
                objectClassNameValue = value
            End Set
        End Property

        Private ReadOnly Property ObjectClassName2() As String Implements IObjectClassSpecifier.ObjectClassName
            Get
                Return objectClassNameValue
            End Get
        End Property

        <OutputsCategory()> _
        <Description("The current number of objects registered.")> _
        Public Property Count() As Integer
            Get
                Return Me.countValue
            End Get
            Private Set(ByVal value As Integer)
                Me.countValue = value
            End Set
        End Property

        Public Overrides Sub Paint(ByVal graphics As Graphics, ByVal bounds As RectangleF)
            MyBase.Paint(graphics, bounds)

            Using font = New Font("Webdings", 32)
                Dim format = New StringFormat(StringFormat.GenericTypographic)
                format.Alignment = StringAlignment.Center
                graphics.DrawString("+", font, Brushes.Black, bounds, format)
            End Using
        End Sub

        Public Overrides Sub ReadXml(ByVal reader As XmlReader)
            reader.ExceptionIfNull("reader")
            Me.Quantity = reader.GetAttributeAs(Of Integer)("InitialQuantity", QuantityDefault)
            Me.ObjectClassName = reader.GetAttributeAs(Of String)("ObjectClassName", ObjectClassNameDefault)
```

```
            MyBase.ReadXml(reader)
        End Sub

        Public Overrides Sub WriteXml(ByVal writer As XmlWriter)
            writer.ExceptionIfNull("writer")
            writer.WriteAttribute("InitialQuantity", Me.Quantity)
            writer.WriteAttribute("ObjectClassName", Me.ObjectClassName)
            MyBase.WriteXml(writer)
        End Sub

        Protected Overrides Sub InitializeRun(ByVal runIndex As Integer)
            MyBase.InitializeRun(runIndex)
            Me.Count = 0
            Me.rtiAmb = Me.GetService(Of IRTIambassador)()
            Me.proxies = Me.GetService(Of IProxyProvider)()
            Me.theClass = Me.rtiAmb.GetObjectClassHandle(Me.ObjectClassName)
        End Sub

        Private Sub RegisterObjectInstance(ByVal Entity As Entity)
            Dim theObject = Me.rtiAmb.RegisterObjectInstance(Me.theClass)
            Dim newEntity = New ProxyEntity(Me.proxies(theObject))
            Me.OutputPoint.TransferOut(newEntity)
            Me.Count = Me.Count + 1
            If Me.Count < Me.Quantity Then
                Dim handler = New Action(Of Entity)(AddressOf RegisterObjectInstance)
                Me.Engine.ScheduleEvent(Entity, handler, Me.Interval)
            End If
        End Sub

        Public Sub BeginExecution() Implements Cosye.Modeling.ICosyeElement.BeginExecution
            Dim entity = New Entity()
            Dim handler = New Action(Of Entity)(AddressOf RegisterObjectInstance)
            Me.Engine.ScheduleEvent(entity, handler, 0)
        End Sub

        Public Sub EndExecution() Implements Cosye.Modeling.ICosyeElement.EndExecution
            'Do nothing.
        End Sub

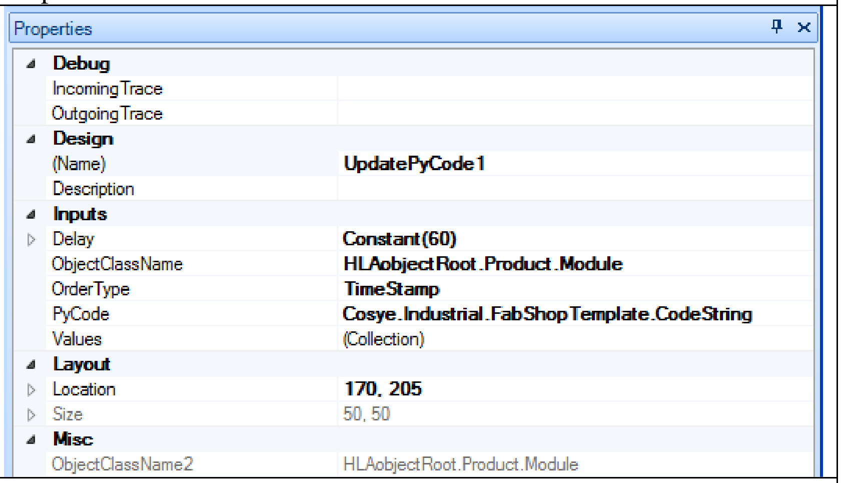
        Public Sub InitializeInitialInstances() Implements Cosye.Modeling.ICosyeElement.InitializeInitialInstances
            'Do nothing.
        End Sub

        Public Sub MakeInitialDeclarations() Implements Cosye.Modeling.ICosyeElement.MakeInitialDeclarations
            Me.theClass = Me.rtiAmb.GetObjectClassHandle(Me.ObjectClassName)
            Dim pTDO = Me.rtiAmb.GetAttributeHandle(Me.theClass, "HLAprivilegeToDeleteObject")
            Me.rtiAmb.PublishObjectClassAttributes(Me.theClass, New AttributeHandle() {pTDO})
        End Sub

        Public Sub RegisterInitialInstances() Implements Cosye.Modeling.ICosyeElement.RegisterInitialInstances
            'Do nothing.
        End Sub

    End Class

End Namespace
```

Element: Update Module Attributes	Properties
	

Properties

Debug	
IncomingTrace	
OutgoingTrace	
Design	
(Name)	**UpdatePyCode1**
Description	
Inputs	
Delay	**Constant(60)**
ObjectClassName	**HLAobjectRoot.Product.Module**
OrderType	**TimeStamp**
PyCode	**Cosye.Industrial.FabShopTemplate.CodeString**
Values	(Collection)
Layout	
Location	**170, 205**
Size	50, 50
Misc	
ObjectClassName2	HLAobjectRoot.Product.Module

Code:

```
Imports System
Imports System.Collections.Generic
Imports System.ComponentModel
Imports System.ComponentModel.Design
Imports System.Drawing
Imports System.Drawing.Design
Imports System.Xml
Imports Cosye.Modeling
Imports Cosye.Hla.Rti
Imports Simphony
Imports Simphony.ComponentModel
Imports Simphony.Mathematics
Imports Simphony.Modeling
Imports Simphony.Simulation

Imports Microsoft
Imports Microsoft.Scripting
Imports Microsoft.Scripting.Hosting
Imports Microsoft.Scripting.Hosting.Providers
Imports Microsoft.Scripting.Runtime
Imports IronPython.Hosting
Imports IronPython.Runtime
Imports IronPython.Modules
Imports IronPython.Runtime.Types
Namespace CosyeModelingVB

    ''' <summary>
    ''' A modeling element that updates an attribute of an object instance using Python script.
    ''' </summary>
    <Description("Updates an attribute of an object instance from using Python Script.")> _
    Public Class UpdatePyCode
        Inherits FlowElement(Of ProxyEntity)
        Implements IObjectClassSpecifier
        Implements ICosyeElement

#Region "Private Constants"
        Private Const ObjectClassNameDefault As String = "HLAobjectRoot"
        Private Const OrderTypeDefault As OrderType = OrderType.TimeStamp
#End Region
```

```
#Region "Private Fields"
        Private theClass As ObjectClassHandle
        Private rtiAmb As IRTIambassador

        Private m_PyCode As New CodeString(Me)
        Private m_Values As AttributeNameValueMap
        Private updatedValues As New AttributeNameValueMap(Me)

        Private PyEngine As ScriptEngine
        Private PyRunTime As ScriptRuntime
        Private PyScope As ScriptScope
        Private PySource As ScriptSource

#End Region

#Region "Public Constructors"

#Region "Update()"
        ''' <summary>
        ''' Initializes a new instance of the Update class.
        ''' </summary>
        Public Sub New()
            Me.Delay = New Constant(60)
            Me.ObjectClassName = ObjectClassNameDefault
            Me.OrderType = OrderTypeDefault
            Me.Values = New AttributeNameValueMap(Me)
        End Sub
#End Region

#End Region

#Region "Public Properties"

#Region "Delay"
        ''' <summary>
        ''' Gets or sets the amount of time by which entities will be delayed.
        ''' </summary>
        ''' <value>
        ''' The amount of time by which entities will be delayed.
        ''' </value>
        <InputsCategory()> _
        <Description("The amount of time by which entities will be delayed.")> _
        Public Property Delay() As Distribution
            Get
                Return m_Delay
            End Get
            Set(ByVal value As Distribution)
                m_Delay = value
            End Set
        End Property
        Private m_Delay As Distribution
#End Region

#Region "ObjectClassName"
        ''' <summary>
        ''' Gets or sets the object class the register element should register.
        ''' </summary>
        ''' <value>
        ''' The object class the register element should register.
        ''' </value>
        <InputsCategory()> _
        <DefaultValue(ObjectClassNameDefault)> _
        <Description("The object class the register element should register.")> _
        <TypeConverter(GetType(ObjectClassNameConverter))> _
        Public Property ObjectClassName() As String
            Get
                Return m_ObjectClassName
            End Get
            Set(ByVal value As String)
                m_ObjectClassName = value
            End Set
        End Property
        Public ReadOnly Property ObjectClassName2() As String Implements IObjectClassSpecifier.ObjectClassName
            Get
                Return m_ObjectClassName
            End Get
        End Property
        Private m_ObjectClassName As String
#End Region

#Region "OrderType"
        ''' <summary>
        ''' Gets or sets the order type of the update.
        ''' </summary>
        ''' <value>
        ''' The order type of the update.
        ''' </value>
        <InputsCategory()> _
        <DefaultValue(OrderTypeDefault)> _
        <Description("The order type of the update.")> _
        Public Property OrderType() As OrderType
            Get
                Return m_OrderType
            End Get
            Set(ByVal value As OrderType)
                m_OrderType = value
            End Set
        End Property
        Private m_OrderType As OrderType
#End Region

#Region "Values"
        ''' <summary>
        ''' Gets a collection containing the attribute values.
        ''' </summary>
        ''' <value>
        ''' A collection containing the attribute values.
        ''' </value>
        <InputsCategory()> _
        <Description("The attributes and their values.")> _
        Public Property Values() As AttributeNameValueMap
            Get
                Return m_Values
            End Get
            Private Set(ByVal value As AttributeNameValueMap)
                m_Values = value
            End Set

        End Property

#End Region

#Region "Python Code"
        ''' <summary>
```

```
    ''' Gets or sets IronPython code that the element should execute.
    ''' </summary>
    ''' <value>
    ''' String representing the code to execute.
    ''' </value>
    <InputsCategory()> _
    <DefaultValue("")> _
    <Description("IronPython Code to execute")> _
    <Editor(GetType(DialogEditor(Of PythonEditor)), GetType(Drawing.Design.UITypeEditor))> _
    Public Property PyCode() As CodeString
        Get
            Return m_PyCode
        End Get
        Set(ByVal value As CodeString)
            m_PyCode = value

        End Set
    End Property
#End Region

#End Region

#Region "Public Methods"

#Region "Paint(Graphics, RectangleF)"
    ''' <summary>
    ''' Renders the current element on a GDI+ drawing surface.
    ''' </summary>
    ''' <param name="graphics">
    ''' The GDI+ drawing surface on which the element should be drawn.
    ''' </param>
    ''' <param name="bounds">
    ''' The boundaries of the region to paint on the drawing surface.
    ''' </param>
    Public Overrides Sub Paint(ByVal graphics As Graphics, ByVal bounds As RectangleF)
        MyBase.Paint(graphics, bounds)

        Using font = New Font("Webdings", 32)
            Dim format = New StringFormat(StringFormat.GenericTypographic)
            format.Alignment = StringAlignment.Center
            graphics.DrawString(ChrW(156), font, Brushes.Black, bounds, format)
        End Using
    End Sub
#End Region

#Region "ReadXml(XmlReader)"
    ''' <summary>
    ''' Deserializes the class from an XML reader.
    ''' </summary>
    ''' <param name="reader">
    ''' The XML reader to deserialize from.
    ''' </param>
    ''' <exception cref="ArgumentNullException">
    ''' Thrown if the specified XML reader is a null reference.
    ''' </exception>
    Public Overrides Sub ReadXml(ByVal reader As XmlReader)
        reader.ExceptionIfNull("reader")
        Me.ObjectClassName = reader.GetAttributeAs(Of String)("ObjectClassName", ObjectClassNameDefault)
        Me.OrderType = reader.GetAttributeAs(Of OrderType)("OrderType", OrderTypeDefault)
        Me.PyCode.Code = reader.GetAttributeAs(Of String)("PyCode", Nothing)
        MyBase.ReadXml(reader)
        Me.Delay = reader.ReadComplexElementAs(Of Distribution)("Delay")
```

```
            reader.ReadComplexElement("Values", Me.Values)
        End Sub
#End Region

#Region "WriteXml(XmlWriter)"
        ''' <summary>
        ''' Serializes the class to an XML writer.
        ''' </summary>
        ''' <param name="writer">
        ''' The XML writer to serialize to.
        ''' </param>
        ''' <exception cref="ArgumentNullException">
        ''' Thrown if the specified XML writer is a null reference.
        ''' </exception>
        Public Overrides Sub WriteXml(ByVal writer As XmlWriter)
            writer.ExceptionIfNull("writer")
            writer.WriteAttribute("ObjectClassName", Me.ObjectClassName)
            writer.WriteAttribute("OrderType", Me.OrderType)
            writer.WriteAttribute("PyCode", Me.PyCode.Code)
            MyBase.WriteXml(writer)
            writer.WriteComplexElement("Delay", Me.Delay)
            writer.WriteComplexElement("Values", Me.Values)
        End Sub
#End Region

#End Region

#Region "Protected Internal Methods"


#End Region

#Region "Protected Methods"

#Region "InitializeRun(int runIndex)"
        ''' <summary>
        ''' Called prior to simulation of each run.
        ''' </summary>
        ''' <param name="runIndex">
        ''' The zero-based index of the run.
        ''' </param>
        Protected Overrides Sub InitializeRun(ByVal runIndex As Integer)
            MyBase.InitializeRun(runIndex)
            rtiAmb = Me.GetService(Of IRTIambassador)()
            Me.theClass = Me.rtiAmb.GetObjectClassHandle(Me.ObjectClassName)
            Me.Values.InitializeRun(runIndex)
        End Sub
#End Region

#Region "OnTransferOut(T entity)"
        ''' <summary>
        ''' Called when an entity needs to be transfered out.
        ''' </summary>
        ''' <param name="entity">
        ''' The entity to send.
        ''' </param>
        Protected Overridable Sub OnTransferOut(ByVal entity As ProxyEntity)
            Me.OutputPoint.TransferOut(entity)
        End Sub
#End Region

#Region "TransferIn(GeneralEntity, TransferInEventArgs)"
```

```
''' <summary>
''' Handles arrival of an entity at an input point.
''' </summary>
''' <param name="entity">
''' The entity.
''' </param>
''' <param name="point">
''' The input point at which the entity arrived.
''' </param>
Protected Overrides Sub TransferIn(ByVal entity As ProxyEntity, ByVal point As InputPoint)
    Dim theObject = entity.Instance

    ' Initialize IronPython script engine
    PyEngine = Python.CreateEngine
    PyRunTime = PyEngine.Runtime
    PyScope = PyRunTime.CreateScope
    PySource = PyEngine.CreateScriptSourceFromString(PyCode.Code, SourceCodeKind.AutoDetect)


    'Add attribute names defined in the element as variables in the python code
    For Each entry In Values
        PyScope.SetVariable(entry.AttributeName, entry.Value)
        'Also add reference to current elemnt (me)just in case we need access to other stuff
        PyScope.SetVariable("me", Me)
        ' Me.Scenario.Ints(1)

    Next

    'Execute Python Script
    Try
        PySource.Execute(PyScope)
    Catch ex As Exception
        MsgBox("Exception: " & ex.Message & ControlChars.NewLine & "Exiting without executing Python script")
        Exit Sub
    End Try

    'Harvest updated values from script scope
    Try
        For Each entry In Values
            entry.Value = PyScope.GetVariable(entry.AttributeName)
            'MsgBox(entry.AttributeName & " : " & entry.Value.ToString)
        Next

    Catch ex As Exception
        MsgBox(ex.Message)
        Exit Sub
    End Try

    ' Request ownership of the attributes that will be updated
    Dim theAttributes = Me.Values.GetAttributeHandleSet()
    'Do not request ownership of attributes already owned
    Dim AttributesToRequest As New List(Of AttributeHandle)
    For Each Attr In theAttributes
        If Not rtiAmb.IsAttributeOwnedByFederate(theObject, Attr) Then
            AttributesToRequest.Add(Attr)
        End If
    Next

    'MsgBox(AttributesToRequest.Count)
    Try
        Me.rtiAmb.AttributeOwnershipAcquisition(theObject, AttributesToRequest, Nothing)
```

```
            Catch ex As Exception
                MsgBox(ex.Message & ControlChars.NewLine & ex.ToString)
                Exit Sub
            End Try

