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Towards Linking Virtual Models with Physical Objects in Construction using RFID - Review of Ontologies

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ABSTRACT
Virtual models have in recent years proven their worth in practice relating to building design. Today virtual models of the complete project are created before the project is carried out in practice. The immediate advantages of this are great; it introduces fewer errors, gives a better production basis, improved clarity and enhanced communication methods compared to traditional 2D drafting methods. However, there is still much unutilized potential in the virtual models, especially in the construction and operation phases. It is expected that a digital link between the virtual models and the physical objects in the construction process can improve the information and knowledge handling from design to construction, operation and maintenance. The link can be created by use of Radio Frequency Identification (RFID) technology. This paper describes a review and assessment of existing ontologies relevant in relation to creating this link. The ontologies are categorised according to their applicability to specify technical services, resources, organisational relations, business processes and overall frameworks for ontology descriptions and their relations. It is concluded that, with few modifications the technical service and resource ontologies are applicable for industrial use and the meta, organisational and business process ontologies needs further development and industrial maturity to be applicable.

KEYWORDS:
Virtual Models, RFID, Ontologies, Project Progress Management, Ubiquitous Computing

1. INTRODUCTION

Virtual models have in recent years proven their worth in practice relating to building design. Today it is practice in Ramboll Denmark A/S to create a virtual model of the complete project before it is build. The immediate advantages of this are great and the authors' experiences with using this new working method show that it; introduces fewer errors, gives better production basis, improved clarity and enhanced communication methods compared to traditional 2D drafting methods. Other researchers have recently reported about similar productivity gains using virtual modelling compared to traditional drafting (Sacks and Barak 2008, Woksepp, 2007).

Virtual modelling and virtual models are not new inventions; hence the terms have been used in many contexts and also under different names. In construction practice and research names like object oriented model, information model, 3D model, building information model (BIM) and virtual building model are often used interchangeably. In this paper the word virtual model is used to describe any digital object oriented model of a physical object (e.g. a person, a building part, a room, a house, a city or a planet etc.). The term virtual model is used rather than e.g. BIM to reflect that the subjects discussed are not only applicable to buildings, but generally applicable in the construction industry. The virtual model often, but not necessarily, contains a geometrical 3D representation of the objects it models.

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There is still much unutilized potential in the virtual models, especially in the construction and operation phases. It is expected that a digital link between the virtual models and the physical objects in the construction process can improve the information and knowledge handling from design to construction and operation. The link can be made with the use of Radio Frequency Identification (RFID) technology. It is created by adding a unique electronic RFID tag to the physical objects and including the ID from the tag in the objects virtual model attributes. As illustrated in section 3.1 it enables the user by means of mobile technology to real-time and at any location to access and update information in the virtual models such as production status, component locations and work instructions.

To be able to share information between trading partners, reuse data from one phase in construction to the next, integrate process and product models with enterprise resource planning (ERP) systems, easily access information, communicate data through networks, read data stored in electronic tags etc. ontologies play an important role. The term ontology does not have just a single definition. Within knowledge engineering the term has been widely discussed in the 1990's (Guarino 1996). Guarino argues that Tom Gruber's definition is the best known (Gruber 1993): "An ontology is an explicit specification of a conceptualization." For use within IT in construction the similar but more detailed definition by DLI Glossary (1998) is also a good definition: "An ontology is an explicit formal specification of how to represent the objects, concepts, and other entities that are assumed to exist in some area of interest and the relationships that hold among them."

In IT in construction practice it means that ontologies are all the certified and upcoming standards, commonly accepted working methods and services that enable unambiguous identification of entities in heterogeneous systems. Furthermore ontologies are also the assertion of applicable named relationships that connect these entities together. Adequate and widely accepted ontologies are needed especially when developing IT systems where scalability and interorganisational interoperability is of importance. Therefore this paper discusses ontologies for IT systems supporting the linking of virtual models with physical objects in construction by use of RFID technology.

Firstly in this paper, an introduction to RFID in construction is given. Secondly, the method used for evaluation of suggested ontologies is described. This is followed by an overview and discussion of ontologies relevant for fulfilling the potential to digitally link the virtual models and the physical objects in construction within the five domains: 1) meta ontologies, 2) technical service ontologies, 3) resource ontologies, 4) organisational ontologies and 5) business process onotologies. In Figure 1 an overview of the ontology domains and their relations is given. They are further described in chapter 4-8.

