Ontology in the Core of Information Management
Information Management in Infrastructure Building

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Abstract: Information explosion sets challenges for companies but on the other hand offers opportunities to achieve competitive advantage through successful information management. Semantic interoperability solutions and ontologies especially, offer a powerful tool for information management. Ontologies provide a way to integrated disparate information sources in complex environment. Large scale infrastructure building process is extremely challenging assignment which successful follow through requires tool for effective information management. Earlier research presented a prototype implementation called Dynamic Site Control Centre (DSCC) for road construction process management. In this paper the formation and structure of ontology for the prototype implementation is described.

1 INTRODUCTION

Earlier the gaining of information was on the focus in information utilize; now the management of information is the most important issue. The amount of available information is enormous and still growing; finding the right information from the vast amount of data is the key issue in information management. Kings of the hill are those companies and organizations that are able to find the essential information from the information flood, and utilize it in a way the others cannot. This requires seamless communication between men and machines, and interoperability between systems.

Using semantics of data provides a powerful tool for information management. Semantic interoperability focuses on enabling content, data, and information to interoperate with software systems outside their origin (Pollock and Hogdson, 2004), and enables integration of data sources using different vocabularies and different perspectives on data (Ram and Park, 2004). Ontologies provide a way to define semantics, provide support for handling disparate data sources and provide a mechanism to define complex knowledge models (Zimmermann et al., 2005).

In complex environments mere technical integration is not enough; information integration is required (Pollock, 2001). Large scale infrastructure building process is extremely challenging assignment: several parallel and consecutive tasks, complexity of structure, many companies involved, technological variety, etc. Although research and technological development have brought new tools for leading such a process, there are still things to do in information management of infrastructure building.

In the domain of architecture, engineering, and construction (AEC) and facilities management (FM) lot of research is conducted to enhance the information management. Due to diversity and uniqueness of AEC/FM domains building an universal solution or standard has been challenging (Turk, 2006); (Venugopal et al., 2012), and the development and deployment of systems integration and collaboration technologies are behind other sectors (e.g., manufacturing) (Shen et al., 2010). One of the most recognized standardization efforts in AEC/FM domain is Industry Foundation Classes (IFC), but it has been criticized for the slow adaptation in the real life (Howard and Björk, 2008). Current solutions for information management in AEC/FM domain are mostly made for building of buildings and there are only few solutions for infrastructure construction. Due to clear need for enhanced information management in infrastructure

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building industry Dynamic Site Control Centre (DSCC) for road construction process management was developed (Viljamaa et al., 2012); (Viljamaa et al., 2013). This paper describes the formation and structure of ontology for prototype implementation.

2 STATE OF THE ART

During past year's information and communication technologies have been developed and deployed widely to various application areas; including AEC/FM. Boddy et al., (2007) have made an extensive review from data and application integration research in construction domain, and Shen et al., (2010) have conducted a comprehensive review on system integration technologies in AEC/FM. In the following the concepts of interoperability and ontology are examined, and some construction side ontologies and standards are explored.

2.1 Semantics

Semantic interoperability is the ability of participating system domains to understand the meaning and use of terminology from different domains, and to map between agreed concepts in order to make a semantically compatible information environment (Park and Ram, 2004). It also enables data exchange between applications and multiple applications to jointly contribute to the work at hand; leading to smoother workflows and sometimes to facilitated automation (Eastman et al., 2011). Semantic interoperability focuses on enabling content, data, and information to interoperate with software systems outside their origin (Pollock and Hogdson, 2004). Therefore semantic interoperability enables integration data sources developed using different vocabularies and different perspectives on data. To achieve semantic interoperability, systems must be able to exchange data in such a way that the precise meaning of the data is readily accessible and the data can be translated by any system into a form that it understands (Ram and Park, 2004).