            'Do HLA update
            Try
                Dim theValues = Me.Values.GetAttributeHandleValueMap()
                If Me.OrderType = OrderType.TimeStamp Then
                    Dim delay = Me.Delay.Sample()
                    Me.rtiAmb.UpdateAttributeValues(theObject, theValues, Nothing, Me.Engine.TimeNow + delay)
                    Dim handler = New Action(Of ProxyEntity)(AddressOf Me.OnTransferOut)
                    Me.Engine.ScheduleEvent(entity, handler, delay)
                Else
                    Me.rtiAmb.UpdateAttributeValues(theObject, theValues, Nothing)
                    MyBase.TransferIn(entity, point)
                End If

            Catch ex As Exception
                MsgBox("Exception: " & ex.Message & ControlChars.NewLine & "Failed to complete HLA attribute update call")
                Exit Sub

            End Try

            ' Divest ownership of the updated attributes
            Me.rtiAmb.UnconditionalAttributeOwnershipDivestiture(theObject, theAttributes)
        End Sub
#End Region

#End Region

        Public Sub BeginExecution() Implements Cosye.Modeling.ICosyeElement.BeginExecution

        End Sub

        Public Sub EndExecution() Implements Cosye.Modeling.ICosyeElement.EndExecution

        End Sub

        Public Sub InitializeInitialInstances() Implements Cosye.Modeling.ICosyeElement.InitializeInitialInstances

        End Sub
#Region "MakeInitialDeclarations()"
        ''' <summary>
        ''' Called when the federation is synchronized at ready to declare.
        ''' </summary>
        Public Sub MakeInitialDeclarations() Implements ICosyeElement.MakeInitialDeclarations
            'MyBase.MakeInitialDeclarations()
            Me.theClass = Me.rtiAmb.GetObjectClassHandle(Me.ObjectClassName)
            Me.rtiAmb.PublishObjectClassAttributes(Me.theClass, Me.Values.GetAttributeHandleSet())
        End Sub
#End Region

        Public Sub RegisterInitialInstances() Implements Cosye.Modeling.ICosyeElement.RegisterInitialInstances

        End Sub
    End Class
End Namespace
```

Element: Module Entity		

Code:

```
Imports Simphony.Mathematics
Imports Simphony.Simulation
Imports System.IO
Imports System.Drawing.Imaging
Imports Cosye.Hla.Rti
Imports Cosye.Modeling
Public Enum ModuleState
    Fabshop
    ModuleYard
End Enum
Public Class ModuleEntity
    Inherits GeneralEntity
    Private _TotalNumberofSpool As Integer
    Private _StartDate As Date
    Private _FinishDate As Date
    Private _ShippingDate As Date
    Private _NumberofSpoolsFabricated As Integer
    Private _ModuleID As Integer
    Private _State As ModuleState
    Private _Priority As Integer
    Private _ModuleName As String
    Public Property ShippingDate() As Date
        Get
            Return Me._ShippingDate
        End Get
        Set(ByVal value As Date)
            _ShippingDate = value
        End Set
    End Property
    Public Property StartDate() As Date
        Get
            Return Me._StartDate
        End Get
        Set(ByVal value As Date)
            _StartDate = value
        End Set
    End Property
    Public Property FinishDate() As Date
        Get
            Return Me._FinishDate
        End Get
        Set(ByVal value As Date)
            _FinishDate = value
        End Set
    End Property
    Public Property TotalNumberofSpool() As Integer
        Get
            Return Me._TotalNumberofSpool
        End Get
        Set(ByVal value As Integer)
            _TotalNumberofSpool = value
        End Set
    End Property
    Public Property NumberofSpoolsFabricated() As Integer
        Get
            Return Me._NumberofSpoolsFabricated
        End Get
        Set(ByVal value As Integer)
            _NumberofSpoolsFabricated = value
```

```
      End Set
   End Property
   Public Property Priority() As Double
      Get
         Return Me._Priority
      End Get
      Set(ByVal value As Double)
         _Priority = value
      End Set
   End Property
   Public Property State() As [Enum]
      Get
         Return Me._State
      End Get
      Set(ByVal value As [Enum])
         _State = value
      End Set
   End Property
   Public Property ModuleName() As String
      Get
         Return Me._ModuleName
      End Get
      Set(ByVal value As String)
         _ModuleName = value
      End Set
   End Property
   Public Property ModuleID() As Integer
      Get
         Return Me._ModuleID
      End Get
      Set(ByVal value As Integer)
         _ModuleID = value
      End Set
   End Property
End Class
```

Element: Spool Entity		
Code:		

```
Spool Entity
Imports Simphony.Mathematics
Imports Simphony.Simulation
Imports System.IO
Imports System.Drawing.Imaging
Imports Cosye.Hla.Rti
Imports Cosye.Modeling
Public Enum SpoolState
   Issued
   Cut
   FittingStorage
   Fitted
   WeldStorage
   Welded
End Enum
Public Enum SpoolSize
   Small
   Intermediate
   Large
End Enum
Public Enum SpoolLength
```

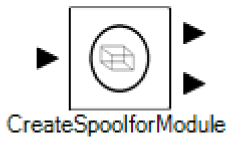
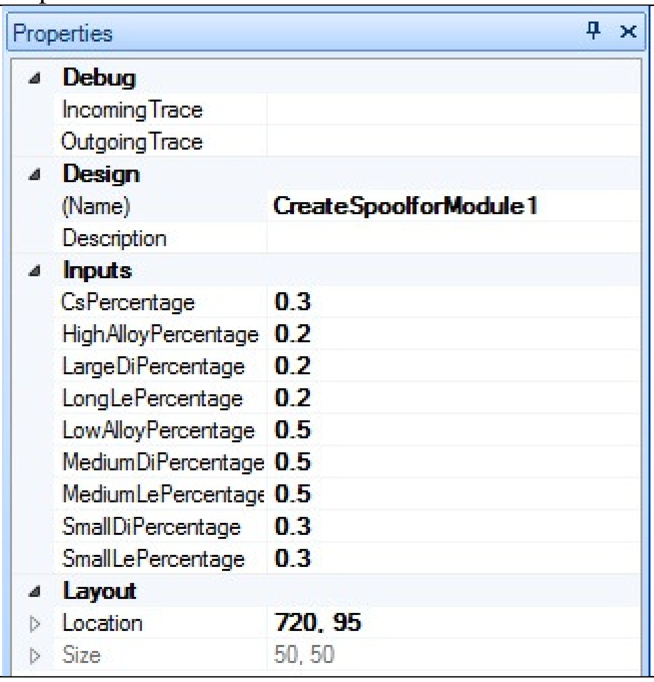
```
    Small
    Medium
    [Long]
End Enum
Public Enum SpoolMaterial
    CarbonSteel
    LowAlloySteel
    HighAlloySteel
End Enum
Public Class SpoolEntity
    Inherits GeneralEntity
    Private _SpoolID As Integer
    Private _NumberofComponents As Integer
    Private _ModuleID As Integer
    Private _ModuleHandle As ObjectInstanceHandle
    Private _ModuleName As String
    Private _DiameterSize As SpoolSize
    Private _Length As SpoolLength
    Private _Material As SpoolMaterial
    Private _State As SpoolState
    Private _PositionWork As Double
    Private _RollingWork As Double
    Private _TotalWork As Double
    Private _Priority As Double
    Public Property Priority() As Double
        Get
            Return Me._Priority
        End Get
        Set(ByVal value As Double)
            _Priority = value
        End Set
    End Property

    Public Property TotalWork() As Double
        Get
            Return Me._TotalWork
        End Get
        Set(ByVal value As Double)
            _TotalWork = value
        End Set
    End Property
    Public Property RollingWork() As Double
        Get
            Return Me._RollingWork
        End Get
        Set(ByVal value As Double)
            _RollingWork = value
        End Set
    End Property

    Public Property PositionWork() As Double
        Get
            Return Me._PositionWork
        End Get
        Set(ByVal value As Double)
            _PositionWork = value
        End Set
    End Property

    Public Property ModuleHandle() As ObjectInstanceHandle
        Get
            Return Me._ModuleHandle
        End Get
        Set(ByVal value As ObjectInstanceHandle)
            _ModuleHandle = value
        End Set
    End Property
    Public Property DiameterSize() As [Enum]
        Get
            Return Me._DiameterSize
        End Get
        Set(ByVal value As [Enum])
            _DiameterSize = value
        End Set
    End Property
    Public Property Length() As [Enum]
        Get
            Return Me._Length
        End Get
        Set(ByVal value As [Enum])
            _Length = value
        End Set
    End Property
    Public Property Material() As [Enum]
        Get
            Return Me._Material
        End Get
        Set(ByVal value As [Enum])
            _Material = value
        End Set
    End Property
    Public Property State() As [Enum]
        Get
            Return Me._State
        End Get
        Set(ByVal value As [Enum])
            _State = value
        End Set
    End Property
    Public Property ModuleName() As String
        Get
            Return Me._ModuleName
        End Get

        Set(ByVal value As String)
            _ModuleName = value
        End Set
    End Property
    Public Property NumberofComponents() As Integer
        Get
            Return Me._NumberofComponents
        End Get
        Set(ByVal value As Integer)
            _NumberofComponents = value
        End Set
    End Property
    Public Property SpoolID() As Integer
        Get
            Return Me._SpoolID
        End Get
        Set(ByVal value As Integer)
            _SpoolID = value
        End Set
    End Property
    Public Property ModuleID() As Integer
        Get
            Return Me._ModuleID
        End Get
        Set(ByVal value As Integer)
            _ModuleID = value
        End Set
    End Property
End Class
```

Element: Create Spool for Module	Properties
	

Properties	
Debug	
IncomingTrace	
OutgoingTrace	
Design	
(Name)	CreateSpoolforModule1
Description	
Inputs	
CsPercentage	0.3
HighAlloyPercentage	0.2
LargeDiPercentage	0.2
LongLePercentage	0.2
LowAlloyPercentage	0.5
MediumDiPercentage	0.5
MediumLePercentage	0.5
SmallDiPercentage	0.3
SmallLePercentage	0.3
Layout	
Location	720, 95
Size	50, 50

Code:

```
Imports System.Drawing
Imports Simphony.Simulation
Imports Cosye.Hla.Rti
Imports Cosye.Modeling
Imports Simphony
Imports Simphony.Mathematics

Public Class CreateSpoolforModule
    Inherits DivergeElement(Of ProxyEntity)
    'Inherits DivergeElement(Of GeneralEntity)

    Private rtiAmb As IRTIambassador
    Private NoSpool As Integer
    Private NoModulesIn As Integer = 0
    Private NoSpoolOut As Integer = 0
    Private SpoolNoComponent As Integer = 3
    Private _CsPercentage As Double = 0.3
    Private _LowAlloyPercentage As Double = 0.5
    Private _HighAlloyPercentage As Double = 0.2
    Private _SmallDiPercentage As Double = 0.3
    Private _MediumDiPercentage As Double = 0.5
    Private _LargeDiPercentage As Double = 0.2
    Private _SmallLePercentage As Double = 0.3
    Private _MediumLePercentage As Double = 0.5
    Private _LongLePercentage As Double = 0.2
    <InputsCategory()> _
<Description("The amount of earth to haul in cubic meters.")> _
 Public Property CsPercentage() As Double
        Get
            Return Me._CsPercentage
        End Get
        Set(ByVal value As Double)
            _CsPercentage = value
        End Set
    End Property
    <InputsCategory()> _
 <Description("The amount of earth to haul in cubic meters.")> _
  Public Property LowAlloyPercentage() As Double
        Get
            Return Me._LowAlloyPercentage
        End Get
        Set(ByVal value As Double)
            _LowAlloyPercentage = value
        End Set
    End Property
    <InputsCategory()> _
<Description("The amount of earth to haul in cubic meters.")> _
Public Property HighAlloyPercentage() As Double
        Get
            Return Me._HighAlloyPercentage
        End Get
        Set(ByVal value As Double)
            _HighAlloyPercentage = value
        End Set
    End Property
    <InputsCategory()> _
<Description("The amount of earth to haul in cubic meters.")> _
 Public Property LongLePercentage() As Double
        Get
            Return Me._LongLePercentage
        End Get
        Set(ByVal value As Double)
            _LongLePercentage = value
        End Set
    End Property
    <InputsCategory()> _
 <Description("The amount of earth to haul in cubic meters.")> _
  Public Property MediumLePercentage() As Double
        Get
            Return Me._MediumLePercentage
        End Get
        Set(ByVal value As Double)
            _MediumLePercentage = value
        End Set
    End Property
    <InputsCategory()> _
<Description("The amount of earth to haul in cubic meters.")> _
Public Property SmallLePercentage() As Double
        Get
```

```
            Return Me._SmallLePercentage
        End Get
        Set(ByVal value As Double)
            _SmallLePercentage = value
        End Set
    End Property
    <InputsCategory()> _
<Description("The amount of earth to haul in cubic meters.")> _
 Public Property LargeDiPercentage() As Double
        Get
            Return Me._LargeDiPercentage
        End Get
        Set(ByVal value As Double)
            _LargeDiPercentage = value
        End Set
    End Property
    <InputsCategory()> _
 <Description("The amount of earth to haul in cubic meters.")> _
  Public Property MediumDiPercentage() As Double
        Get
            Return Me._MediumDiPercentage
        End Get
        Set(ByVal value As Double)
            _MediumDiPercentage = value
        End Set
    End Property
    <InputsCategory()> _
<Description("The amount of earth to haul in cubic meters.")> _
Public Property SmallDiPercentage() As Double
        Get
            Return Me._SmallDiPercentage
        End Get
        Set(ByVal value As Double)
            _SmallDiPercentage = value
        End Set
    End Property
    '    <InputsCategory()> _
    '<Description("The amount of earth to haul in cubic meters.")> _
    'Public Property SpoolNoComponent() As Integer
    '        Get
    '            Return Me._SpoolNoComponent
    '        End Get
    '        Set(ByVal value As Integer)
    '            _SpoolNoComponent = Math.Max(0, value)
    '        End Set
    '    End Property
    'Private AmountLoadedValue As Double = 100
    '   <InputsCategory()> _
    '<Description("The amount of earth to haul in cubic meters.")> _
    ' Public Property NoSpool() As Integer
    '       Get
    '           Return Me._NoSpool
    '       End Get
    '       Set(ByVal value As Integer)
    '           _NoSpool = value
    '       End Set
    '   End Property
    Protected Overrides Sub TransferIn(ByVal entity As ProxyEntity, ByVal point As Simphony.Modeling.InputPoint)
        'MyBase.TransferIn(entity, point)
        NoModulesIn += 1
        Dim theClass = rtiAmb.GetObjectClassHandle("Product.Module")
        Dim theModuleName = rtiAmb.GetAttributeHandle(theClass, "Name")
        'entity.Instance
        'Dim theModuleInstanceHandler = rtiAmb.GetObjectInstanceHandle(entity)
        Dim theModuleTotalNumberofSpools = rtiAmb.GetAttributeHandle(theClass, "TotalNumberofSpool")
        Dim ModulePriority = rtiAmb.GetAttributeHandle(theClass, "Priority")

        Me.FirstOutputPoint.TransferOut(entity)
        Trace.WriteLine("Module " & entity.Values(theModuleName) & entity.Values(theModuleTotalNumberofSpools))
        Dim NoSpool = (entity.Values(theModuleTotalNumberofSpools))
        Trace.WriteLine("NSpool " & NoSpool)
        For I As Integer = 1 To NoSpool
            Dim Spool As New SpoolEntity
            NoSpoolOut += 1
            Spool.ModuleName = entity.Values(theModuleName)
            Spool.Priority = entity.Values(ModulePriority)
            'Spool.ModuleName = entity.
            Spool.ModuleID = NoModulesIn
            Spool.ModuleHandle = entity.Instance
            Spool.SpoolID = NoSpoolOut
            Spool.NumberofComponents = SpoolNoComponent
            Dim l1 As Double = Rnd()

            If l1 <= LargeDiPercentage Then
                Spool.DiameterSize = SpoolSize.Large

            ElseIf LargeDiPercentage < l1 And l1 <= (LargeDiPercentage + MediumDiPercentage) Then
                Spool.DiameterSize = SpoolSize.Intermediate

            Else
                Spool.DiameterSize = SpoolSize.Small

            End If

            Dim l2 As Double = Rnd()

            If l2 <= LongLePercentage Then
                Spool.Length = SpoolLength.Long

            ElseIf LongLePercentage < l2 And l2 <= (LongLePercentage + MediumLePercentage) Then
                Spool.Length = SpoolLength.Medium

            Else
                Spool.Length = SpoolLength.Small

            End If

            Dim l3 As Double = Rnd()

            If l3 <= LongLePercentage Then
                Spool.Material = SpoolMaterial.CarbonSteel

            ElseIf LongLePercentage < l3 And l3 <= (LongLePercentage + MediumLePercentage) Then
                Spool.Material = SpoolMaterial.LowAlloySteel