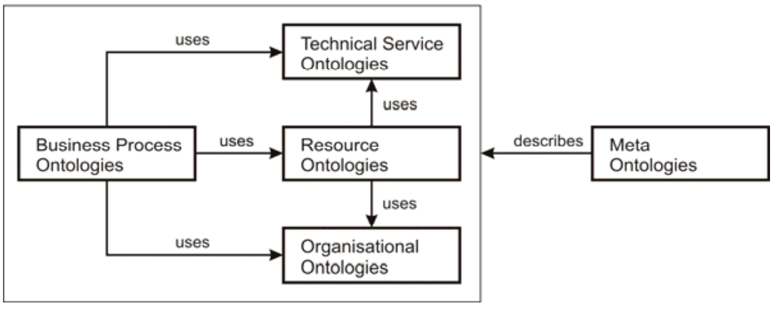

Figure 1: Overview of ontology domains and their relations.

2. RFID IN CONSTRUCTION

RFID stands for Radio Frequency Identification and denotes any identification system in which electronic devices occur that use radio waves or pulsating magnetic fields to communicate with identification units fastened to objects. In the 1970’s and 1980’s RFID was first introduced in the industrial sector to keep track of railway wagons, dairy cattle and auto chassis’s in production lines. Since then it has spread to other areas such as identification of animals, clothing in laundries, billeting systems, admittance control etc. From the beginning of this century there has been an increasing focus on the employment of RFID. This is, among other things, because of recommendations from the U.S. Department of Defence and the U.S. Food and Drug Administration about using the technology. Furthermore, the world’s largest retail chain, the Wal-Mart Stores, Inc., has since 2005 required its largest suppliers to use RFID on all their product pallets and larger units. The supply of RFID equipment has gradually increased, and there is now a higher degree of standardisation in the area than earlier. (Glover and Bhatt 2006)

The most referenced components in RFID systems are tags, readers and middleware. Tags, also termed transponders, are identification units that are attached to the objects to be localised. The interrogator, the transceiver or the RFID reader, as they are often called, is that component which via the antenna is used for scanning the data contents of the tag. The middleware is the software component which ties the RFID reader together with the other software components in an IT system and, if necessary, also filters the data before it is relayed. RFID is a technique whose applications are far from finally developed and new areas appear in a still increasing pace. (Glover and Bhatt 2006)

As early as in 1995 it was stated that automatic identification of objects using RFID technology, was a promising technology for the construction industry (Jaselskis et al. 1995). However, 13 years later the applications of RFID in the construction industry are rare and mostly used in prototype projects or for theft and access control but not in interorganisational applications (Erabuild 2006). The reason for this should be found in the lack of widely used ontologies and the shortcomings of virtual product and process model applications used in the construction industry rather than in shortcomings of the the hardware for RFID systems. The true benefits and complexity of automatic identification systems does not arise from the hardware itself, but from possibilities to get information in the right place, at the right time in a usable form.
A number of recently published papers describe various examples of tested RFID implementations in construction: 1) Automating the task of tracking the delivery and receipt of fabricated pipe spools described in Song et al. (2006), 2) inspection and management in concrete test lab described in Wang (2008), 3) on-site tool tracking described in Goodrum et al. (2006), 4) project progress management with virtual models described in Chin et al. (2005) and 5) tracking and locating components in a precast storage described in Ergen (2007). In all the papers it is concluded that RFID technology can be bought to function efficiently even in the harsh construction environment.

3. METHODOLOGY FOR EVALUATING ONTOLOGIES

A method based on user scenarios and informal questioning described by Grünninger and Fox (1995) is used to evaluate and select the ontologies illustrated in the following sections. First of all, scenarios for future use were developed based on the method contextual design (Beyer and Holtzblatt 1998). Interviews of future users were made as well as brainstorming and state of the art reviews of available literature. The scenarios are used to capture future needs and, afterwards, to evaluate the ontologies by informal questioning. They reflect future applications of the technologies and work processes to be supported by the ontologies. A characteristic user scenario for future use of RFID in production management and component element installation is described in section 3.1. The scenario is presented using story telling and is based on a working process relating to precast concrete element fabrication and installation. It is supplemented by the rich picture in Figure 2. Similar user scenarios for use of RFID and virtual models can be found in many working processes in construction such as quality assurance, facility management, logistics etc. The questions to be answered relating to each ontology or category of ontologies are; 1) Why are they relevant, 2) Who are they relevant for, 3) What are they supporting, 4) When are they used, 5) How are they used.

