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

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ABSTRACT

Simulation models are knowledge intense computational entities. Simulation model development consumes lots of time and resources. The research described in this paper is motivated by necessity of reuse, composability and interoperability of the construction simulation models. The innovate architecture presented in this paper blends semantic web technologies and construction simulation models presented in a machine interpretable metadata for storing, sharing and discovery of knowledge within construction simulation models and properly linking them to their related information sources.

For this purpose a repository of construction simulation models has been developed. Construction modeling repository mainly contains simulation templates and models and other relevant sources. Sharing and integration of these simulation componets enables inference and extraction of meaningful information through structuring queries.

INTRODUCTION

Simulation modeling is an effective tool for analysis of construction operations and supporting 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 domain and also simulation modeling techniques and tools. When the model is used for its initial intention, reuse of it is not straightforward; mostly because the process of finding the appropriate modelling components for reuse has not been yet addressed (Aronson and Bose 1999, Chreyh and Wainer 2009). This problem can be traced back to 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 advances of internet technology models of can be shared in repositories and distributed over the Web while with efficient discovery services the residing knowledge within them can be extracted. These advancements have not become introduced to construction industry yet. In order to share construction simulation models over the Web, simulation models including model features and model behaviour must be represented in an appropriate format processable for semantic web to facilitate meaningful discovery. Sharing and discovery of 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, image, video and audio files).

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

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

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 World Wide Web. The traditional web is just about displaying information lacking the meaning or semantics underpinning for meaningful sharing and discovery of resources on the web. Data, information and knowledge sharing is more prolific in semantic web because it can expressively 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 to act upon the web content. This fact enables more efficient searching, sharing and combining information.

There are languages and technologies creating semantic web. The foundation technologies for hypertext web are the basis for semantic web too. Unicode, Uniform Resource Identifier (URI) and XML are technologies that are used for character encoding, resource indexing and syntax for data serialization. RDF, RDF Schema (RDF-S) and 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 (Berners-Lee et. al 2001).

RELATED WORK

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 world views (Fishwick and Miller 2004). This ontology is suitable resource in order to get a comprehensive understanding of DES.

Process Interaction Modeling Ontology for Discrete Event Simulations (PIMODES) is another simulation ontology by Lacy (2005) 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 and this makes connecting PIMODES to software packages easy. PIMODES can be used for ontology based representation of models which facilitates 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 simulation repository of Base Object Models (BOM). BOM is a Simulation Interoperability Standards Organization (SISO) standard for conceptual modeling documentation which provide a formal way for capturing and sharing conceptual simulation documentation. (Gustavson 1998) (BOM web site). Moradi et al. have investigated ontological BOM discovery and composition for building new models (Moradi et al. 2007). Hypermodeling, the general theory and practice of linking system models and their components, has been recently proposed by Fishwick (2011).

One of few efforts in construction domain towards use of web services has been done 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 any advantage of semantic web.

ADAPTATION OF SEMANTIC WEB INTO CONSTRUCTION SIMULATION MODELING

Adapting semantic web techniques and technologies has significant effects in method approaching model ontology, discovery, composition, interoperability and reuse. In order to be able to apply them on 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 semantic web is highly depended on the structure and encoding of the model. As it was mentioned before information encoded within semantic mark up languages such as XML, RDF or OWL are semantic web readable. In the coming first section it is explained how 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 needs enhancement both in representation and content. The XML text view of models contains full description of the modeling elements and their input, output properties along with the relationships within the elements. But it lacks providing essential big picture information about the model. This information are important for sharing and discovery purposes and they are added to the model through a separate section added to XML model description, called model “profile”.

3- Linking the relevant sources of data and information: An important aspect about semantic web is proper linking to relevant information. Simulation models are always built based on vast amount of knowledge coming from conceptual models and documents containing input data. We have tried to include these sources 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 towards the end.