Interoperability is comprised both technical integration and information integration. The main technical challenge is the lack of interoperability of different systems and data sources thus most of the current solutions are focused only on technical integration, to link disparate software systems to become part of a larger system. Information integration is focused on preserving the meaning of information while transforming the context. Metadata must include human-defined context and business rules in addition to typical metadata to fully enable system interoperability. (Pollock, 2001)

Interoperability-based approaches focus on the exchange of meaningful, context-driven data between autonomous systems, concentrating on exchanging minimal amount of information (Pollock, 2001). Interoperability is considered as achieved only if the interaction between two systems can, at least, take place at the three levels: data, resource and business process with the semantics defined in a business context. This leads to achieving interoperability on multiple levels: inter-enterprise coordination, business process integration, semantic application integration, syntactical application integration, and physical integration. (Chen and Doumeingts, 2003)

2.2 Ontology

Implementation of semantic interoperability requires enhancing of data with the semantics, mapping and combining the information by reasoning and making the information available to the users personalized according user needs and preferences. These tasks require specific methodologies and tools. One prerequisite of semantic interoperability is use of ontologies.

Ontologies aim to capture consensual knowledge in a generic way to be reused and shared across software applications and by groups of people (Gomez-Perez et al., 2005); (Gruber, 1995). Ontology defines a common vocabulary for information sharing in a domain (Uschold and Gruninger, 1996); (Noy and McGuinness, 2001) and it includes machine-interpretable definitions of basic concepts in the domain and relations among them (Noy and McGuinness, 2001).According to Zimmermann et al. (2005) ontologies provide a way to define semantics, provide support for handling disparate data sources and provide a mechanism to define complex knowledge models. Semantic interoperability can be ensured by providing contextual knowledge of domain applications (Ram and Park, 2004).

Several researchers have compiled instructions for developing ontologies (Gruber, 1995); (Uschold and Gruninger, 1996); (Studer et al., 1998); (Noy and McGuinness, 2001). In this research ontology development follows the guidance introduced by Noy and McGuinness (2001).

In order to successfully use ontologies commitments has to be made, that are agreements to use the shared vocabulary in a coherent and consistent manner. (Gruber, 1995) Also reusability of the ontology is important feature of the ontology. To achieve the requirements set by the reusability the ontology must consists of small modules with a high internal coherence and a limited amount of interaction between the modules (Studer et al., 2000). In this research the ontology is forming of sub-ontologies, which define sub-processes of the infrastructure building processes i.e. design process and work progress.

It will rarely be the case that a single ontology fulfils the needs of a particular application (El-Diraby and Kashif, 2005); (Antoniou and van Harmelen, 2008); (El-Gohary et al., 2011); more often than not, multiple ontologies will have to be combined. In the case of multiple ontologies, ontology integration is challenging and important task. (Antoniou and van Harmelen, 2008) The techniques for ontology integration include matching, mapping and alignment (Rebstock et al., 2008).

In general there are three ontology architectures to integrate information from heterogeneous information sources: the single ontology approach, the multiple ontology approach, and the hybrid approach. Single ontology approach use one global ontology for providing a shared vocabulary for the specification of the semantics; all information sources are related to the one global ontology (single-shared ontology). In multiple ontology approach, each information source is described by its own ontology and source ontologies are mapped to each other using inter-ontology mappings (one-to-one). In hybrid approach the semantics of each source is described by its own ontology, which is built upon one global shared vocabulary or ontology (mixed). (Uschold, 2000); (Wache et al., 2001); (Alexiev et al., 2005); (Pradhan et al., 2011)

In this research, single ontology approach for ontology utilization is used; each source is preserving its own ontology and global, shared ontology is constructed to act as common vocabulary.

2.3 Standards and Applications

There have been numerous efforts to build AEC/FM standards during past decades. The developments of standards have been made in Europe and in America (Eastman et al., 2011) and individual countries have made their own standards (Kosovac, 2007). The key problems in standardization have been low stage of actual implementation and deciding the level of generalization (Kosovac, 2007).