In order to structure the studied ontologies they are separated into five domains: meta ontologies, technical service ontologies, resource ontologies, organisational ontologies and business process ontologies. A similar split in organising ontologies is also proposed in (Christiansson 2007). See Figure 1 for an overview of the ontology domains and their relations.

3.1 SCENARIO FOR FUTURE USE OF RFID IN CONSTRUCTION

A future user scenario is presented below to outline how the ontologies will support a simple method for continuous project follow up and progress management. The scenario is presented using story telling with the following fictive protagonists; John the virtual model coordinator, Jane the construction manager, Michael a precast concrete manufacturer and Paul the foreman.

Model generation and precast element management

John is model coordinator of the design and construction of a new office building. His task is to secure a smooth flow of information between all parties in the project. During the design of the building John is responsible for the 3D and 4D modelling and work in close collaboration with the general contractor's construction manager, Jane, and project manager, Michael, at the precast concrete manufacturer. John is also responsible for adding the ID's from the RFID tags to the objects in the virtual 3D and 4D model stored on the model server.
When the concrete elements are ready for shipping Jane is responsible for updating 4D production status information on the model server. She does that by reading the RFID tag in each concrete element with her mobile phone and subsequently presses the button "In transit". Together with the production status information the mobile application automatically updates the model server with data about time, date, user and current location from the GPS. Her mobile phone has Internet access and connects to the service provided by the model server.

On site precast element acceptance and inventory management

When the precast elements arrive at the construction site Jane uses the RFID enabled mobile phone to identify the elements. While doing the acceptance check Jane writes any comments on the phone and updates the model server with new element data about, production status, location, time, date, and user. For every element she receives information about installation time, date, storey and gridline from the virtual model server. The acceptance checking also includes finish, transportation damages and measurements of window and door holes.

On site element location

A continued update of the virtual model enables any user of the system to retrieve information about current production status, location, comments and direction of any of the precast concrete elements. Foreman Paul uses his mobile phone to retrieve information about where he can find the next element to be installed and read the comments input during element acceptance at the construction site. In case the element is not in place on the construction site, he is notified where in the supply chain it is currently located.

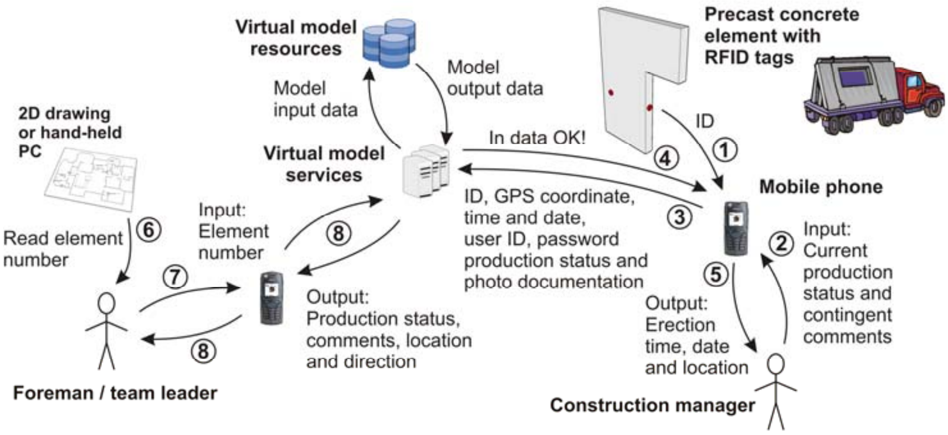

Figure 2: Rich picture illustrating future use of a digital link between virtual models and physical objects in construction for on site element acceptance and inventory management. The numbered events refers to sequence of execution.

Task accomplished update

When a precast concrete element is installed Paul updates the virtual model with his mobile phone by reading the RFID-tag and selecting the "Task finished" button. He supplements the input with a photo for the quality assurance documentation. He now receives information about the next task and the location of the elements.