            Else
                Spool.Material = SpoolMaterial.HighAlloySteel

            End If

            Me.SecondOutputPoint.TransferOut(Spool)
            Trace.WriteLine("SpoolID " & Spool.SpoolID & " DiameterSize " & Spool.DiameterSize.ToString) ' " ModuleName " &
Spool.ModuleName & "ModuleID " & Spool.ModuleID & "ModuleHandle" & Spool.ModuleHandle.ToString)
```

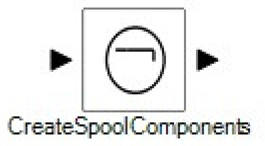
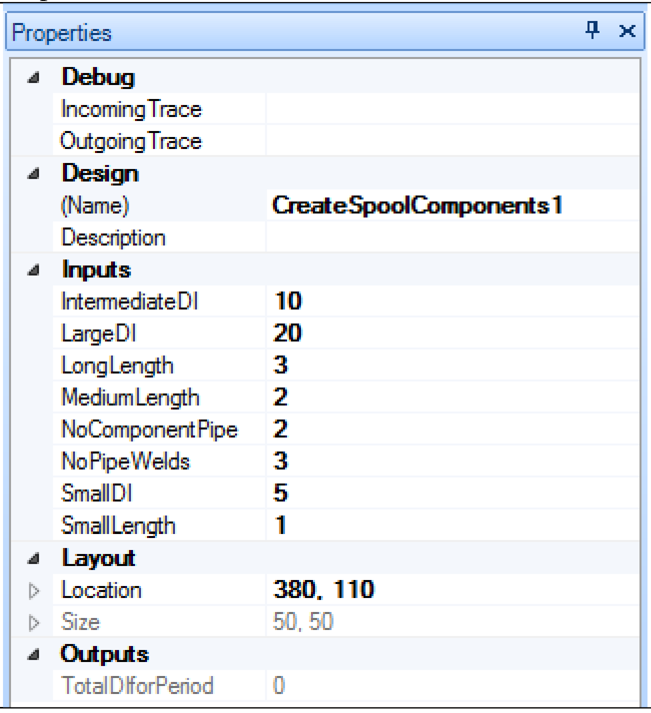
```
        Next

    End Sub
    Public Overrides Sub Paint(ByVal graphics As System.Drawing.Graphics, ByVal bounds As System.Drawing.RectangleF)

        MyBase.Paint(graphics, bounds)
        graphics.DrawImage(My.Resources.CreateModuls.ToBitmap(), bounds)

    End Sub
    Protected Overrides Sub InitializeRun(ByVal runIndex As Integer)
        MyBase.InitializeRun(runIndex)
        Me.rtiAmb = Me.GetService(Of IRTIambassador)()
    End Sub

End Class
```

Element: Create Spool Components	Properties
	

Properties

Debug	
IncomingTrace	
OutgoingTrace	
Design	
(Name)	**CreateSpoolComponents1**
Description	
Inputs	
IntermediateDI	**10**
LargeDI	**20**
LongLength	**3**
MediumLength	**2**
NoComponentPipe	**2**
NoPipeWelds	**3**
SmallDI	**5**
SmallLength	**1**
Layout	
Location	**380, 110**
Size	50, 50
Outputs	
TotalDIforPeriod	0

Code:

```
Imports System.Drawing

Public Class CreateSpoolComponents1
    Inherits OutputElement(Of ComponentEntity)

    Private _NoModule As Integer = 2
    Private _NoofSpoolperModule As Integer = 10
    Private _SpoolNoComponent As Integer = 3
    Private _ComponentNoPipe As Integer = 2
    Private _SmallPercentage As Double = 0.3
    Private _MediumPercentage As Double = 0.5
```

```
   Private _LargePercentage As Double = 0.2
   Private _SmallDI As Double = 5
   Private _MediumDI As Double = 10
   Private _LargeDI As Double = 20
   Private _TotalDI As Double
   <OutputsCategory()> _
<Description("Total amount of Diameter Inch")> _
Public Property TotalDI() As Double
       Get
          Return Me._TotalDI
       End Get
       Private Set(ByVal value As Double)
          Me._TotalDI = value
       End Set
   End Property
   <InputsCategory()> _
 <Description("Number of Pipes in each Component")> _
  Public Property ComponentNoPipe() As Double
       Get
          Return Me._ComponentNoPipe
       End Get
       Set(ByVal value As Double)
          _ComponentNoPipe = value
       End Set
   End Property
   <InputsCategory()> _
 <Description("Number of Spools in each Module")> _
  Public Property NoofSpoolperModule() As Double
       Get
          Return Me._NoofSpoolperModule
       End Get
       Set(ByVal value As Double)
          _NoofSpoolperModule = value
       End Set
   End Property
   <InputsCategory()> _
 <Description("Value of Large DI")> _
  Public Property LargeDI() As Double
       Get
          Return Me._LargeDI
       End Get
       Set(ByVal value As Double)
          _LargeDI = value
       End Set
   End Property
   <InputsCategory()> _
<Description("Value of Medium DI")> _
Public Property MediumDI() As Double
       Get
          Return Me._MediumDI
       End Get
       Set(ByVal value As Double)
          _MediumDI = value
       End Set
   End Property
   <InputsCategory()> _
<Description("Value of Small DI")> _
Public Property SmallDI() As Double
       Get
          Return Me._SmallDI
       End Get
       Set(ByVal value As Double)
```

```
            _SmallDI = value
        End Set
    End Property
    <InputsCategory()> _
 <Description("Percentage of Large DI")> _
  Public Property LargePercentage() As Double
        Get
            Return Me._LargePercentage
        End Get
        Set(ByVal value As Double)
            _LargePercentage = value
        End Set
    End Property
    <InputsCategory()> _
 <Description("Percentage of Medium DI")> _
  Public Property MediumPercentage() As Double
        Get
            Return Me._MediumPercentage
        End Get
        Set(ByVal value As Double)
            _MediumPercentage = value
        End Set
    End Property
    <InputsCategory()> _
<Description("Percentage of Small DI")> _
Public Property SmallPercentage() As Double
        Get
            Return Me._SmallPercentage
        End Get
        Set(ByVal value As Double)
            _SmallPercentage = value
        End Set
    End Property
    <InputsCategory()> _
 <Description("Related Module No")> _
Public Property NoModule() As Integer
        Get
            Return Me._NoModule
        End Get
        Set(ByVal value As Integer)
            _NoModule = Math.Max(0, value)
        End Set
    End Property
    <InputsCategory()> _
<Description("Number of Components for each Spool")> _
Public Property SpoolNoComponent() As Integer
        Get
            Return Me._SpoolNoComponent
        End Get
        Set(ByVal value As Integer)
            _SpoolNoComponent = Math.Max(0, value)
        End Set
    End Property
    Protected Overrides Sub InitializeRun(ByVal runIndex As Integer)
        MyBase.InitializeRun(runIndex)

        For i = 1 To NoModule
            Dim TotalWorkUnit As Double
            For k = 1 To NoofSpoolperModule


                For j = 1 To SpoolNoComponent
                Dim MyEntity As New ComponentEntity
                Dim WorkUnit As Double

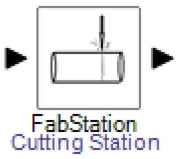
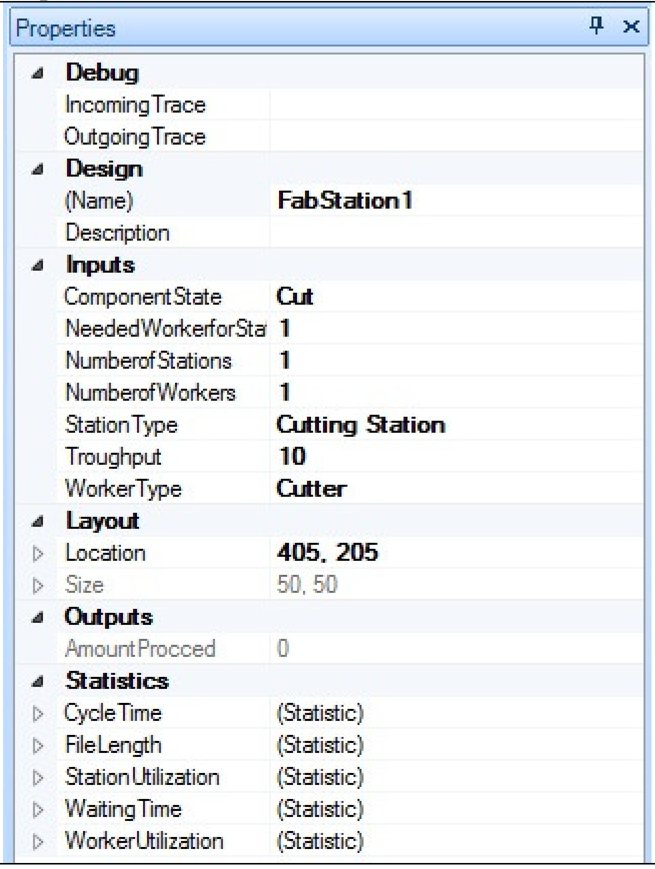
                MyEntity.ModuleID = i
                MyEntity.SpoolID = k + (i - 1) * (NoofSpoolperModule)

                MyEntity.ComponentID = j
                MyEntity.DI = 0
                MyEntity.NoPipesforComponent = ComponentNoPipe
                MyEntity.NumberofComponents = SpoolNoComponent
                MyEntity.AvailableNoComponents = 0

                Dim l As Double = Rnd()
                'Trace.WriteLine("l " & l)
                If l <= LargePercentage Then
                   MyEntity.Diameter = "Large"
                   WorkUnit = LargeDI
                ElseIf LargePercentage < l And l <= (LargePercentage + MediumPercentage) Then
                   MyEntity.Diameter = "Medium"
                   WorkUnit = MediumDI
                Else
                   MyEntity.Diameter = "Small"
                   WorkUnit = SmallDI
                End If

                For m = 1 To MyEntity.NoPipesforComponent
                   MyEntity.DI += WorkUnit
                Next

                Me.OutputPoint.TransferOut(MyEntity)
                Trace.WriteLine(MyEntity.SpoolID)
                TotalWorkUnit = MyEntity.DI
                _TotalDI += TotalWorkUnit
             Next
          Next
       Next
    End Sub
End Class
```

Element: Fab Station	Properties
	

Properties

Debug	
IncomingTrace	
OutgoingTrace	
Design	
(Name)	FabStation1
Description	
Inputs	
ComponentState	Cut
NeededWorkerforSta	1
NumberofStations	1
NumberofWorkers	1
StationType	Cutting Station
Troughput	10
WorkerType	Cutter
Layout	
Location	405, 205
Size	50, 50
Outputs	
AmountProcced	0
Statistics	
CycleTime	(Statistic)
FileLength	(Statistic)
StationUtilization	(Statistic)
WaitingTime	(Statistic)
WorkerUtilization	(Statistic)

Code:

```
Imports System.Drawing
Imports Simphony.Simulation
Imports Cosye.Modeling
Imports Simphony
Imports Simphony.Mathematics
Imports System.IO
Imports System.Xml
Imports System.Drawing.Imaging
Public Class FabStation
    Inherits FlowElement(Of ComponentEntity)

    Private _NumberofStations As Integer = 1
    Private _NumberofWorkers As Integer = 1
    Private _NeededWorkerforStation As Integer = 1
    Private _WorkerType As String = "Cutter"
    Private _StationType As String = "Cutting Station"
    Private Station As New Resource(StationType, NumberofStations)
    Private Worker As New Resource(WorkerType, NumberofWorkers)
    Private ComponentsQueue As New WaitingFile("ComponentQueue")
    Private _AmountProcced As New Double
    Private _Troughput As Double = 10
    Private _ComponentState As String = "Cut"
    Private ReadOnly CycleTimeValue As New NumericStatistic("CycleTime", False)
    <InputsCategory()> _
<Description("")> _
 Public Property Troughput() As Integer
        Get
            Return Me._Troughput
        End Get
        Set(ByVal value As Integer)
            _Troughput = value
        End Set
    End Property
    <InputsCategory()> _
<Description("")> _
 Public Property NeededWorkerforStation() As Integer
        Get
            Return Me._NeededWorkerforStation
        End Get
        Set(ByVal value As Integer)
            _NeededWorkerforStation = value
        End Set
    End Property
    <InputsCategory()> _
 <Description("")> _
  Public Property WorkerType() As String
        Get
            Return Me._WorkerType
        End Get
        Set(ByVal value As String)
            _WorkerType = value
        End Set
    End Property
    <InputsCategory()> _
<Description("")> _
 Public Property StationType() As String
        Get
            Return Me._StationType
        End Get
        Set(ByVal value As String)
            _StationType = value
        End Set
    End Property
    <InputsCategory()> _
 <Description("")> _
  Public Property NumberofWorkers() As Integer
        Get
            Return Me._NumberofWorkers
        End Get
        Set(ByVal value As Integer)
            _NumberofWorkers = value
        End Set
    End Property
    <InputsCategory()> _
 <Description("")> _
  Public Property NumberofStations() As Integer
        Get
            Return Me._NumberofStations
        End Get
        Set(ByVal value As Integer)
            _NumberofStations = value
        End Set
    End Property
```

```
   <InputsCategory()> _
 <Description("")> _
  Public Property ComponentState() As String
        Get
            Return Me._ComponentState
        End Get
        Set(ByVal value As String)
            _ComponentState = value
        End Set
    End Property
    <OutputsCategory()> _
<Description("")> _
Public Property AmountProcced() As Double
        Get
            Return Me._AmountProcced
        End Get
        Private Set(ByVal value As Double)
            Me._AmountProcced = value
        End Set
    End Property
    <StatisticsCategory()> _
<Description("")> _
Public ReadOnly Property WorkerUtilization() As NumericStatistic
        Get
            Return Me.Worker.Utilization
        End Get
    End Property
    <StatisticsCategory()> _
<Description("")> _
Public ReadOnly Property StationUtilization() As NumericStatistic
        Get
            Return Me.Station.Utilization
        End Get
    End Property
    <StatisticsCategory()> _
<Description("")> _
Public ReadOnly Property FileLength() As NumericStatistic
        Get
            Return Me.ComponentsQueue.FileLength
        End Get
    End Property
    <StatisticsCategory()> _
<Description("")> _
Public ReadOnly Property WaitingTime() As NumericStatistic
        Get
            Return Me.ComponentsQueue.WaitingTime
        End Get
    End Property
    <StatisticsCategory()> _
<Description("")> _
Public ReadOnly Property CycleTime() As NumericStatistic
        Get
            Return Me.CycleTimeValue
        End Get
    End Property
    Public Sub New()
        Me.AddResource(Me.Station) 'Adding a resource to the constructor
                            Me.AddResource(Me.Worker)
        Me.AddWaitingFile(Me.ComponentsQueue) 'Adding a waiting file to the constructor
        Me.Station.WaitingFiles.Add(Me.ComponentsQueue) 'Linking up the Resource and Waiting File
        Me.Worker.WaitingFiles.Add(Me.ComponentsQueue)
        Me.AddStatistic(Me.CycleTime)
        'Me.Size = My.Resources.Fabrication.Size
    End Sub
    Public Overrides Sub Paint(ByVal graphics As System.Drawing.Graphics, ByVal bounds As System.Drawing.RectangleF)

        Dim myBrush As New SolidBrush(Color.DarkSlateBlue)
        Dim f As Font = New Font("Arial", 8, FontStyle.Regular)
        graphics.DrawString(Me.StationType.ToString, f, myBrush, bounds.Left - 15, bounds.Top + 60)

        MyBase.Paint(graphics, bounds)
        graphics.DrawImage(My.Resources.Fabrication.ToBitmap, bounds)

    End Sub
    Protected Overrides Sub InitializeRun(ByVal runIndex As Integer)
        MyBase.InitializeRun(runIndex)
        Me.AmountProcced = 0
    End Sub
    Protected Overrides Sub TransferIn(ByVal entity As ComponentEntity, ByVal point As Simphony.Modeling.InputPoint)
        'MyBase.TransferIn(entity, point)

        Dim Handler = New Action(Of ComponentEntity)(AddressOf Me.StartFabProcess)
        Dim MyRequirements As New MultipleResourceRequirement()
        MyRequirements.Add(Me.Station, 1)
        MyRequirements.Add(Me.Worker, 1)
        Me.Engine.RequestResource(entity, MyRequirements, Handler, Me.ComponentsQueue, entity.Priority)
        Trace.WriteLine("Queue " & Me.ComponentsQueue.FileLength.ToString & "WaitingTime " & Me.ComponentsQueue.WaitingTime.ToString)
        'Me.GetType.GetElementType.