Recently, Building Information Modelling (BIM) has been considered as an important enabling technology for building lifecycle information integration. It can facilitate collaboration among stakeholders during the design, construction, and maintenance of buildings and facilities. (Shen et al., 2012)

BIM tools serving the AEC/FM industry cover various domains and have different internal data model representation to suit each domain. There is no one single application that can provide the entire set of functionalities required for the AEC/FM industry. Yet there is a clear need for data exchange between various actors in order to integrate the various types of expertise needed to realize the overall project. (Venugopal et al., 2012)

In BIM interoperability has traditionally relied on file-based exchange formats limited to geometry, and direct links based on the Application Programming Interfaces (APIs) are the oldest and still-important route to interoperability. Data models were developed to support product and object model exchanges within different industries. Data models e.g. IFC, distinguish the schema used to organize the data and the schema language to carry the data. The major benefits of interoperability are not only to automate an exchange (although replicating the data in another application is certainly redundant activity), but the larger benefits that refine workflows, eliminate steps, and improve processes. (Eastman et al., 2011)

However, Howard and Björk (2008) state that the formal standards on BIM, such as the IFCs are complex and have not had the resources for rapid development and promotion that their potential deserved. Therefore it will take some time for this approach to be widely adopted. (Shen et al., 2012)

El-Diraby et al., (2005) presents domain taxonomy for construction. The taxonomy is based on IFC and several other classification systems. The operation of developed domain ontology was evaluated during e-COGNOS project (Vallejos et al., 2007) as a part of web based knowledge management software, which connected various systems using Web Service technology. The development of ontology architecture was continued by adding more knowledge levels (application knowledge, user knowledge) to domain ontology (El-Diraby and Kashif, 2005).

In Finland determined work has been done to develop the utilization of information models in planning, construction and maintenance in infrastructure building. The aim is that all big infrastructure owners demand information model based services from year 2014 onwards. To support this purpose an information transfer format Inframodel (IM) has been developed. IM is based on international LandXML standard. (InfraBIM, 2013) In this research the design process sub-ontology is based on the IM2 definition.

3 CASE DIGIINFRA

Viljamaa et al., (2013) introduces a prototype implementation of DSCC, which purpose is to enhance the information acquisition during road construction process. DSCC integrates information from different companies' information systems participating to road construction process. It combines and refines the information gained and visualizes the information for users, primarily to construction work managers. The information integration is done utilizing the semantics of information, and ontologies. This chapter introduces the development and structure of the ontology for DSCC, and gives some examples of the use of the ontology.

3.1 Overall Structure of the Ontology

DSCC ontology forms of sub-ontologies, which define sub-processes of the infrastructure building processes. Sub-ontologies include design process, work progress, resource management, and user management. Work progress ontology is the central part of DSCC ontology, and it contains information from several road construction process participants.

As ontology description language OWL Lite is used and the ontology is created using Protégé (Protégé, 2013) ontology editor. The ontology structure and process data is stored to triplet database to enable convenient deployment of the data. As triplestore Sesame (OpenRDF.org, 2013) framework with OWLIM (OWLIM, 2013) semantic repository extension was used. As query language SPARQL 1.1 is used.

3.2 Design Process

Design process sub-ontology is based on IM2 (InfraBIM, 2013); (Inframodel, 2013) information transfer format, which is based on LandXML standard. IM2 defines the geometry plan for the infrastructure to be built. The model enables the designing of different kinds of infrastructure, like route design, road- and street design, railway design, and waterway design. It also provides way to design water supply and sewerage, surfaces, and landscaping. DSCC prototype implementation concentrates on route design phase.

Every route has one continuous horizontal alignment, and it is made up of geometric elements and stinglines. Route design consists of stringline model and surface description. Alignments are collections of geometric lines and stringlines. The stringline model of the route is composed of alignment descriptions depicted in stringlines presented in layers. Alignment is an element, which describes either geometric line or stringline. Geometric line consists of horizontal geometry, which is defined with lines, curves, and spirals; and corresponding vertical geometry squared with horizontal geometry, defined with points of vertical intersection and circular curves. The surface of route is defined with triangulation network. (InfraBIM, 2013)

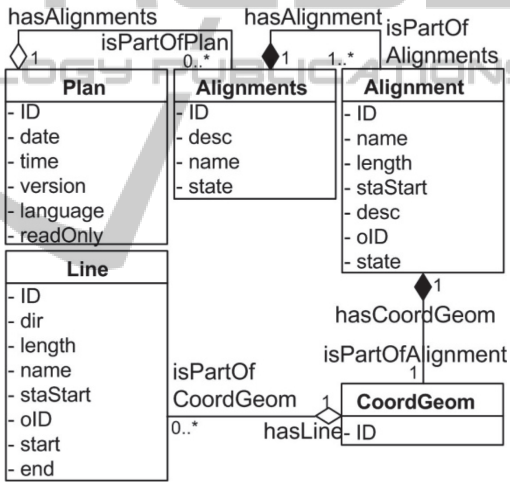

Figure 1: Ontology snippet of design process sub-ontology.