On-going information retrieval

Thus, during the construction process contractors, engineers, architects and the client can follow the project's progress in their own offices by means of a virtual 4D model viewer. For elements where they have subscribed to notification they receive an e-mail, SMS or RSS feed whenever their status change. The structural engineer uses this option to get information about when he has to go to the construction site to do follow-up quality checks, and the construction manager is quickly informed when new elements arrive on the construction site.

4. META ONTOLOGIES

Meta ontologies are the ontologies for ontologies. They specify frameworks and identify languages for defining ontologies and their relations. In relation to the scenario presented in section 3.1 they are needed to describe how the business processes will make use of the technical services, the resources and people working in the related organisations as illustrated in Figure 1.

The Semantic Web's vision is to extend today's World Wide Web from being a medium for document sharing to becoming a medium for data sharing - a universal medium for data, information, and knowledge exchange. Therefore it is considered as an important framework for future ontologies (including meta ontologies) supporting knowledge handling in construction supported by RFID. The Semantic Web provides a common framework (building blocks for ontologies) that allows data to be shared and reused across application, enterprise, and community boundaries. It is a collaborative effort led by the World Wide Web Consortium (W3C) with participation of a large number of researchers and industrial partners. "The Semantic Web is an extension of the current web in which information is given well-defined meaning, better enabling computers and people to work in cooperation." (Berners-Lee et al. 2001)

Some of the important building blocks in the Semantic Web include the specifications of the Resource Description Frame (RDF) and the Web Ontology Language which are intended to provide a formal description of concepts, terms and relationships within a given knowledge domain (W3C 2004). A triple in RDF consist of a subject, predicate and object. The subject denotes the resource e.g. a web page. The predicate denotes traits or aspects of the resource and expresses a relationship between the subject and the object.

The InteliGrid project is an example of a research project related to the construction industry that makes use of the Semantic Web to define meta ontologies. The InteliGrid Ontology Framework (Gehre et al. 2006) describes a meta ontology and four independent but inter-related ontologies that can be further specialised in an extensible set of domain-specific ontologies serving particular industry purposes. The four ontologies are: 1) Business process ontology, 2) organisational ontology, 3) service ontology and 4) resource ontology. This structure is similar to the one given in this paper with the exceptions that this paper does not differentiate between business process ontologies and service ontologies and this paper also includes technical service ontologies. A comprehensive framework and supporting ontologies are described in the InteliGrid project deliveries but one of the author's major concerns for its success in construction and in relation to the scenario in section 3.1 is the project's lack of significant business drivers who can manage to make it industry adaptable.

5. TECHNICAL SERVICE ONTOLOGIES

Technical service ontologies are the specifications enabling data communication through heterogeneous networks and also a standardised use of hardware and software from different suppliers necessary to fulfil the scenario described in section 3.1. Mature technical communication ontologies such as the TCP/IP protocol for the Internet, GPRS/EDGE for mobile phone communication are used daily by many people and they are also ready for use when linking virtual models with physical objects in construction. In addition 3G mobile broadband will give faster data transfer speeds as a breeding ground for new rich mobile applications and easier on-site Internet access.

The Internet and WWW, as we know it today, dates back to 1992 and is facing some comprehensive paradigm shifts that will introduce new ICT (Information and Communication Technology) applications. First of all, the introduction of XML cleared the way for separating the storage and the access medium for digital information on the Internet. The following introduction in 2000 of Web services and Semantic Web and its supporting standards (SOAP, WSDL, and UDDI respectively OWL, RDF, RDF Schema) forms the basis of efficient and interoperable future handling of information associated with meta data and data stored in information containers globally distributed on the Internet. SOAP denotes Simple Object Access Protocol, WDSL denotes Web Services Description Language and UDDI denotes Universal Description, Discovery and Integration. See W3C (2002) for an overview of activities, specifications, working groups and recommendations related to Web services.

Another paradigm shift is the introduction of IPv6. The internet protocol (IP) specifies a hierarchical addressing system that enables unique identification of all units connected to the Internet. The present version 4 of IP is from the 1970's and consists of a 32 bit address which will not continue to be sufficient for all units connected to the Internet. IPv6 uses 128 bit addressing which gives 4 million unique addresses per square metre which should be sufficient for supporting the growth of the Internet for at least the next 50-100 years and for allowing a dense integration of IP addresses and RFID. These paradigm shifts form the potential for an 'Internet of things' that is a network where all physical objects such as humans, clothes, machines, building components etc. have a unique identification and where information about them can be structured and used rationally by humans and machines. Great potential is expected from using the next generation of the Internet in interaction with virtual models in the construction industry.