    End Sub
    Private Sub StartFabProcess(ByVal Entity As ComponentEntity)

        Dim Handler = New Action(Of ComponentEntity)(AddressOf Me.FinishFabProcess)
        Me.Scenario.Floats(1) = Me.Engine.TimeNow
        Dim duration = Entity.TotalWork * _Troughput
        'Trace.WriteLine("Vasat" & Entity.Id)
        Me.Engine.ScheduleEvent(Entity, Handler, duration)

        Trace.WriteLine("TIME " & Me.Scenario.Floats(1))
    End Sub
    Private Sub FinishFabProcess(ByVal Entity As ComponentEntity)
        Entity.State = ComponentState
        Me.AmountProcced += Entity.TotalWork
        'Trace.WriteLine("Bye" & Entity.Id)
        Me.Engine.ReleaseResource(Entity, Me.Station, 1)
        Me.Engine.ReleaseResource(Entity, Me.Worker, 1)
        Me.OutputPoint.TransferOut(Entity)
        Me.CycleTime.Collect(Me.Engine.TimeNow - Me.Scenario.Floats(1))
    End Sub
End Class
```

Element: Worker	
Code:	

```
Imports System.Drawing
Imports Simphony.Simulation
Imports Cosye.Modeling
Imports Simphony
Imports Simphony.Mathematics
Imports System.IO
Imports System.Xml
Imports System.Drawing.Imaging
Public Class Worker
   Inherits ElementBase

   'Private _WorkerType As String = "Cutter"
   Private _NumberofWorkers As Integer = 4
   'Private Worker As New Resource(WorkerType, NumberofWorkers)
   Private ComponentsQueue As New WaitingFile("ComponentQueue")
   Private ReadOnly _Worker As New Resource("Worker", 4)
   Friend ReadOnly Property Worker() As Resource
      Get
         Return Me._Worker
      End Get
   End Property
   <OutputsCategory()> _
<Description("")> _
Public ReadOnly Property AvailableWorkers() As Integer
      Get
         Return Me.Worker.Available
      End Get
   End Property
   <OutputsCategory()> _
<Description("")> _
Public ReadOnly Property InUseWorkers() As Integer
      Get
         Return Me.Worker.InUse
      End Get
   End Property
   <InputsCategory()> _
 <Description("")> _
  Public Property NumberofWorkers() As Integer
      Get
         Return Me._NumberofWorkers
      End Get
      Set(ByVal value As Integer)
         _NumberofWorkers = value
      End Set
   End Property
   <StatisticsCategory()> _
<Description("")> _
Public ReadOnly Property WorkerUtilization() As NumericStatistic
      Get
         Return Me.Worker.Utilization
      End Get
   End Property
   <StatisticsCategory()> _
<Description("")> _
Public ReadOnly Property FileLength() As NumericStatistic
      Get
         Return Me.ComponentsQueue.FileLength
      End Get
   End Property
   <StatisticsCategory()> _
<Description("")> _
Public ReadOnly Property WaitingTime() As NumericStatistic
      Get
         Return Me.ComponentsQueue.WaitingTime
      End Get
   End Property
   Public Sub New()

      Me.AddResource(Me.Worker)
```

```
        Me.AddWaitingFile(Me.ComponentsQueue) 'Adding a waiting file to the constructor
        Me.Worker.WaitingFiles.Add(Me.ComponentsQueue) 'Linking up the Resource and Waiting File
        ' Me.Worker.WaitingFiles.Add(Me.ComponentsQueue)

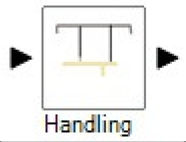
    End Sub
    Public Overrides Sub Paint(ByVal graphics As System.Drawing.Graphics, ByVal bounds As System.Drawing.RectangleF)

        Dim myBrush As New SolidBrush(Color.DarkSlateBlue)
        Dim f As Font = New Font("Arial", 8, FontStyle.Regular)
        graphics.DrawString(Me.Name.ToString, f, myBrush, bounds.Left - 15, bounds.Top + 60)

        MyBase.Paint(graphics, bounds)
        graphics.DrawImage(My.Resources.Fabrication.ToBitmap, bounds)

    End Sub
    Protected Overrides Sub InitializeRun(ByVal runIndex As Integer)
        MyBase.InitializeRun(runIndex)

    End Sub
End Class
```

Element: Handling	Input	Output
		

Code:

```
Imports System.Drawing
Imports Simphony.Simulation
Imports Cosye.Modeling
Imports Simphony
Imports Simphony.Mathematics
Imports System.IO
Imports System.Xml
Imports System.Drawing.Imaging


Public Class Handling
    Inherits FlowElement(Of ComponentEntity)

    Private _NoCranes As Integer = 2
    Private _NoWorkers As Integer = 2
    Private _PercentageofCraneNeed As Double = 1
    Private _NeededWorkerforCrane As Double = 1
    Private _NoofHandling As Integer
    Private _HanlingFleetType As String = "Cran"
    Private _WorkerType As String = "Operator"
    Private Crane As New Resource(HanlingFleetType, NoCranes)
    Private Worker As New Resource(WorkerType, NoWorkers)
    Private HandlingComponentsQueue As New WaitingFile("HandlingComponentQueue")
    Private _NoofPipesHandled As New Integer
    Private _Duration As Double = 1
    Private _ComponentState As String = "Moved"
    Private ReadOnly CycleTimeValue As New NumericStatistic("CycleTime", False)
    <StatisticsCategory()> _
    <Description("")> _
```

```
Public ReadOnly Property WorkerUtilization() As NumericStatistic
   Get
      Return Me.Worker.Utilization
   End Get
End Property
<StatisticsCategory()> _
<Description("")> _
Public ReadOnly Property CraneUtilization() As NumericStatistic
   Get
      Return Me.Crane.Utilization
   End Get
End Property
<StatisticsCategory()> _
<Description("")> _
Public ReadOnly Property FileLength() As NumericStatistic
   Get
      Return Me.HandlingComponentsQueue.FileLength
   End Get
End Property
<StatisticsCategory()> _
<Description("")> _
Public ReadOnly Property CycleTime() As NumericStatistic
   Get
      Return Me.CycleTimeValue
   End Get
End Property
<InputsCategory()> _
<Description("")> _
Public Property PercentageofCraneNeed() As Integer
   Get
      Return Me._PercentageofCraneNeed
   End Get
   Set(ByVal value As Integer)
      _PercentageofCraneNeed = value
   End Set
End Property
<InputsCategory()> _
<Description("")> _
Public Property NoCranes() As Integer
   Get
      Return Me._NoCranes
   End Get
   Set(ByVal value As Integer)
      _NoCranes = value
   End Set
End Property
<InputsCategory()> _
<Description("")> _
Public Property NoWorkers() As Integer
   Get
      Return Me._NoWorkers
   End Get
   Set(ByVal value As Integer)
      _NoWorkers = value
   End Set
End Property
<InputsCategory()> _
<Description("")> _
Public Property WorkerType() As String
   Get
      Return Me._WorkerType
   End Get
```

```
        Set(ByVal value As String)
            _WorkerType = value
        End Set
    End Property
    <InputsCategory()> _
    <Description("")> _
    Public Property HanlingFleetType() As String
        Get
            Return Me._HanlingFleetType
        End Get
        Set(ByVal value As String)
            _HanlingFleetType = value
        End Set
    End Property
    <OutputsCategory()> _
    <Description("")> _
    Public Property NoofPipesHandled() As Integer
        Get
            Return Me._NoofPipesHandled
        End Get
        Private Set(ByVal value As Integer)
            Me._NoofPipesHandled = value
        End Set
    End Property
    Public Sub New()
        Me.AddResource(Me.Crane) 'Adding a resource to the constructor
        Me.AddResource(Me.Worker)
        Me.AddStatistic(Me.CycleTime)
        Me.AddWaitingFile(Me.HandlingComponentsQueue) 'Adding a waiting file to the constructor
        Me.Crane.WaitingFiles.Add(Me.HandlingComponentsQueue) 'Linking up the Resource and Waiting File
    End Sub
    Protected Overrides Sub InitializeRun(ByVal runIndex As Integer)
        MyBase.InitializeRun(runIndex)
        Me.NoofPipesHandled = 0
    End Sub
    Public Overrides Sub Paint(ByVal graphics As System.Drawing.Graphics, ByVal bounds As System.Drawing.RectangleF)

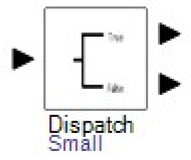
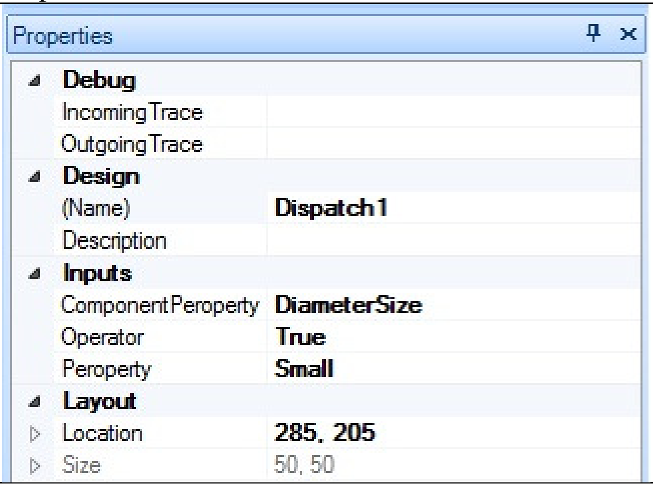
        MyBase.Paint(graphics, bounds)
        graphics.DrawImage(My.Resources.Handling.ToBitmap(), bounds)

    End Sub
    Protected Overrides Sub TransferIn(ByVal entity As ComponentEntity, ByVal point As Simphony.Modeling.InputPoint)
        'MyBase.TransferIn(entity, point)
        Dim Handler = New Action(Of ComponentEntity)(AddressOf Me.StartHandling)
        Dim l As Double = Rnd()
        Dim MyRequirements As New MultipleResourceRequirement()
        If l <= PercentageofCraneNeed Then
            MyRequirements.Add(Me.Crane, 1)
            MyRequirements.Add(Me.Worker, 1)
        Else
            MyRequirements.Add(Me.Crane, 1)
        End If

        Me.Engine.RequestResource(entity, MyRequirements, Handler, Me.HandlingComponentsQueue)

    End Sub
    Private Sub StartHandling(ByVal Entity As ComponentEntity)
        Dim Handler = New Action(Of ComponentEntity)(AddressOf Me.FinishHandling)
        Dim duration = Entity.NoPipesforComponent * _Duration
        Me.Engine.ScheduleEvent(Entity, Handler, duration)
    End Sub
    Private Sub FinishHandling(ByVal Entity As ComponentEntity)
```

```
        'Entity.State = ComponentState
        Me.NoofPipesHandled += Entity.NoPipesforComponent
        Me.Engine.ReleaseResource(Entity, Me.Crane, 1)
        Me.Engine.ReleaseResource(Entity, Me.Worker, 1)
        Me.OutputPoint.TransferOut(Entity)
    End Sub
End Class
```

Element: Dispatch	Properties
	

Properties

Debug	
IncomingTrace	
OutgoingTrace	
Design	
(Name)	**Dispatch1**
Description	
Inputs	
ComponentPeroperty	**DiameterSize**
Operator	**True**
Peroperty	**Small**
Layout	
Location	**285, 205**
Size	50, 50

Code:

```
Imports System.Drawing
Imports Simphony.Simulation
Imports Cosye.Modeling
Imports Simphony
Imports Simphony.Mathematics
Imports System.IO
Imports System.Xml
Imports System.Drawing.Imaging

Public Class Dispatch
    Inherits DivergeElement(Of ComponentEntity)

    Private OperatorValue As String = "True"
    Private ComponentPeropertyValue As String = "DiameterSize"
    Private PeropertyValue As String = "Small"
    <InputsCategory()> _
<Description("")> _
 Public Property [Operator]() As String
        Get
            Return Me.OperatorValue
        End Get
        Set(ByVal value As String)
            OperatorValue = value
        End Set
    End Property
    <InputsCategory()> _
<Description("")> _
 Public Property ComponentPeroperty() As String
```

```
        Get
            Return Me.ComponentPeropertyValue
        End Get
        Set(ByVal value As String)
            ComponentPeropertyValue = value
        End Set
    End Property
    <InputsCategory()> _
 <Description("")> _
  Public Property Peroperty() As String
        Get
            Return Me.PeropertyValue
        End Get
        Set(ByVal value As String)
            PeropertyValue = value
        End Set
    End Property
    Protected Overrides Sub InitializeRun(ByVal runIndex As Integer)
        MyBase.InitializeRun(runIndex)
    End Sub
    Public Overrides Sub Paint(ByVal graphics As System.Drawing.Graphics, ByVal bounds As System.Drawing.RectangleF)

        Dim myBrush As New SolidBrush(Color.DarkSlateBlue)
        Dim f As Font = New Font("Arial", 8, FontStyle.Regular)
        graphics.DrawString(Me.Peroperty.ToString, f, myBrush, bounds.Left, bounds.Top + 60)

        MyBase.Paint(graphics, bounds)
        graphics.DrawImage(My.Resources.Dispatch, bounds)

    End Sub
    Protected Overrides Sub TransferIn(ByVal entity As ComponentEntity, ByVal point As Simphony.Modeling.InputPoint)
        'MyBase.TransferIn(entity, point)
        Select Case ComponentPeropertyValue
            Case "DiameterSize" : If entity.DiameterSize.ToString = Peroperty Then
                    Me.FirstOutputPoint.TransferOut(entity)
                Else
                    Me.SecondOutputPoint.TransferOut(entity)
                End If

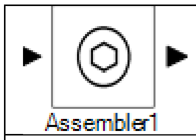
            Case "Length" : If entity.Length.ToString = Peroperty Then
                    Me.FirstOutputPoint.TransferOut(entity)
                Else
                    Me.SecondOutputPoint.TransferOut(entity)
                End If

            Case "Material" : If entity.Material.ToString = Peroperty Then
                    Me.FirstOutputPoint.TransferOut(entity)
                Else
                    Me.SecondOutputPoint.TransferOut(entity)
                End If

        End Select

    End Sub
End Class
```

Element: Assembler	Input	Output



Code:

```
Imports System.Collections
Imports System
Imports System.Drawing
Imports System.Data

Public Class Assembler
   Inherits FlowElement(Of ComponentEntity)
   Private SpoolinfoTable As New DataTable()
   Dim NSpoolSArrived As Integer = 0
   Private Sub CreatSpoolinfoTable()

      Dim myDataColumn As New DataColumn("SpoolID1", GetType(System.String))
      SpoolinfoTable.Columns.Add(myDataColumn)

      myDataColumn = New DataColumn("NoComponents1", GetType(System.Int32))
      SpoolinfoTable.Columns.Add(myDataColumn)

      myDataColumn = New DataColumn("FinishedNoComponents1", GetType(System.Int32)) 'enum type
      SpoolinfoTable.Columns.Add(myDataColumn)

      myDataColumn = New DataColumn("PositionDI1", GetType(System.String))
      SpoolinfoTable.Columns.Add(myDataColumn)


      SpoolinfoTable.AcceptChanges()

   End Sub
   Private Sub InitialzeSpoolinfoTable()

      For i As Integer = 0 To 100
         Dim myDataRow As DataRow
         myDataRow = SpoolinfoTable.NewRow()

         myDataRow("SpoolID1") = "0"
         myDataRow("NoComponents1") = 0
         myDataRow("FinishedNoComponents1") = 0
         myDataRow("PositionDI1") = "0"
         SpoolinfoTable.Rows.Add(myDataRow)

      Next
   End Sub
   Public Sub New()
      CreatSpoolinfoTable()
   End Sub
   Protected Overrides Sub InitializeRun(ByVal runIndex As Integer)
      MyBase.InitializeRun(runIndex)
      InitialzeSpoolinfoTable()
   End Sub
   Public Overrides Sub Paint(ByVal graphics As System.Drawing.Graphics, ByVal bounds As System.Drawing.RectangleF)

      MyBase.Paint(graphics, bounds)
      graphics.DrawImage(My.Resources.Assembler.ToBitmap(), bounds)

   End Sub
   Protected Overrides Sub TransferIn(ByVal entity As ComponentEntity, ByVal point As Simphony.Modeling.InputPoint)
```

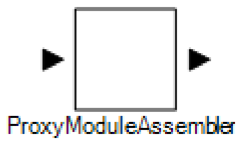
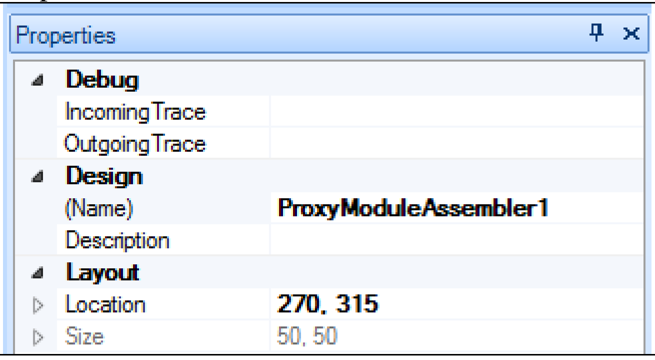
```
        Dim exsist As String = "NO"

        For i As Integer = 0 To NSpoolSArrived - 1
            If entity.SpoolID = SpoolinfoTable.Rows.Item(i)("SpoolID1") Then
                exsist = "YES"
                SpoolinfoTable.Rows.Item(i)("FinishedNoComponents1") += 1
                Trace.WriteLine("EntityStayes" & entity.SpoolID)
                If SpoolinfoTable.Rows.Item(i)("FinishedNoComponents1") = entity.NumberofComponents Then
                    Me.OutputPoint.TransferOut(entity)
                    Trace.WriteLine("EntityOut" & entity.SpoolID)
                End If
            End If
        Next