Simulation Modeling Representation

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

- Graphical view which is generated by 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 model including textual description of elements along with input and output results in Extensible Mark-up Language (XML) 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 our primary goal to use existing resources instead of creating and suggesting a completely new model representation for the purpose of proper sharing and discovery, XML view has been the best candidate for semantic representation of simulation models. It can be used as the starting point and enhanced to higher level to richer semantic representation.

The approach taken in this paper is to use the exiting textual XML format which is easily storable and readable and with minor changes and add-ons show its potential for the purpose of meaning sharing and discovery of models. Hence the changes should be applied towards both the content and format of simulation document.

Firstly enriching the simulation model content by adding semantic representation components and in order to to make the documents semantically interpretable by machines another step is required; transforming the syntax from XML to more expressive web languages such as RDF and OWL, which are used for semantic web development.

In the following firstly 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.

Simphony

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

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 modeller drags from modeling element library into modeling layout and links them together in order to build the relationships. Each of these modeling elements has its own behaviour to produce 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 also graphical representation information. At the end it provides information about the interconnection between the elements <Relationship>. Figure 1 summarizes the XML view models' specifications.

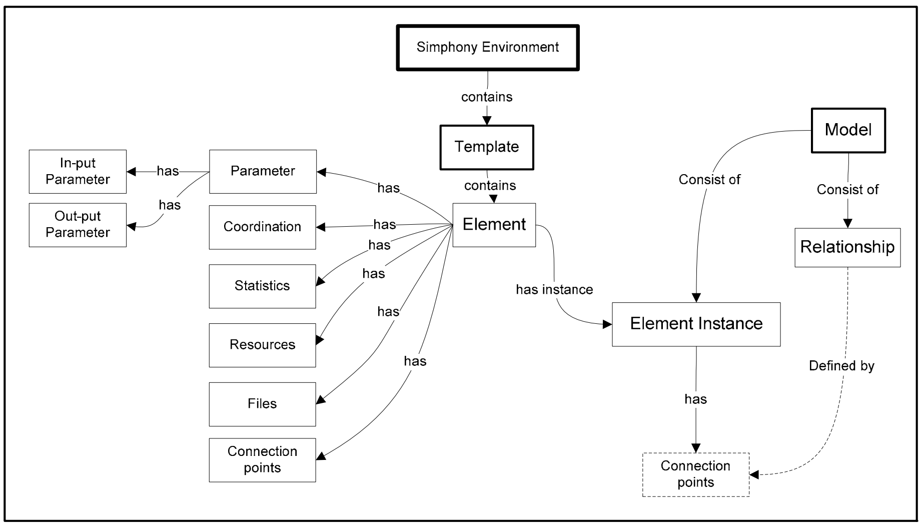

Figure 1: Simphony Model Representation

General and specific information about the model are suggested to be added to simulation models. Mainly because they provide a unique description for each simulation model making them distinguishable from other simulation models and also more semantic weight in the process of storing and discovery of the simulation models. In the following section, the suggested semantic enrichment of simulation document is explained.

Semantic Enrichment of Construction Simulation Models (Modeling Content and Proper Linking)

BOMs are the only structured modeling documentation developed by military simulation community. Modeling documentation has been investigated in military domain more than any other domains, because military simulations often involve large scale models which lead to more interest towards structured documentation of models and reuse (Robinson 2006).

As the only reference for modeling documentation, BOM documentation process has been investigated. BOM documentation is for conceptual modeling documentation and it is carried forward as simulation components through 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 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.

Within our approach we have tried to enhance the existing simulation textual documentation with insight from BOMs without discarding the existing Simphony documentation. The current presentation presents the simulation application interface which is why all the XML tags are restricted to presenting the graphical representation of model; elements and their input and output parameters and relationships, but nothing about their simulation role. As an instance in a simulation document through the XML tag a particular simulation component is identified as a simulation element but there is no tags regarding the content of element if the element is presenting a process, resource or product. That is because the simulation application has another component which is remained untouched in the current simulation documentation which is simulation world view which is the domain language representation, expressing the dynamics of process and linking the simulation model to the root conceptual model. In the current research it is tried to briefly introduce this component to simulation documentation.