A large number of standards exist for RFID technologies but only a few of them have relevance for the construction industry. Two of the RFID standards for contactless smart cards, ISO 14443 and ISO 15963, working on the HF-band (13.56 MHz) have already become popular in other industries. They where originally developed for ID cards but have experienced a wide spread use in general for track and trace, cash less payment, production line optimization and similar purposes, as a cause of cheap tags and good all round attributes. ISO 14443 is developed for proximity coupling (0-10 cm) and ISO 15963 for vicinity coupling (0-1m). Tags supporting both standards are delivered with a pre-printed unique ID, which cannot easily be changed and therefore also can be used for unique identification in interorganisational settings. However it is important to use high quality tags because tags from less reliable manufactures also exist where the ID uniqueness is not definite. The advantage of ISO 15963 tags compared to ISO 14443 tags is their longer reading range which can have significant influence on the system performance. From a construction business view point the ISO 14443 also has a significant advantage. It is compatible with the NFC technology (Near Field Communication) which combines the function of a contactless smart card reader and peer-to-peer communication, and is defined in ISO 18092 (NFC Forum 2008). Today NFC is available in smart phones from e.g. Nokia, Samsung and ARYGON etc. for the traditional consumer marked making them cost efficient also for the construction industry. The traditional mobile phone is one of few modern ICT technologies widely accepted and used generally in construction, and therefore it can be an important gate opener for introduction of RFID in construction. Another important standard is the ISO 18000 series of RFID standards for item management. The 6 standards in the series defines the air interface between tags and readers on 5 frequency bands from 135 kHz to 2.45 GHz and a common architecture (ISO 2004) but not the data content or the data structure. Currently ISO 18000 is less appreciated for industrial use than ISO 15963 and ISO 14443.

EPCglobal is an important developer of ontologies for RFID. EPCglobal develops standards to expedite a commercial use of the technology. EPCglobal is centred on what is called Electronic Product Code (EPC), which is a fundamental ID system for identification of physical objects in an EPC network (EPCglobal 2008). Possibly, it is a successor to the widespread bar codes. EPC uses an URI (Uniform Resource Identifier) in URN (Uniform Resource Name) notation to represent a unique topic with a digital code. A URI is a compact string of characters used for identifying or naming a resource. A URN is a URI that identifies a resource or an object in a specific name space. The name space can be e.g. an ISBN number for books, MAC-address (Media Access Control Address) or IP number for computers or a Serialized Global Trade Item Number (SGTIN) identifier for objects in a supply chain. For a SGTIN-96 identification, in which 96 designates that a 96 bit EPC coding is employed, the URN looks as follows:

- urn:epc:id:sgtin-96:FilterValue.CompanyPrefix.ItemReference.Serialnumber

The filter value is not part of the SGTIN number system but is a 3 bit value that can be used to quickly identify whether the SGTIN-96 ID is a number of a single object or a whole pallet of objects. Furthermore, the SGTIN code identifies the manufacturer, the product type and, finally, the unique object, by means of the serial number. The entire URN is coded into a 96 bit ID saved in the tags.

EPCglobal standards describe components and architecture for what EPCglobal call the “EPCglobal network”. The idea is that this network of standardised and compatible RFID tags, RFID readers and information systems should connect the entire supply chain – from the producer to distributors and transport companies to the retail trade. By means of a network service, ONS (Object Naming Service), it will be possible to route requests for objects to servers containing information about the objects. The ONS-system is hierarchic and similar to the DNS (Domain Name System) where a set of server functions implemented as a large distributed database of URL names and IP addresses. Together with the IP protocol in version 6, the EPCglobal Network makes up the cornerstone of the future 'Internet of things'.

As described in this section there is a comprehensive range of ontologies supporting the scenario presented in section 3.1 but meta ontologies are needed to enable a better integration of the to a large extent separately develop technical ontologies.