        If exsist = "NO" Then

            SpoolinfoTable.Rows.Item(NSpoolSArrived)("SpoolID1") = entity.SpoolID
            SpoolinfoTable.Rows.Item(NSpoolSArrived)("FinishedNoComponents1") += 1
            NSpoolSArrived += 1

        End If
    End Sub
End Class
```

Element: Proxy Module Assembler	Properties
	

Properties

Debug	
IncomingTrace	
OutgoingTrace	
Design	
(Name)	ProxyModuleAssembler1
Description	
Layout	
Location	270, 315
Size	50, 50

Code:

```
Imports System.Drawing
Imports Simphony.Simulation
Imports Cosye.Hla.Rti
Imports Cosye.Modeling
Imports Simphony
Imports Simphony.Mathematics
Public Class ProxyModuleAssembler
    Inherits FlowElement(Of SpoolEntity)

    Private ReadOnly spoolCount As New Dictionary(Of ObjectInstanceHandle, Integer)

    Private rtiAmb As IRTIambassador
    Private proxies As IProxyProvider
    Private SpoolinfoTable As New DataTable()
    Dim NModuleSArrived As Integer = 0

    Protected Overrides Sub InitializeRun(ByVal runIndex As Integer)
        MyBase.InitializeRun(runIndex)
        'SpoolinfoTable.Clear()
        'InitialzeModuleinfoTable()
        Me.spoolCount.Clear()
        Me.rtiAmb = Me.GetService(Of IRTIambassador)()
        Me.proxies = Me.GetService(Of IProxyProvider)()
    End Sub
    Protected Overrides Sub TransferIn(ByVal entity As SpoolEntity, ByVal point As Simphony.Modeling.InputPoint)
        'MyBase.TransferIn(entity, point)
        Trace.WriteLine("Modulehandle:** " & entity.ModuleHandle.ToString)

        Dim proxy = Me.proxies(entity.ModuleHandle)
        Dim theClass = rtiAmb.GetKnownObjectClassHandle(entity.ModuleHandle)
        Dim theModuleTotalNumberofSpools = rtiAmb.GetAttributeHandle(theClass, "TotalNumberofSpool")
        Dim theModuleFinishedNumberofSpools = rtiAmb.GetAttributeHandle(theClass, "NumberofSpoolsFabricated")
        Dim CompReadyTime = rtiAmb.GetAttributeHandle(theClass, "CompReadyTime")

        If Me.spoolCount.ContainsKey(entity.ModuleHandle) Then
            Me.spoolCount(entity.ModuleHandle) += 1
        Else
            Me.spoolCount(entity.ModuleHandle) = 1
        End If
        rtiAmb.AttributeOwnershipAcquisition(entity.ModuleHandle, New AttributeHandle() {theModuleFinishedNumberofSpools}, Nothing)
        rtiAmb.AttributeOwnershipAcquisition(entity.ModuleHandle, New AttributeHandle() {CompReadyTime}, Nothing)

        Dim theValues As New AttributeHandleValueMap()
        Dim lookahead = CType(Me.Scenario, CosyeScenario).Lookahead
        theValues.Add(theModuleFinishedNumberofSpools, Me.spoolCount(entity.ModuleHandle))
        theValues.Add(CompReadyTime, Me.Engine.TimeNow)

        rtiAmb.UpdateAttributeValues(entity.ModuleHandle, theValues, Nothing, Me.Engine.TimeNow + lookahead)

        rtiAmb.UnconditionalAttributeOwnershipDivestiture(entity.ModuleHandle, New AttributeHandle() {theModuleFinishedNumberofSpools})
        rtiAmb.UnconditionalAttributeOwnershipDivestiture(entity.ModuleHandle, New AttributeHandle() {CompReadyTime})

        If Me.spoolCount(entity.ModuleHandle) = proxy.Values(theModuleTotalNumberofSpools) Then
            Dim newEntity = New ProxyEntity(proxy)
            Dim handler = New Action(Of ProxyEntity)(AddressOf TransferOut)
            Me.Engine.ScheduleEvent(newEntity, handler, lookahead)
            Trace.WriteLine("Lookahead" & lookahead)
        End If

    End Sub

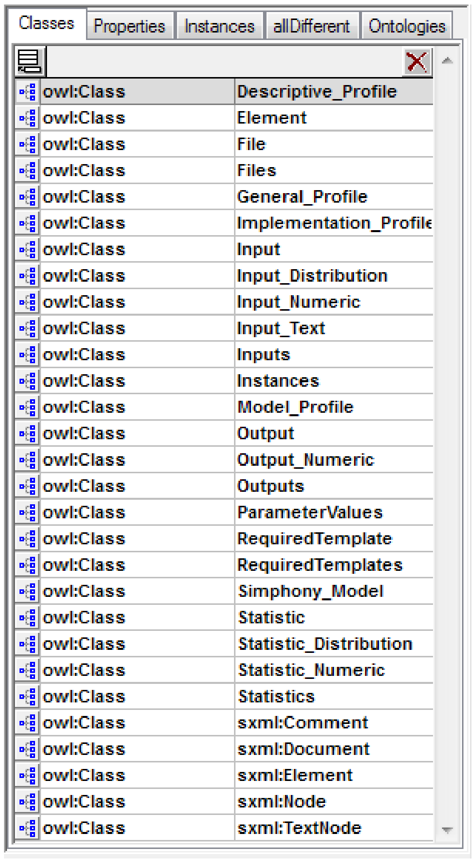
    Private Sub TransferOut(ByVal entity As ProxyEntity)
        Me.OutputPoint.TransferOut(entity)
    End Sub

End Class
```

Appendix IV

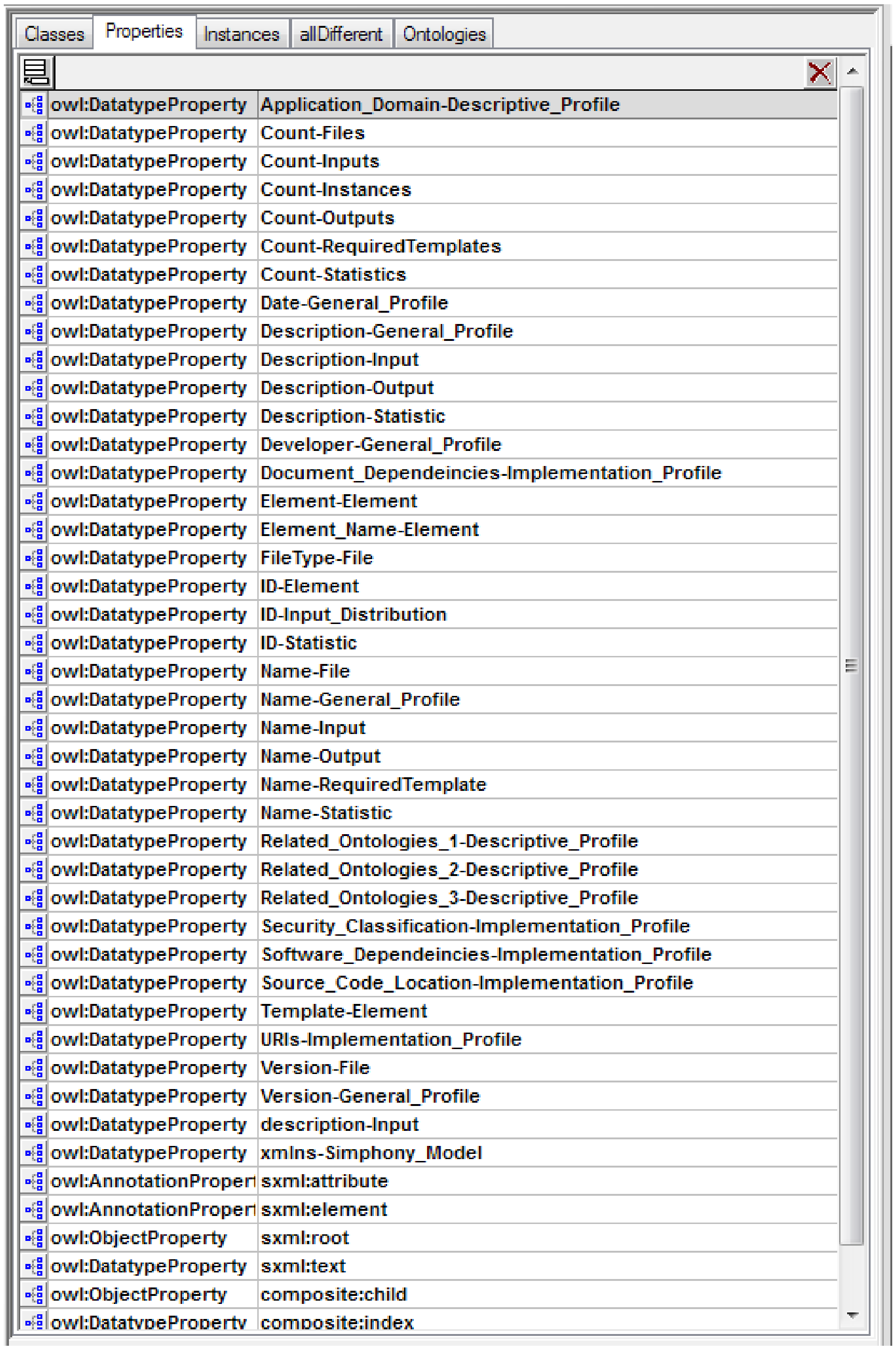
An Example of Stored Model (Spool Fabrication Shop Model_M1) in Construction Modeling Repository

Fig A-IV-1: Classes in Spool_Fabrication_Model_M1



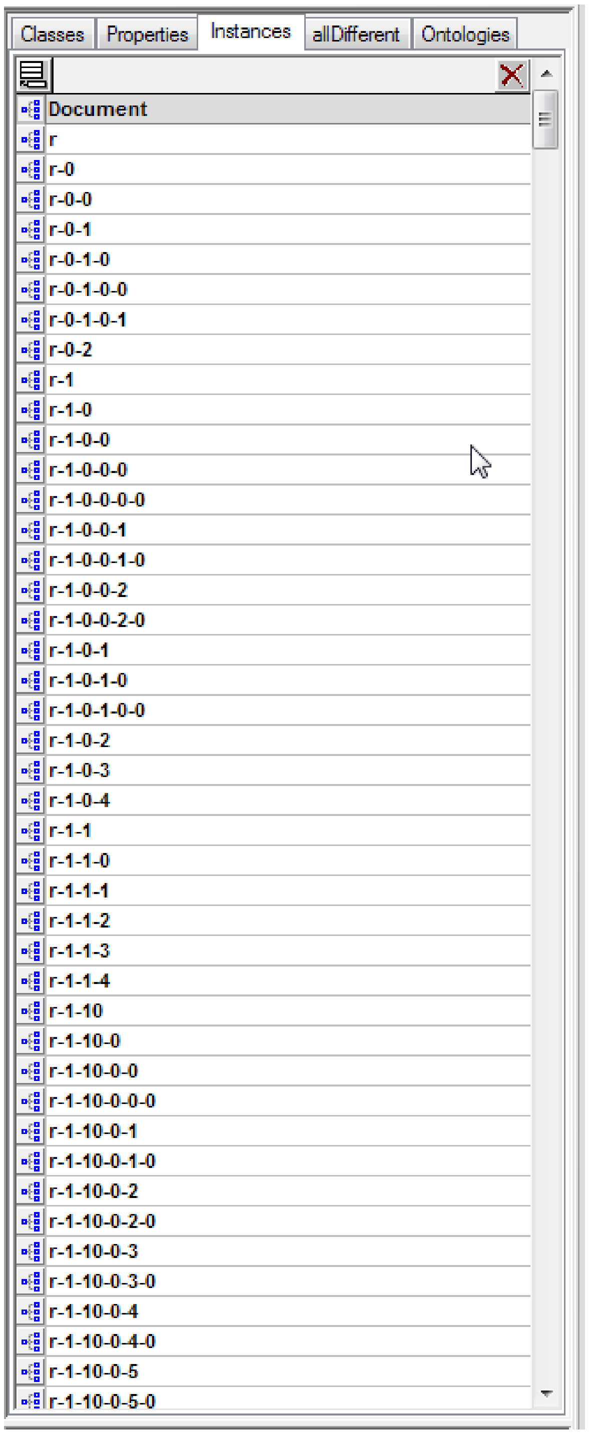
owl:Class	Descriptive_Profile
owl:Class	Element
owl:Class	File
owl:Class	Files
owl:Class	General_Profile
owl:Class	Implementation_Profile
owl:Class	Input
owl:Class	Input_Distribution
owl:Class	Input_Numeric
owl:Class	Input_Text
owl:Class	Inputs
owl:Class	Instances
owl:Class	Model_Profile
owl:Class	Output
owl:Class	Output_Numeric
owl:Class	Outputs
owl:Class	ParameterValues
owl:Class	RequiredTemplate
owl:Class	RequiredTemplates
owl:Class	Simphony_Model
owl:Class	Statistic
owl:Class	Statistic_Distribution
owl:Class	Statistic_Numeric
owl:Class	Statistics
owl:Class	sxml:Comment
owl:Class	sxml:Document
owl:Class	sxml:Element
owl:Class	sxml:Node
owl:Class	sxml:TextNode

Fig A-IV-2: Properties in Spool_Fabrication_Model_M1



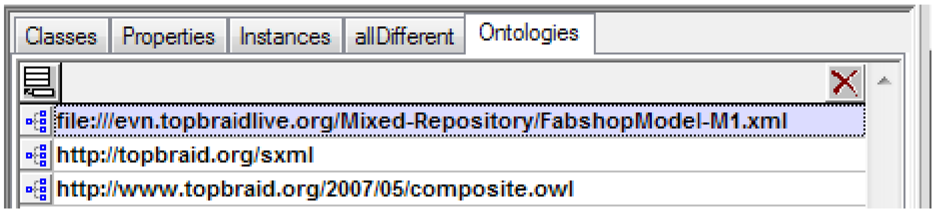
owl:DatatypeProperty	Application_Domain-Descriptive_Profile
owl:DatatypeProperty	Count-Files
owl:DatatypeProperty	Count-Inputs
owl:DatatypeProperty	Count-Instances
owl:DatatypeProperty	Count-Outputs
owl:DatatypeProperty	Count-RequiredTemplates
owl:DatatypeProperty	Count-Statistics
owl:DatatypeProperty	Date-General_Profile
owl:DatatypeProperty	Description-General_Profile
owl:DatatypeProperty	Description-Input
owl:DatatypeProperty	Description-Output
owl:DatatypeProperty	Description-Statistic
owl:DatatypeProperty	Developer-General_Profile
owl:DatatypeProperty	Document_Dependeincies-Implementation_Profile
owl:DatatypeProperty	Element-Element
owl:DatatypeProperty	Element_Name-Element
owl:DatatypeProperty	FileType-File
owl:DatatypeProperty	ID-Element
owl:DatatypeProperty	ID-Input_Distribution
owl:DatatypeProperty	ID-Statistic
owl:DatatypeProperty	Name-File
owl:DatatypeProperty	Name-General_Profile
owl:DatatypeProperty	Name-Input
owl:DatatypeProperty	Name-Output
owl:DatatypeProperty	Name-RequiredTemplate
owl:DatatypeProperty	Name-Statistic
owl:DatatypeProperty	Related_Ontologies_1-Descriptive_Profile
owl:DatatypeProperty	Related_Ontologies_2-Descriptive_Profile
owl:DatatypeProperty	Related_Ontologies_3-Descriptive_Profile
owl:DatatypeProperty	Security_Classification-Implementation_Profile
owl:DatatypeProperty	Software_Dependeincies-Implementation_Profile
owl:DatatypeProperty	Source_Code_Location-Implementation_Profile
owl:DatatypeProperty	Template-Element
owl:DatatypeProperty	URIs-Implementation_Profile
owl:DatatypeProperty	Version-File
owl:DatatypeProperty	Version-General_Profile
owl:DatatypeProperty	description-Input
owl:DatatypeProperty	xmlns-Simphony_Model
owl:AnnotationPropert	sxml:attribute
owl:AnnotationPropert	sxml:element
owl:ObjectProperty	sxml:root
owl:DatatypeProperty	sxml:text
owl:ObjectProperty	composite:child
owl:DatatypeProperty	composite:index

Fig A-IV-2: Instances in Spool_Fabrication_Model_M1



Document
r
r-0
r-0-0
r-0-1
r-0-1-0
r-0-1-0-0
r-0-1-0-1
r-0-2
r-1
r-1-0
r-1-0-0
r-1-0-0-0
r-1-0-0-0-0
r-1-0-0-1
r-1-0-0-1-0
r-1-0-0-2
r-1-0-0-2-0
r-1-0-1
r-1-0-1-0
r-1-0-1-0-0
r-1-0-2
r-1-0-3
r-1-0-4
r-1-1
r-1-1-0
r-1-1-1
r-1-1-2
r-1-1-3
r-1-1-4
r-1-10
r-1-10-0
r-1-10-0-0
r-1-10-0-0-0
r-1-10-0-1
r-1-10-0-1-0
r-1-10-0-2
r-1-10-0-2-0
r-1-10-0-3
r-1-10-0-3-0
r-1-10-0-4
r-1-10-0-4-0
r-1-10-0-5
r-1-10-0-5-0

Fig A-IV-2: Ontologies in Spool_Fabrication_Model_M1



file:///evn.topbraidlive.org/Mixed-Repository/FabshopModel-M1.xml
http://topbraid.org/sxml
http://www.topbraid.org/2007/05/composite.owl

Spool_Fabrication_Model_M1 RDF Code (just first and last page):

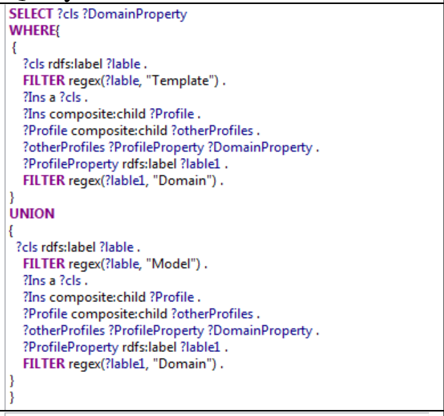
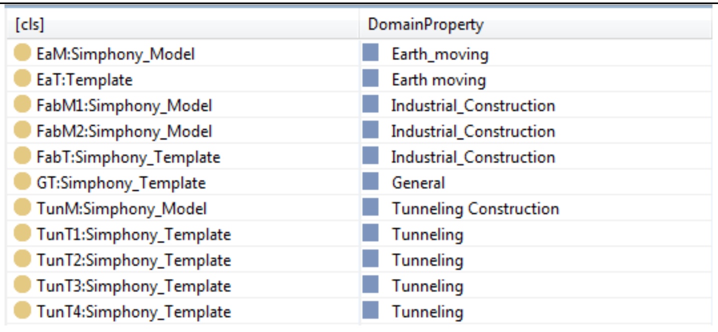
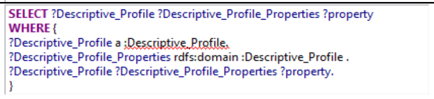
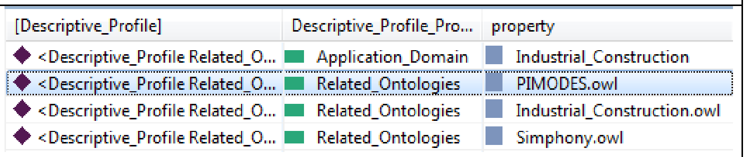
```
<?xml version="1.0"?>
<rdf:RDF
   xmlns:sxml="http://topbraid.org/sxml#"
   xmlns:rdf="http://www.w3.org/1999/02/22-rdf-syntax-ns#"
   xmlns:owl="http://www.w3.org/2002/07/owl#"
   xmlns:xsd="http://www.w3.org/2001/XMLSchema#"
   xmlns:composite="http://www.topbraid.org/2007/05/composite.owl#"
   xmlns="file:///evn.topbraidlive.org/Mixed-Repository/FabshopModel-M1.xml#"
   xmlns:rdfs="http://www.w3.org/2000/01/rdf-schema#"
  xml:base="file:///evn.topbraidlive.org/Mixed-Repository/FabshopModel-M1.xml">
  <owl:Ontology rdf:about="">
   <owl:imports rdf:resource="http://topbraid.org/sxml"/>
  </owl:Ontology>
  <owl:Class rdf:ID="Input_Text">
   <rdfs:label>Input_Text</rdfs:label>
   <sxml:element>Input_Text</sxml:element>
  </owl:Class>
  <owl:Class rdf:ID="Simphony_Model">
   <rdfs:label>Simphony_Model</rdfs:label>
   <sxml:element>Simphony_Model</sxml:element>
  </owl:Class>
  <owl:Class rdf:ID="ParameterValues">
   <rdfs:label>ParameterValues</rdfs:label>
   <sxml:element>ParameterValues</sxml:element>
  </owl:Class>
  <owl:Class rdf:ID="Element">
   <rdfs:label>Element</rdfs:label>
   <sxml:element>Element</sxml:element>
  </owl:Class>
  <owl:Class rdf:ID="Files">
   <rdfs:label>Files</rdfs:label>
  <sxml:element>Files</sxml:element>
</owl:Class>
<owl:Class rdf:ID="Input_Distribution">
  <rdfs:label>Input_Distribution</rdfs:label>
  <sxml:element>Input_Distribution</sxml:element>
</owl:Class>
<owl:Class rdf:ID="RequiredTemplates">
  <rdfs:label>RequiredTemplates</rdfs:label>
  <sxml:element>RequiredTemplates</sxml:element>
</owl:Class>
<owl:Class rdf:ID="Statistic_Numeric">
  <rdfs:label>Statistic_Numeric</rdfs:label>
  <sxml:element>Statistic_Numeric</sxml:element>
</owl:Class>
<owl:Class rdf:ID="Implementation_Profile">
  <rdfs:label>Implementation_Profile</rdfs:label>
  <sxml:element>Implementation_Profile</sxml:element>
</owl:Class>
<owl:Class rdf:ID="Input_Numeric">
  <rdfs:label>Input_Numeric</rdfs:label>
  <sxml:element>Input_Numeric</sxml:element>
</owl:Class>
<owl:Class rdf:ID="Model_Profile">
  <rdfs:label rdf:datatype="http://www.w3.org/2001/XMLSchema#string"
  >Model_Profile</rdfs:label>
  <sxml:element rdf:datatype="http://www.w3.org/2001/XMLSchema#string"
  >Model_Profile</sxml:element>
</owl:Class>
<owl:Class rdf:ID="Output_Numeric">
  <rdfs:label>Output_Numeric</rdfs:label>
  <sxml:element>Output_Numeric</sxml:element>
</owl:Class>
<owl:Class rdf:ID="Input">
  <rdfs:label>Input</rdfs:label>
  <sxml:element>Input</sxml:element>
</owl:Class>
.
.
.
   <RequiredTemplate rdf:ID="r-0-1-0-0">
              <composite:index rdf:datatype="http://www.w3.org/2001/XMLSchema#int"
```