In IM2 the relations between different elements of the design are described hierarchically. In DSCC ontology the IM2 hierarchy was transformed to 'isPartOf' and 'hasPart' object properties. The foundation class of design process sub-ontology is *Plan*. Plan has some data properties, like date, and time; and object properties, like `hasAlignments`, and `hasCoordinateSystem`. In Figure 1 a snippet of design process sub-ontology is depicted. Object properties link formed individuals to traceable chains. Plan has object property `hasAlignments` which connects *Alignments* class to Plan. Correspondingly Alignments has object property `isPartOfPlan`, which connects Alignments to Plan. Plan may have none or one Alignments, and

Alignments have one Plan.

Since IM2 geometry plan is XML formatted, it is transferred to ontology format using XSLT transformation simultaneously when the IM2 file in question is selected in DSCC as a project geometry file. In practise, the IM2 DOM is accessed using SimpleXML PHP extension. The generated file is imported in triplestore.

3.3 Work Progress

The development of work progress sub-ontology was done from scratches. During specification phase of the research several interviews were conducted for the personnel of the companies participating road construction process. The base structure of work progress sub-ontology is described in Figure 2.

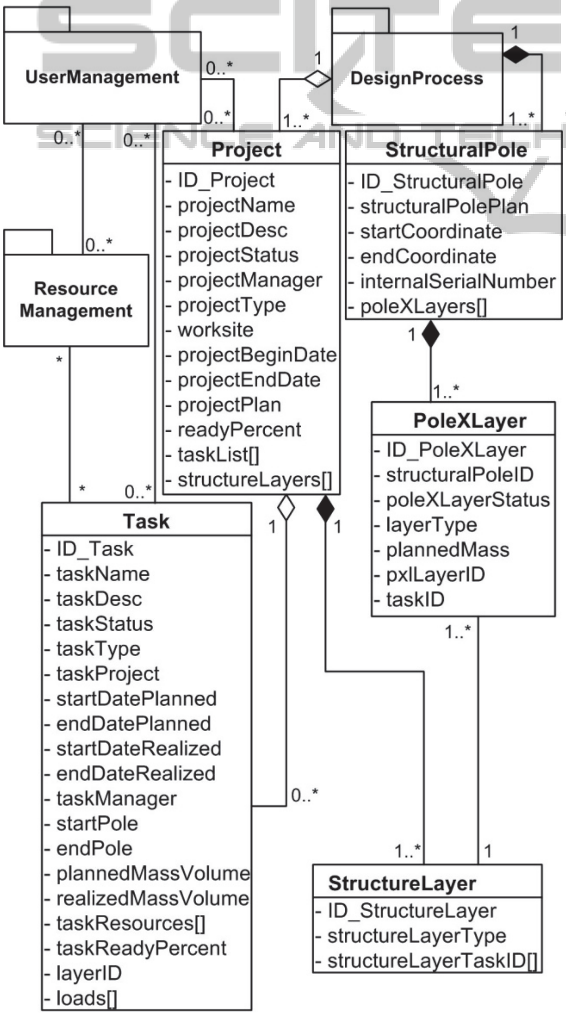

Figure 2: Work Progress ontology snippet.

The natural way to describe the road construction process seemed to be project based, so the foundation class of work progress sub-ontology is *Project*. Project class is connected to one plan individual. According to definitions in plan, the structure of the road is created to Project. In road design the road is divided in smaller sections to ease up the handling of the information of the road design. The section of road called structural pole, can be e.g. 100 meters long. Road is also divided lengthways in structure layers according to different mass layers forming the road. In DSCC ontology an intersection of a structural pole and structure layer is called PoleXLayer. This enables the separation of structure layer for different tasks. Example of PoleXLayer definition can be found from Figure 3.