In construction application mostly process are models based on process oriented world view which are fully capable of representing construction operations. 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. This give more expressiveness to the model and it can simply get linked to other process oriented applications and even more importantly the model can be compared to ontolgies of domain conceptual model. Linkage to conceptual models can bring new opportunities towards model composition and interoperability such as comparison and verification with other soures, which are discussed later.

Adding new content to simulation models through model profiles

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

The current Simphony documentation has a few components such as name of 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 simulation model which gives the simulation models brief individual identity and facilitate model discovery. The simulation profile we came up with has three main categories: General profile, Descriptive Profile and implementation profile (Table 1).

Table 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, name of model developer and finally modification date and version of the simulation model (Table 2).

Table 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 application domain of the model is specified and more detailed specifications of the model such as the client or modeling case is provided and finally the related ontologies to the model are stated (Table 3).

Table 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	Domain and none-domain the model is related to them.

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

Table 4: Implementation Profile Descriptors

Profile component	Profile component	Description
Implementation Profile	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.
	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.

Repository of Models

Construction modeling repository mainly contains simulation templates and models and other relevant sources; Simulation templates contain a collection of elements serving a particular construction simulation domain. Simulation templates' description consists of two parts: template profile and belonging elements. Simulation models on other hand are composed of modeling element instances which can be created from different templates. And 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 finally the relationships between the elements. All these components reside in the repository and sharing and integration of them enables inference and extraction of meaningful information through structuring queries.

Discovery process focuses on three main areas:

1- Content of simulation models: Accessing the simulation models and their content is inevitably important regarding both 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 semantic web without need to any other application. The queries can be quantitative or qualitative.

2- Related sources of information: Acquiring 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 it 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.

Semantic Repository for Construction Operations Simulation modeling

Prototype repository of construction simulation models has been developed in order to evaluate usability and performance of such discovery environment. The simulation models are stored within ontologies using RDF and OWL syntax and accessed through SPARQL queries. The prototype repository, as it is shown in the following tables, contains of 7 templates and 4 models with the total number of 7995 RDF resources. Repository has been built within TopBraid Composer (TBC) (2010) and Protégé (2006) tools (Table 5). .

In the Table 6 there are sample queries expressed in SPARQL, the results are the matching simulation components retrieved from the modeling repository. Table 7 shows Q6 query syntax and results displayed in TBC.

Table 5: Prototype Construction Modeling Repository

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

Table 6: Prototype Construction Modeling Repository

#	**Query**	Explanation
Q1	What are models and templates in the repository and which domain they belong to?	Repository content
Q2	What are “Descriptive Profile” properties and what are the properties’ values for “Spool Fabrication” Model?	Profile of a model
Q3	Find the simulation component which have “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	What are required templates for developing a model of “Tunnelling operations”?	The query returns an URI for third part supporting documents
Q5	What are the differences between two models of “Spool Fabrication Shops”?	Comparing two models

Table 7: Sample Query and Results in TBC

#	Query	Result
Q5	(see query below)	(see result below)

Query:

```
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
```

Result:

[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		

SUMMARY

The innovate approach presented in this paper blends semantic web technologies and construction simulation models for meaning storing, sharing and discovery of construction simulation models and properly linking them to their related information sources. The repository of simulation models contains three main components: composed models of construction processes, templates containing simulation elements (components), and related data and information sources. Model discovery is achieved by web service semantic search. Emerging the semantic web into construction simulation modeling as its earliest outcomes bring i) easy storage and accessibility of models, ii) knowledge extraction from simulation model content iii) accessing related sources of data and knowledge. This is just the start of using semantic web presentation, sharing, and discovery and there are lots to be explored in future works.

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