```
                  >0</composite:index>
                  <Name-RequiredTemplate>General</Name-RequiredTemplate>
                </RequiredTemplate>
              </composite:child>
              <Count-RequiredTemplates>2</Count-RequiredTemplates>
            </RequiredTemplates>
          </composite:child>
          <Related_Ontologies_3-Descriptive_Profile>PIMODES.owl</Related_Ontologies_3-
Descriptive_Profile>
          <Related_Ontologies_2-Descriptive_Profile>Simphony.owl</Related_Ontologies_2-
Descriptive_Profile>
          <Related_Ontologies_1-
Descriptive_Profile>Industrial_Construction.owl</Related_Ontologies_1-Descriptive_Profile>
          <Application_Domain-
Descriptive_Profile>Industrial_Construction</Application_Domain-Descriptive_Profile>
        </Descriptive_Profile>
      </composite:child>
      <composite:child>
        <General_Profile rdf:ID="r-0-0">
          <composite:index rdf:datatype="http://www.w3.org/2001/XMLSchema#int"
          >0</composite:index>
          <Version-General_Profile>2</Version-General_Profile>
          <Name-General_Profile>Spool_Fabrication_Shop</Name-General_Profile>
          <Developer-General_Profile>Naeimeh_Sadeghi</Developer-General_Profile>
          <Description-General_Profile>Lockerbie and Hole fabrication shop</Description-
General_Profile>
          <Date-General_Profile>Septermber2009</Date-General_Profile>
        </General_Profile>
      </composite:child>
      <composite:index rdf:datatype="http://www.w3.org/2001/XMLSchema#int"
      >0</composite:index>
    </Model_Profile>
  </composite:child>
  <xmlns-Simphony_Model>http://www.construction.ualberta.ca/Simphony/Model</xmlns-
Simphony_Model>
  </Simphony_Model>
 </sxml:root>
</sxml:Document>
</rdf:RDF>
<!-- Created with TopBraid -->
```

Appendix V

Construction Modeling Repository SPARQL Queries

Table A-III-1: Construction Modeling Repository SPARQL queries syntax and results displayed in TBC

#	Query	Result
Q1		
Q2		

Q1 query:

```
SELECT ?cls ?DomainProperty
WHERE{
 {
   ?cls rdfs:label ?lable .
   FILTER regex(?lable, "Template") .
   ?Ins a ?cls .
   ?Ins composite:child ?Profile .
   ?Profile composite:child ?otherProfiles .
   ?otherProfiles ?ProfileProperty ?DomainProperty .
   ?ProfileProperty rdfs:label ?lable1 .
   FILTER regex(?lable1, "Domain") .
 }
UNION
{
  ?cls rdfs:label ?lable .
   FILTER regex(?lable, "Model") .
   ?Ins a ?cls .
   ?Ins composite:child ?Profile .
   ?Profile composite:child ?otherProfiles .
   ?otherProfiles ?ProfileProperty ?DomainProperty .
   ?ProfileProperty rdfs:label ?lable1 .
   FILTER regex(?lable1, "Domain") .
}
}
```

Q1 result:

[cls]	DomainProperty
● EaM:Simphony_Model	▪ Earth_moving
● EaT:Template	▪ Earth moving
● FabM1:Simphony_Model	▪ Industrial_Construction
● FabM2:Simphony_Model	▪ Industrial_Construction
● FabT:Simphony_Template	▪ Industrial_Construction
● GT:Simphony_Template	▪ General
● TunM:Simphony_Model	▪ Tunneling Construction
● TunT1:Simphony_Template	▪ Tunneling
● TunT2:Simphony_Template	▪ Tunneling
● TunT3:Simphony_Template	▪ Tunneling
● TunT4:Simphony_Template	▪ Tunneling

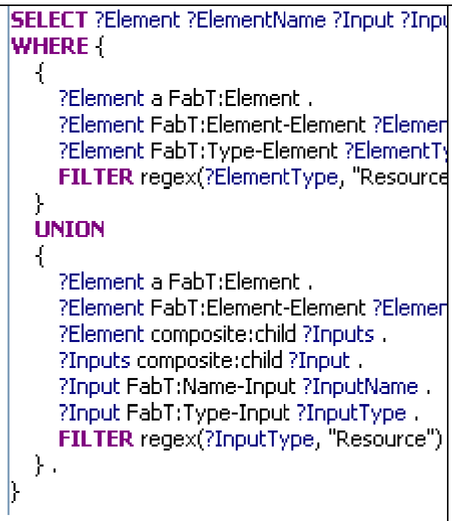
Q2 query:

```
SELECT ?Descriptive_Profile ?Descriptive_Profile_Properties ?property
WHERE {
?Descriptive_Profile a :Descriptive_Profile.
?Descriptive_Profile_Properties rdfs:domain :Descriptive_Profile .
?Descriptive_Profile ?Descriptive_Profile_Properties ?property.
}
```

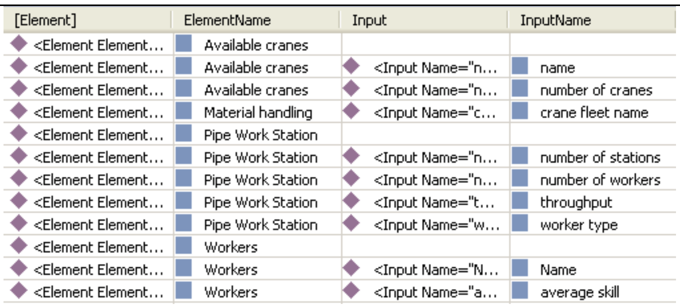
Q2 result:

[Descriptive_Profile]	Descriptive_Profile_Pro...	property
◆ <Descriptive_Profile Related_O...	▬ Application_Domain	▪ Industrial_Construction
◆ <Descriptive_Profile Related_O...	▬ Related_Ontologies	▪ PIMODES.owl
◆ <Descriptive_Profile Related_O...	▬ Related_Ontologies	▪ Industrial_Construction.owl
◆ <Descriptive_Profile Related_O...	▬ Related_Ontologies	▪ Simphony.owl

Q3

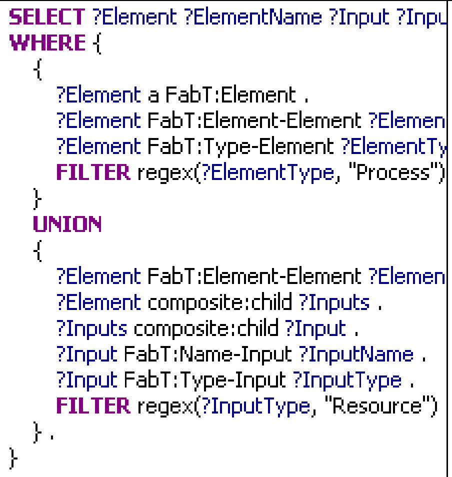


```
SELECT ?Element ?ElementName ?Input ?Inpu
WHERE {
  {
    ?Element a FabT:Element .
    ?Element FabT:Element-Element ?Elemen
    ?Element FabT:Type-Element ?ElementTy
    FILTER regex(?ElementType, "Resource
  }
  UNION
  {
    ?Element a FabT:Element .
    ?Element FabT:Element-Element ?Elemen
    ?Element composite:child ?Inputs .
    ?Inputs composite:child ?Input .
    ?Input FabT:Name-Input ?InputName .
    ?Input FabT:Type-Input ?InputType .
    FILTER regex(?InputType, "Resource")
  } .
}
```

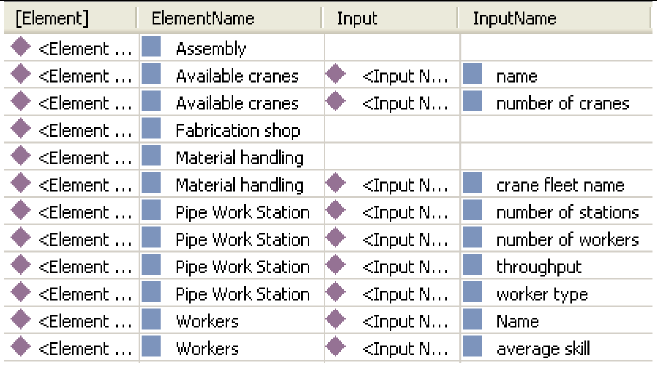


[Element]	ElementName	Input	InputName
<Element Element...	Available cranes		
<Element Element...	Available cranes	<Input Name="n...	name
<Element Element...	Available cranes	<Input Name="n...	number of cranes
<Element Element...	Material handling	<Input Name="c...	crane fleet name
<Element Element...	Pipe Work Station		
<Element Element...	Pipe Work Station	<Input Name="n...	number of stations
<Element Element...	Pipe Work Station	<Input Name="n...	number of workers
<Element Element...	Pipe Work Station	<Input Name="t...	throughput
<Element Element...	Pipe Work Station	<Input Name="w...	worker type
<Element Element...	Workers		
<Element Element...	Workers	<Input Name="N...	Name
<Element Element...	Workers	<Input Name="a...	average skill

Q4

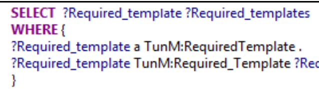


```
SELECT ?Element ?ElementName ?Input ?Inpu
WHERE {
  {
    ?Element a FabT:Element .
    ?Element FabT:Element-Element ?Elemen
    ?Element FabT:Type-Element ?ElementTy
    FILTER regex(?ElementType, "Process")
  }
  UNION
  {
    ?Element FabT:Element-Element ?Elemen
    ?Element composite:child ?Inputs .
    ?Inputs composite:child ?Input .
    ?Input FabT:Name-Input ?InputName .
    ?Input FabT:Type-Input ?InputType .
    FILTER regex(?InputType, "Resource")
  } .
}
```

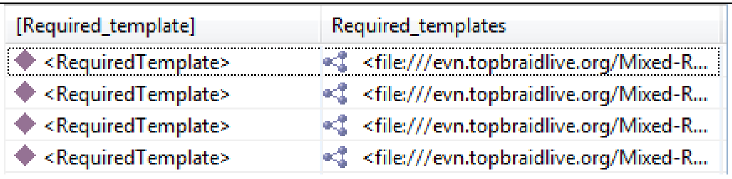


[Element]	ElementName	Input	InputName
<Element ...	Assembly		
<Element ...	Available cranes	<Input N...	name
<Element ...	Available cranes	<Input N...	number of cranes
<Element ...	Fabrication shop		
<Element ...	Material handling		
<Element ...	Material handling	<Input N...	crane fleet name
<Element ...	Pipe Work Station	<Input N...	number of stations
<Element ...	Pipe Work Station	<Input N...	number of workers
<Element ...	Pipe Work Station	<Input N...	throughput
<Element ...	Pipe Work Station	<Input N...	worker type
<Element ...	Workers	<Input N...	Name
<Element ...	Workers	<Input N...	average skill

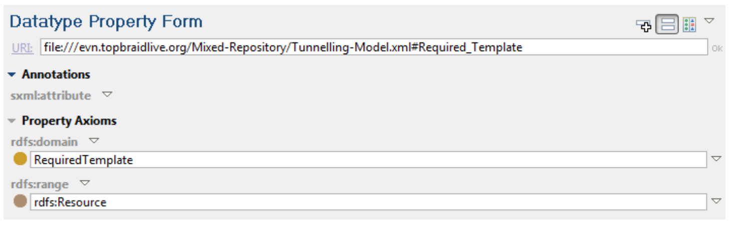
Q5