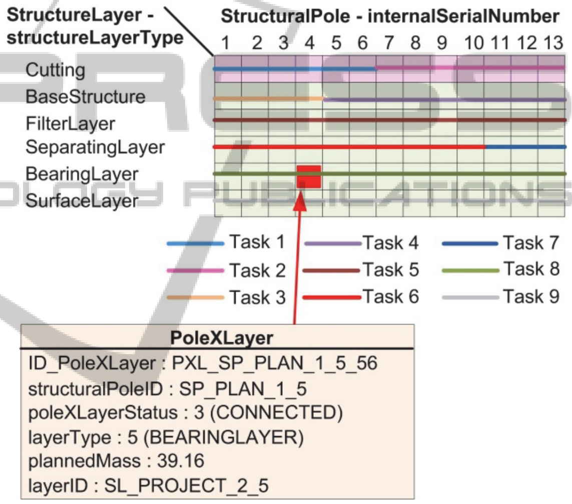

Figure 3: Task structure and PoleXLayer definition.

According to plan, *StructuralPoles*, *PoleXLayers*, and *StructureLayers* are created. Project is divided in smaller unities, *Tasks*, in which the actual work is allocated. Task is connected to certain StructureLayer, and to certain StructuralPoles. Figure 3 presents an example of this connection. The road has been divided in thirteen StructuralPoles and it has six StructureLayers. Cutting-layer is only removal layer, marked with pink; all the other layers are additive layers. The work in StructureLayer BaseStructure is divided to be done in two tasks (Task 3 and 4). The work in Task 3 is allocated to StructuralPoles 1 to 4 and in Task 4 to StructuralPoles 5 to 13. During road design a certain mass is allocated for every pole in every layer. In Figure 3 this mass for the referenced PoleXLayer is 39.16 tonnes.

The information about masses related to PoleXLayers is got from design system. Unfortunately, the used data format for road plan import (IM2) does not yet support direct structure layer volume or mass definition, so the separate text based layer information file was exported from the used design software. The text file contains information of each structure layer per each structural pole pair i.e. for one PoleXLayer. The information includes pole coordinates and ids with Finnish building standard layer type and volume of each layer. The essential information is parsed in DSCC using separation characters like line feeds and spaces. Example snippet of layer information for one structural pole pair:

```
Code: Name: Unit: Quantity:
Group: Paaluväli: 0.00-10.00
1611 Maaleikkaus, eritt. m3ktr 54,09
1817 Luiskatäyte m3rtr 0,40
2100 Pääl.rak.osat,alusr.krkst m3rtr 2,38
2111 Suodatinkerrokset m3rtr 27,65
2131 Sitomattomat kant. krkst m3rtr 12,89
2141 Asfalttipäällysteet m2tr 41,42
2161 Piennartäyte m3rtr 0,13
2321 Nurmikot m2tr 31,39
2411 Tukikerrokset sorasta m3rtr 0,18
Coord: 65,057569264,25,451983081
```

From the basis of this mass information StrucruralPoles and PoleXLayers are formed using SimpleXML PHP extension and imported in RDF/XML format to triplestore.

The creation of project is done using DSCC prototype's graphical user interface (GUI). The project creation phase includes creation of project individual, importing design information, and importing mass information. Also information about tasks and resources connected to tasks received from project management software can be imported to DSCC prototype. Resource and task scheduling information is imported during project creation process. Only supported file format is MS Project XML format that is parsed using SimpleXML PHP extension. The feature makes it possible to reuse existing plans that can usually be converted to MS Project format in many corresponding tools. The tasks mentioned in scheduling are added to project's tasks and resources mentioned are created accordingly. Resources are connected to corresponding tasks according to project schedule management information.

Tasks and resources can also be created using DSCC prototype GUI. The user feeds the information in user interface and a new user or resource is added to triplestore using triplestore interface module.