```
SELECT ?Required_template ?Required_templates
WHERE {
?Required_template a TunM:RequiredTemplate .
?Required_template TunM:Required_Template ?Required_templates .
}
```



[Required_template]	Required_templates
<RequiredTemplate>	<file:///evn.topbraidlive.org/Mixed-R...
<RequiredTemplate>	<file:///evn.topbraidlive.org/Mixed-R...
<RequiredTemplate>	<file:///evn.topbraidlive.org/Mixed-R...
<RequiredTemplate>	<file:///evn.topbraidlive.org/Mixed-R...



Datatype Property Form

URI: file:///evn.topbraidlive.org/Mixed-Repository/Tunnelling-Model.xml#Required_Template

Annotations

sxml:attribute

Property Axioms

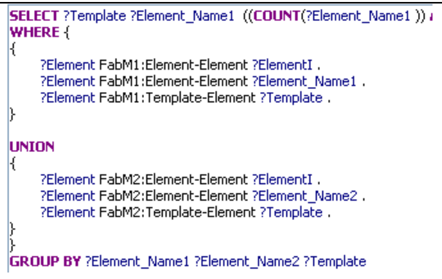
rdfs:domain

RequiredTemplate

rdfs:range

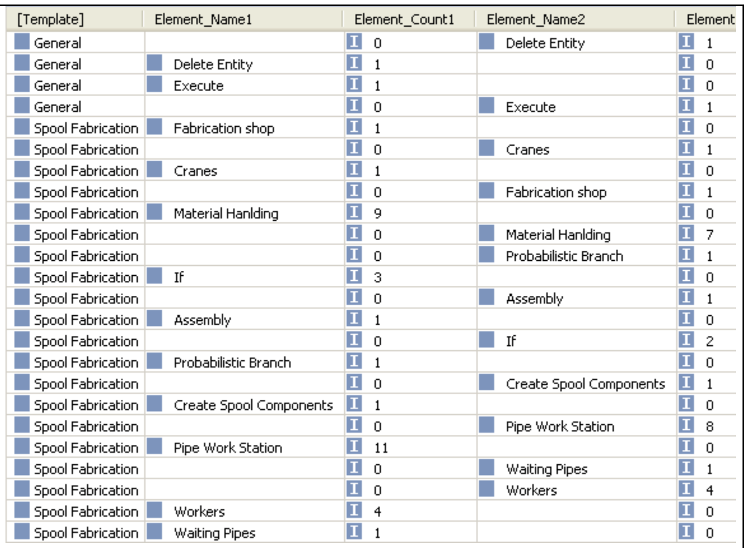
rdfs:Resource

Q6



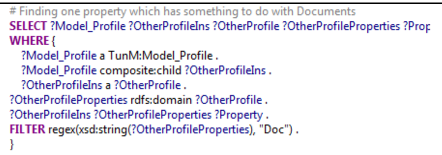
```
SELECT ?Template ?Element_Name1 ((COUNT(?Element_Name1 ))
WHERE {
{
      ?Element FabM1:Element-Element ?ElementI .
      ?Element FabM1:Element-Element ?Element_Name1 .
      ?Element FabM1:Template-Element ?Template .
}

UNION
{
      ?Element FabM2:Element-Element ?ElementI .
      ?Element FabM2:Element-Element ?Element_Name2 .
      ?Element FabM2:Template-Element ?Template .
}
}
GROUP BY ?Element_Name1 ?Element_Name2 ?Template
```

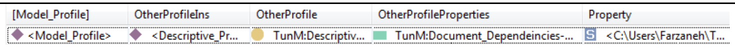


[Template]	Element_Name1	Element_Count1	Element_Name2	Element
General		0	Delete Entity	1
General	Delete Entity	1		0
General	Execute	1		0
General		0	Execute	1
Spool Fabrication	Fabrication shop	1		0
Spool Fabrication		0	Cranes	1
Spool Fabrication	Cranes	1		0
Spool Fabrication		0	Fabrication shop	1
Spool Fabrication	Material Hanlding	9		0
Spool Fabrication		0	Material Hanlding	7
Spool Fabrication		0	Probabilistic Branch	1
Spool Fabrication	If	3		0
Spool Fabrication		0	Assembly	1
Spool Fabrication	Assembly	1		0
Spool Fabrication		0	If	2
Spool Fabrication	Probabilistic Branch	1		0
Spool Fabrication		0	Create Spool Components	1
Spool Fabrication	Create Spool Components	1		0
Spool Fabrication		0	Pipe Work Station	8
Spool Fabrication	Pipe Work Station	11		0
Spool Fabrication		0	Waiting Pipes	1
Spool Fabrication		0	Workers	4
Spool Fabrication	Workers	4		0
Spool Fabrication	Waiting Pipes	1		0

Q7



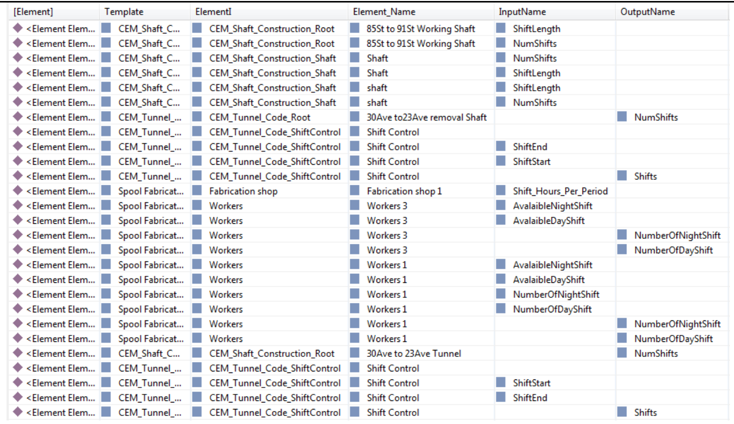
```
# Finding one property which has something to do with Documents
SELECT ?Model_Profile ?OtherProfileIns ?OtherProfile ?OtherProfileProperties ?Prop
WHERE {
  ?Model_Profile a TunM:Model_Profile .
  ?Model_Profile composite:child ?OtherProfileIns .
  ?OtherProfileIns a ?OtherProfile .
?OtherProfileProperties rdfs:domain ?OtherProfile .
?OtherProfileIns ?OtherProfileProperties ?Property .
FILTER regex(xsd:string(?OtherProfileProperties), "Doc") .
}
```



[Model_Profile]	OtherProfileIns	OtherProfile	OtherProfileProperties	Property
<Model_Profile>	<Descriptive_Pr...	TunM:Descriptiv...	TunM:Document_Dependeincies-...	<C:\Users\Farzaneh\T...

Q8

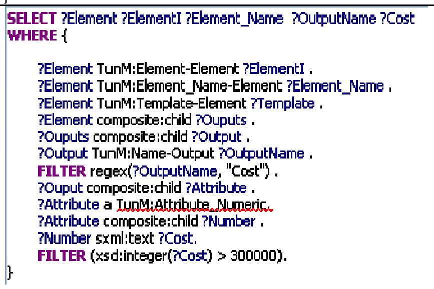
```
WHERE {
   {
      ?Element a TunM:Element .
      ?Element TunM:Element-Element ?ElementI .
      ?Element TunM:Element_Name-Element ?Element_Name .
      FILTER regex(?Element_Name, "Shift") .
      ?Element TunM:Template-Element ?Template .
   }
   UNION
   {
      ?Element TunM:Element-Element ?ElementI .
      ?Element TunM:Element_Name-Element ?Element_Name .
      ?Element TunM:Template-Element ?Template .
      ?Element composite:child ?Inputs .
      ?Inputs composite:child ?Input .
      ?Input TunM:Name-Input ?InputName .
      FILTER regex(?InputName, "Shift") .
   }
   UNION
   {
      ?Element TunM:Element-Element ?ElementI .
      ?Element TunM:Element_Name-Element ?Element_Name .
      ?Element TunM:Template-Element ?Template .
      ?Element composite:child ?Ouputs .
      ?Ouputs composite:child ?Output .
      ?Output TunM:Name-Output ?OutputName .
      FILTER regex(?OutputName, "Shift") .
   }
UNION
 {
      ?Element a FabM1:Element .
      ?Element FabM1:Element-Element ?ElementI .
      ?Element FabM1:Element_Name-Element ?Element_Name .
      FILTER regex(?Element_Name, "Shift") .
      ?Element FabM1:Template-Element ?Template .
}
 UNION
   {
      ?Element FabM1:Element-Element ?ElementI .
      ?Element FabM1:Element_Name-Element ?Element_Name .
      ?Element FabM1:Template-Element ?Template .
      ?Element composite:child ?Inputs .
      ?Inputs composite:child ?Input .
      ?Input FabM1:Name-Input ?InputName .
      FILTER regex(?InputName, "Shift") .
   }
   UNION
   {
      ?Element FabM1:Element-Element ?ElementI .
      ?Element FabM1:Element_Name-Element ?Element_Name .
      ?Element FabM1:Template-Element ?Template .
      ?Element composite:child ?Ouputs .
```



[Element]	Template	ElementI	Element_Name	InputName	OutputName
<Element Elem...	CEM_Shaft_C...	CEM_Shaft_Construction_Root	85St to 91St Working Shaft	ShiftLength	
<Element Elem...	CEM_Shaft_C...	CEM_Shaft_Construction_Root	85St to 91St Working Shaft	NumShifts	
<Element Elem...	CEM_Shaft_C...	CEM_Shaft_Construction_Shaft	Shaft	NumShifts	
<Element Elem...	CEM_Shaft_C...	CEM_Shaft_Construction_Shaft	Shaft	ShiftLength	
<Element Elem...	CEM_Shaft_C...	CEM_Shaft_Construction_Shaft	shaft	ShiftLength	
<Element Elem...	CEM_Shaft_C...	CEM_Shaft_Construction_Shaft	shaft	NumShifts	
<Element Elem...	CEM_Tunnel_...	CEM_Tunnel_Code_Root	30Ave to23Ave removal Shaft		NumShifts
<Element Elem...	CEM_Tunnel_...	CEM_Tunnel_Code_ShiftControl	Shift Control		
<Element Elem...	CEM_Tunnel_...	CEM_Tunnel_Code_ShiftControl	Shift Control	ShiftEnd	
<Element Elem...	CEM_Tunnel_...	CEM_Tunnel_Code_ShiftControl	Shift Control	ShiftStart	
<Element Elem...	CEM_Tunnel_...	CEM_Tunnel_Code_ShiftControl	Shift Control		Shifts
<Element Elem...	Spool Fabricat...	Fabrication shop	Fabrication shop 1	Shift_Hours_Per_Period	
<Element Elem...	Spool Fabricat...	Workers	Workers 3	AvalaibleNightShift	
<Element Elem...	Spool Fabricat...	Workers	Workers 3	AvalaibleDayShift	
<Element Elem...	Spool Fabricat...	Workers	Workers 3		NumberOfNightShift
<Element Elem...	Spool Fabricat...	Workers	Workers 3		NumberOfDayShift
<Element Elem...	Spool Fabricat...	Workers	Workers 1	AvalaibleNightShift	
<Element Elem...	Spool Fabricat...	Workers	Workers 1	AvalaibleDayShift	
<Element Elem...	Spool Fabricat...	Workers	Workers 1	NumberOfNightShift	
<Element Elem...	Spool Fabricat...	Workers	Workers 1	NumberOfDayShift	
<Element Elem...	Spool Fabricat...	Workers	Workers 1		NumberOfNightShift
<Element Elem...	Spool Fabricat...	Workers	Workers 1		NumberOfDayShift
<Element Elem...	CEM_Shaft_C...	CEM_Shaft_Construction_Root	30Ave to 23Ave Tunnel		NumShifts
<Element Elem...	CEM_Tunnel_...	CEM_Tunnel_Code_ShiftControl	Shift Control		
<Element Elem...	CEM_Tunnel_...	CEM_Tunnel_Code_ShiftControl	Shift Control	ShiftStart	
<Element Elem...	CEM_Tunnel_...	CEM_Tunnel_Code_ShiftControl	Shift Control	ShiftEnd	
<Element Elem...	CEM_Tunnel_...	CEM_Tunnel_Code_ShiftControl	Shift Control		Shifts

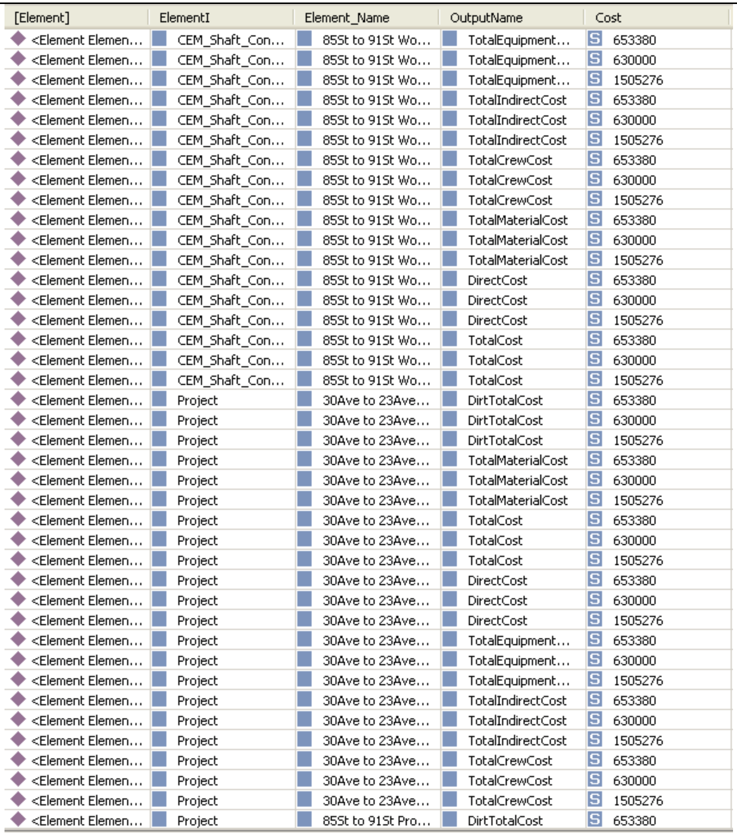
```
        ?Ouputs composite:child ?Output .
        ?Output FabM1:Name-Output ?OutputName .
        FILTER regex(?OutputName, "Shift") .
    } .
}
```

Q9



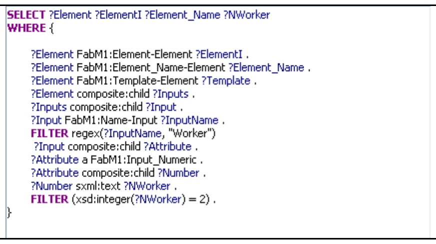
```
SELECT ?Element ?ElementI ?Element_Name  ?OutputName ?Cost
WHERE {