3.4 Resource Management

The development of resource management sub-ontology was also done from scratches. The data to this sub-ontology is mainly coming from work machine information systems, so the model was formed on the basis on this information. The base structure of resource management sub-ontology is described in Figure 4. The foundation class is *Resource*, which contains common data properties for all resource. There are two kinds of resources differentiated from the base resource: *WorkMachine* and *TransportEquipment*. *Load* is connected to TransportEquipment; this class contains information about the quality of cargo (sand, stone, crush, concrete) and the amount of the cargo (in tonnes).

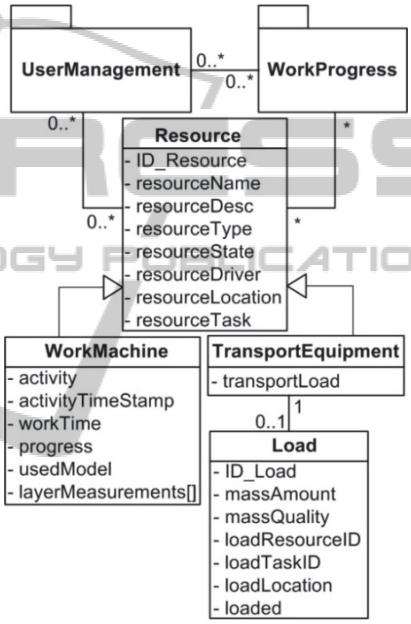

Figure 4: Resource management ontology snippet.

Machine control system is integrated to DSCC prototype using XMPP protocol, which is used by project partner's commercial machine control system. DSCC receives real time information about WorkMachine's e.g. excavator's location and state. The DSCC import client reads essential excavator data from the XMPP multi-chat group where excavators publish their status data, and updates data to the semantic database. The excavator data includes position, status and used control model.

Information about TransportEquipment is uploaded directly to triplestore through mobile web GUI. Uploaded data contains e.g. location of transport equipment and information about load in transportation like mass volume and type. The mobile web GUI uploads and requires information from triplestore using triplestore interface module.

During construction process the information about the realization of mass transportation is imported to DSCC prototype. DSCC is calculating the readiness of tasks and project by comparing the realized mass to planned mass. The planned mass for task is calculated from the mass information of PoleXLayers connected to task. The ratio of realized and planned masses is changed to percentages and visualized to user in GUI. The readiness of the project is calculated from the readiness of tasks correspondingly.

3.5 Usage of Ontology in DSCC

The base structure of the ontology and all the runtime information used in running the DSCC prototype is stored in triplestore. The communication between DSCC prototype and triplestore is done through triplestore interface module, which forms SPARQL queries according to information received from DSCC. SPARQL enables execution of complex queries quite simply without several queries or complex nested queries as is needed in case of Structured Query Language (SQL) and relational databases. The used triplestore implementation Sesame supports also SPARQL update which enables updating of stored information very easily.

The DSCC prototype consists of six GUI views, which contain information about projects, tasks, locations, users, resources, and process status. The GUIs are implemented using up-to-date web technologies which enable device and application independent development and use. According to user requirements DSCC fetches and presents the information stored in triplestore. (Viljamaa et al., 2013)

4 CONCLUSIONS

Information interoperability and information management are complex problems which several research teams have tried to solve in various application domains, including AEC/FM. The diversity and one-of-a-kindness of AEC/FM have hindered of development of information management solutions. Information models tend to grow wide and complex which slows down the adaption, like in case of IFC.

In this paper an ontology development and structure for enhanced information acquisition prototype in infrastructure construction process is introduced. The DSCC prototype aims to intensify the information management during road construction process using semantic interoperability tools, e.g. ontologies. The conducted research concentrates on describing the data semantics of the infrastructure construction process. The idea of ontology development was to keep the accuracy of ontology on suitable level in order to keep the structure as simple as possible. The developed ontology was divided to sub-ontologies according road construction processes. Some of the sub-ontologies were developed from the basis of existing information models and some from scratches. The chosen ontology architecture was single ontology approach, which can be seen as the first stage of integration implementation. The following step could be the use of global ontology with local ontologies, where local ontologies describe the structure of data source currently fused to global ontology using parsers.

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