      ?Element TunM:Element-Element ?ElementI .
      ?Element TunM:Element_Name-Element ?Element_Name .
      ?Element TunM:Template-Element ?Template .
      ?Element composite:child ?Ouputs .
      ?Ouputs composite:child ?Output .
      ?Output TunM:Name-Output ?OutputName .
      FILTER regex(?OutputName, "Cost") .
      ?Ouput composite:child ?Attribute .
      ?Attribute a TunM:Attribute_Numeric.
      ?Attribute composite:child ?Number .
      ?Number sxml:text ?Cost.
      FILTER (xsd:integer(?Cost) > 300000).
}
```



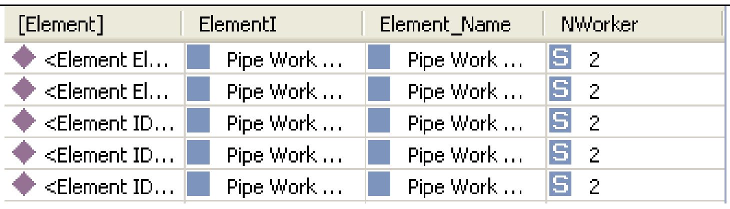
[Element]	ElementI	Element_Name	OutputName	Cost
<Element Elemen…	CEM_Shaft_Con…	85St to 91St Wo…	TotalEquipment…	653380
<Element Elemen…	CEM_Shaft_Con…	85St to 91St Wo…	TotalEquipment…	630000
<Element Elemen…	CEM_Shaft_Con…	85St to 91St Wo…	TotalEquipment…	1505276
<Element Elemen…	CEM_Shaft_Con…	85St to 91St Wo…	TotalIndirectCost	653380
<Element Elemen…	CEM_Shaft_Con…	85St to 91St Wo…	TotalIndirectCost	630000
<Element Elemen…	CEM_Shaft_Con…	85St to 91St Wo…	TotalIndirectCost	1505276
<Element Elemen…	CEM_Shaft_Con…	85St to 91St Wo…	TotalCrewCost	653380
<Element Elemen…	CEM_Shaft_Con…	85St to 91St Wo…	TotalCrewCost	630000
<Element Elemen…	CEM_Shaft_Con…	85St to 91St Wo…	TotalCrewCost	1505276
<Element Elemen…	CEM_Shaft_Con…	85St to 91St Wo…	TotalMaterialCost	653380
<Element Elemen…	CEM_Shaft_Con…	85St to 91St Wo…	TotalMaterialCost	630000
<Element Elemen…	CEM_Shaft_Con…	85St to 91St Wo…	TotalMaterialCost	1505276
<Element Elemen…	CEM_Shaft_Con…	85St to 91St Wo…	DirectCost	653380
<Element Elemen…	CEM_Shaft_Con…	85St to 91St Wo…	DirectCost	630000
<Element Elemen…	CEM_Shaft_Con…	85St to 91St Wo…	DirectCost	1505276
<Element Elemen…	CEM_Shaft_Con…	85St to 91St Wo…	TotalCost	653380
<Element Elemen…	CEM_Shaft_Con…	85St to 91St Wo…	TotalCost	630000
<Element Elemen…	CEM_Shaft_Con…	85St to 91St Wo…	TotalCost	1505276
<Element Elemen…	Project	30Ave to 23Ave…	DirtTotalCost	653380
<Element Elemen…	Project	30Ave to 23Ave…	DirtTotalCost	630000
<Element Elemen…	Project	30Ave to 23Ave…	DirtTotalCost	1505276
<Element Elemen…	Project	30Ave to 23Ave…	TotalMaterialCost	653380
<Element Elemen…	Project	30Ave to 23Ave…	TotalMaterialCost	630000
<Element Elemen…	Project	30Ave to 23Ave…	TotalMaterialCost	1505276
<Element Elemen…	Project	30Ave to 23Ave…	TotalCost	653380
<Element Elemen…	Project	30Ave to 23Ave…	TotalCost	630000
<Element Elemen…	Project	30Ave to 23Ave…	TotalCost	1505276
<Element Elemen…	Project	30Ave to 23Ave…	DirectCost	653380
<Element Elemen…	Project	30Ave to 23Ave…	DirectCost	630000
<Element Elemen…	Project	30Ave to 23Ave…	DirectCost	1505276
<Element Elemen…	Project	30Ave to 23Ave…	TotalEquipment…	653380
<Element Elemen…	Project	30Ave to 23Ave…	TotalEquipment…	630000
<Element Elemen…	Project	30Ave to 23Ave…	TotalEquipment…	1505276
<Element Elemen…	Project	30Ave to 23Ave…	TotalIndirectCost	653380
<Element Elemen…	Project	30Ave to 23Ave…	TotalIndirectCost	630000
<Element Elemen…	Project	30Ave to 23Ave…	TotalIndirectCost	1505276
<Element Elemen…	Project	30Ave to 23Ave…	TotalCrewCost	653380
<Element Elemen…	Project	30Ave to 23Ave…	TotalCrewCost	630000
<Element Elemen…	Project	30Ave to 23Ave…	TotalCrewCost	1505276
<Element Elemen…	Project	85St to 91St Pro…	DirtTotalCost	653380

Q10



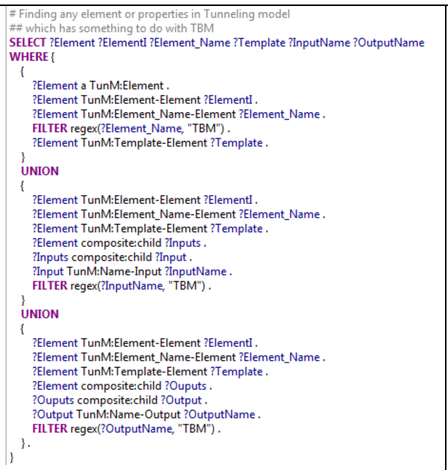
```
SELECT ?Element ?ElementI ?Element_Name ?NWorker
WHERE {

      ?Element FabM1:Element-Element ?ElementI .
      ?Element FabM1:Element_Name-Element ?Element_Name .
      ?Element FabM1:Template-Element ?Template .
      ?Element composite:child ?Inputs .
      ?Inputs composite:child ?Input .
      ?Input FabM1:Name-Input ?InputName .
      FILTER regex(?InputName, "Worker")
       ?Input composite:child ?Attribute .
      ?Attribute a FabM1:Input_Numeric .
      ?Attribute composite:child ?Number .
      ?Number sxml:text ?NWorker .
      FILTER (xsd:integer(?NWorker) = 2) .
}
```

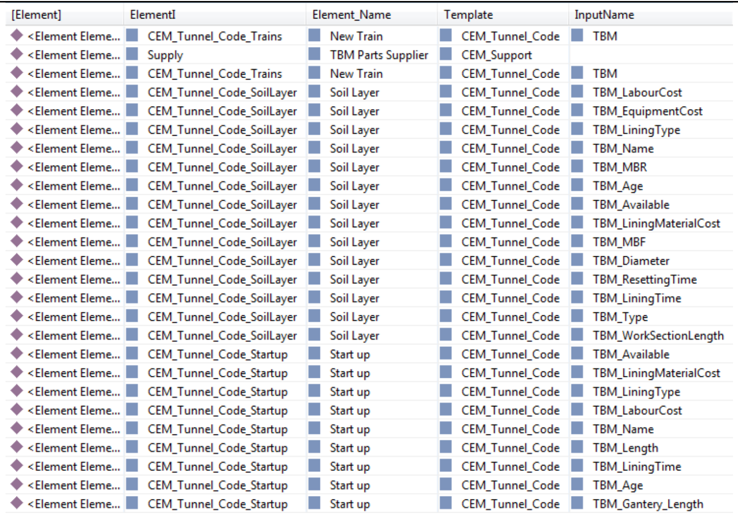


[Element]	ElementI	Element_Name	NWorker
<Element El…	Pipe Work …	Pipe Work …	2
<Element El…	Pipe Work …	Pipe Work …	2
<Element ID…	Pipe Work …	Pipe Work …	2
<Element ID…	Pipe Work …	Pipe Work …	2
<Element ID…	Pipe Work …	Pipe Work …	2

Q10

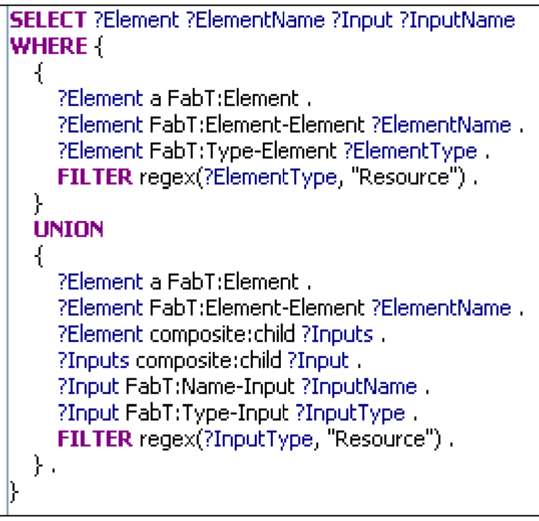


```
# Finding any element or properties in Tunneling model
## which has something to do with TBM
SELECT ?Element ?ElementI ?Element_Name ?Template ?InputName ?OutputName
WHERE {
  {
    ?Element a TunM:Element .
    ?Element TunM:Element-Element ?ElementI .
    ?Element TunM:Element_Name-Element ?Element_Name .
    FILTER regex(?Element_Name, "TBM") .
    ?Element TunM:Template-Element ?Template .
  }
  UNION
  {
    ?Element TunM:Element-Element ?ElementI .
    ?Element TunM:Element_Name-Element ?Element_Name .
    ?Element TunM:Template-Element ?Template .
    ?Element composite:child ?Inputs .
    ?Inputs composite:child ?Input .
    ?Input TunM:Name-Input ?InputName .
    FILTER regex(?InputName, "TBM") .
  }
  UNION
  {
    ?Element TunM:Element-Element ?ElementI .
    ?Element TunM:Element_Name-Element ?Element_Name .
    ?Element TunM:Template-Element ?Template .
    ?Element composite:child ?Ouputs .
    ?Ouputs composite:child ?Output .
    ?Output TunM:Name-Output ?OutputName .
    FILTER regex(?OutputName, "TBM") .
  } .
}
```

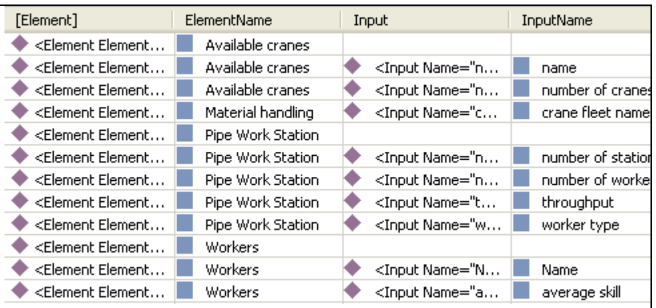


[Element]	ElementI	Element_Name	Template	InputName
<Element Eleme...	CEM_Tunnel_Code_Trains	New Train	CEM_Tunnel_Code	TBM
<Element Eleme...	Supply	TBM Parts Supplier	CEM_Support	
<Element Eleme...	CEM_Tunnel_Code_Trains	New Train	CEM_Tunnel_Code	TBM
<Element Eleme...	CEM_Tunnel_Code_SoilLayer	Soil Layer	CEM_Tunnel_Code	TBM_LabourCost
<Element Eleme...	CEM_Tunnel_Code_SoilLayer	Soil Layer	CEM_Tunnel_Code	TBM_EquipmentCost
<Element Eleme...	CEM_Tunnel_Code_SoilLayer	Soil Layer	CEM_Tunnel_Code	TBM_LiningType
<Element Eleme...	CEM_Tunnel_Code_SoilLayer	Soil Layer	CEM_Tunnel_Code	TBM_Name
<Element Eleme...	CEM_Tunnel_Code_SoilLayer	Soil Layer	CEM_Tunnel_Code	TBM_MBR
<Element Eleme...	CEM_Tunnel_Code_SoilLayer	Soil Layer	CEM_Tunnel_Code	TBM_Age
<Element Eleme...	CEM_Tunnel_Code_SoilLayer	Soil Layer	CEM_Tunnel_Code	TBM_Available
<Element Eleme...	CEM_Tunnel_Code_SoilLayer	Soil Layer	CEM_Tunnel_Code	TBM_LiningMaterialCost
<Element Eleme...	CEM_Tunnel_Code_SoilLayer	Soil Layer	CEM_Tunnel_Code	TBM_MBF
<Element Eleme...	CEM_Tunnel_Code_SoilLayer	Soil Layer	CEM_Tunnel_Code	TBM_Diameter
<Element Eleme...	CEM_Tunnel_Code_SoilLayer	Soil Layer	CEM_Tunnel_Code	TBM_ResettingTime
<Element Eleme...	CEM_Tunnel_Code_SoilLayer	Soil Layer	CEM_Tunnel_Code	TBM_LiningTime
<Element Eleme...	CEM_Tunnel_Code_SoilLayer	Soil Layer	CEM_Tunnel_Code	TBM_Type
<Element Eleme...	CEM_Tunnel_Code_SoilLayer	Soil Layer	CEM_Tunnel_Code	TBM_WorkSectionLength
<Element Eleme...	CEM_Tunnel_Code_Startup	Start up	CEM_Tunnel_Code	TBM_Available
<Element Eleme...	CEM_Tunnel_Code_Startup	Start up	CEM_Tunnel_Code	TBM_LiningMaterialCost
<Element Eleme...	CEM_Tunnel_Code_Startup	Start up	CEM_Tunnel_Code	TBM_LiningType
<Element Eleme...	CEM_Tunnel_Code_Startup	Start up	CEM_Tunnel_Code	TBM_LabourCost
<Element Eleme...	CEM_Tunnel_Code_Startup	Start up	CEM_Tunnel_Code	TBM_Name
<Element Eleme...	CEM_Tunnel_Code_Startup	Start up	CEM_Tunnel_Code	TBM_Length
<Element Eleme...	CEM_Tunnel_Code_Startup	Start up	CEM_Tunnel_Code	TBM_LiningTime
<Element Eleme...	CEM_Tunnel_Code_Startup	Start up	CEM_Tunnel_Code	TBM_Age
<Element Eleme...	CEM_Tunnel_Code_Startup	Start up	CEM_Tunnel_Code	TBM_Gantery_Length

Q1

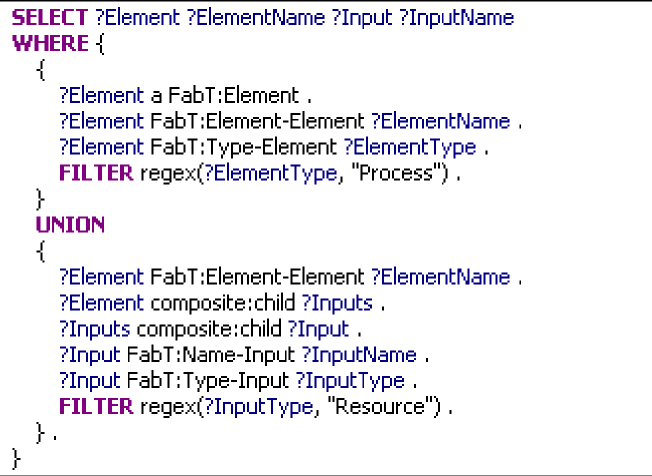


```
SELECT ?Element ?ElementName ?Input ?InputName
WHERE {
  {
    ?Element a FabT:Element .
    ?Element FabT:Element-Element ?ElementName .
    ?Element FabT:Type-Element ?ElementType .
    FILTER regex(?ElementType, "Resource") .
  }
  UNION
  {
    ?Element a FabT:Element .
    ?Element FabT:Element-Element ?ElementName .
    ?Element composite:child ?Inputs .
    ?Inputs composite:child ?Input .
    ?Input FabT:Name-Input ?InputName .
    ?Input FabT:Type-Input ?InputType .
    FILTER regex(?InputType, "Resource") .
  } .
}
```

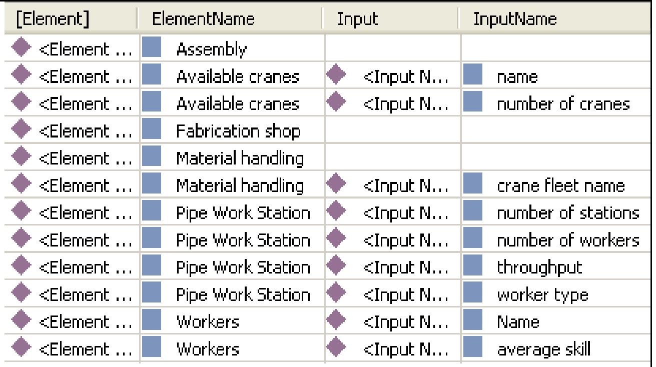


[Element]	ElementName	Input	InputName
<Element Element...	Available cranes		
<Element Element...	Available cranes	<Input Name="n...	name
<Element Element...	Available cranes	<Input Name="n...	number of crane
<Element Element...	Material handling	<Input Name="c...	crane fleet name
<Element Element...	Pipe Work Station		
<Element Element...	Pipe Work Station	<Input Name="n...	number of statio
<Element Element...	Pipe Work Station	<Input Name="n...	number of worke
<Element Element...	Pipe Work Station	<Input Name="t...	throughput
<Element Element...	Pipe Work Station	<Input Name="w...	worker type
<Element Element...	Workers		
<Element Element...	Workers	<Input Name="N...	Name
<Element Element...	Workers	<Input Name="a...	average skill

Q2



```
SELECT ?Element ?ElementName ?Input ?InputName
WHERE {
  {
    ?Element a FabT:Element .
    ?Element FabT:Element-Element ?ElementName .
    ?Element FabT:Type-Element ?ElementType .
    FILTER regex(?ElementType, "Process") .
  }
  UNION
  {
    ?Element FabT:Element-Element ?ElementName .
    ?Element composite:child ?Inputs .
    ?Inputs composite:child ?Input .
    ?Input FabT:Name-Input ?InputName .
    ?Input FabT:Type-Input ?InputType .
    FILTER regex(?InputType, "Resource") .
  } .
}
```



[Element]	ElementName	Input	InputName
<Element …	Assembly		
<Element …	Available cranes	<Input N…	name
<Element …	Available cranes	<Input N…	number of cranes
<Element …	Fabrication shop		
<Element …	Material handling		
<Element …	Material handling	<Input N…	crane fleet name
<Element …	Pipe Work Station	<Input N…	number of stations
<Element …	Pipe Work Station	<Input N…	number of workers
<Element …	Pipe Work Station	<Input N…	throughput
<Element …	Pipe Work Station	<Input N…	worker type
<Element …	Workers	<Input N…	Name
<Element …	Workers	<Input N…	average skill