6. RESSOURCE ONTOLOGIES

Resource ontologies are dedicated to represent all data sources such as files, documents, databases, product models, and product model views. A prerequisite for interoperability in interorganisational settings is a common resource ontology for representing data, information and knowledge. ISO 12006-2 and IFC (Industri Foundation Classes) are the two major candidates for resource ontologies for the construction industry (Ekholm 2005). ISO 12006-2 is a framework for classification of information within construction but does not provide a complete classification system. A number of national implementations of ISO 12006-2 are available e.g. the North American Omniclass, the Swedish BSAB and the Danish DBK. Unfortunately, there is currently no deeper harmonisation between IFC and ISO 12006-2 or between classification systems based on ISO 12006-2. The IFD (International Framework for Dictionaries) Library for Building Smart (Bjørkhaug and Bell 2007) is an international development addressed to bridge between classification systems and product models. This is therefore an important initiative towards enabling the users described in the scenario in section 3.1 with the ability to retrieve context sensitive information such as installation instructions, maintenance instructions and other virtual model views.

Numbering systems are an important part of the mentioned classification systems and can be used for identification of physical objects in buildings by adding numbering codes to the RFID tag. A digital link between the resources such as virtual models and physical objects can thereby be established. However, it is not advisable to use the code for early object identification because it depends on the object’s final placement in the building and the component system of which the object is a part. There may also be many RFID tags attached to the same object. The code is therefore dependent on an instantiated virtual model of the project which is not always available when the actual components are produced. The classification system, on the other hand, is important for organising information about the objects and their relationships. It is therefore recommended by the authors in most cases to only have a global unique ID (GUID) in the RFID tag and store all other data in the supporting virtual models organised by the resource ontologies. It is the simplest and most flexible way to secure the possibilities for reuse of RFID tags in interorganisational relations. The exceptions are situations where access to the virtual model can not be establish or the concrete uses require more object related information to be stored in the RFID tags.

For some years paper based documentation will be necessary and thereby also human interpretable numbering or codes on objects will be necessary. A printed barcode supplemented with the object label could be the first step towards both computer and human interpretable codes on drawings supporting workflow 6 in Figure 2. With the current development in flexible display technology

(Plastic Logic, 2007) the need for human interpretable general numbering systems will decrease and be superseded by hyperlinks on the views.

The product model ontology IFC in its current version 2x3 supports RFID by use of the *IfcClassificationReference* class, a subtype of *IfcExternalReference*. By adding the GUID from the RFID tag to the IFC model as an *ItemReference* it can be associated with any building element in the virtual model. There is, unfortunately, no inverse relationship between an *IfcExternalReference* and *IfcRelAssociatesClassification* declared in the IFC2x3 schema which would give the possibility to navigate back from an External reference to an *IfcBuildingElement*. Future changes to the IFC Schema would require this to fulfil the scenario described in section 3.1, otherwise the software implementations of IFC should provide this additional feature. Following, it would also be beneficial to be able to model RFID tags as an object or property set in IFC with properties as; GUID, current location, planned location, time and date for tag readings, user who has read the tag, active/deactivated tag.

Another approach is to add the IFC object's global ID to the RFID tag. It is, however, not recommended because this will make the virtual model less flexible to changes. Often it is also necessary to let both one RFID tag point to several objects in the virtual model and to have several RFID tags to point to one virtual object. Furthermore, RFID tags are often born with a fixed GUID.

Another project from the construction industry worth mentioning in relation to resource ontologies is the SABLE project (Simple Access to the Building Lifecycle Exchange). The objective of this project is to enable easier access to resources stored in an IFC model server by providing a common framework for linking IFC model servers and a standardized interface for client access to the IFC model servers. (BLIS 2005)

Because of the extreme complexity in developing an international classification system for organising information in construction, information retrieval based on key word tagging and search machine indexing could be a useful technique for retrieval of information related to objects in a building. Key word tagging has emerged as a popular method for categorising content on a web site. Users are allowed to attach arbitrary strings to data items such as blog entries, photos or items for sale. When web sites supporting meta tagging grow, their structure evolves to an ontology for the data the web site present. The ontology is thereby developed by the users who are using the web site. An ontology created in this way is called a folksonomy (Porter 2005). It is an easy and somewhat useful way to structure and link information but it also has some critical downsides. A folksonomy tag is typically 2/3 of an RDF triple. The subject is known: e.g., the URL for the image being tagged, or the URL being bookmarked. The object is known from the tag. But the predicate to connect them is often missing. To enable machine readable information on folksonomy based ICT tools the information providers must add supplementary semantic expressing the relationship between the subject and object. (Herman et. al 2008)

7. ORGANISATIONAL ONTOLOGIES

Development of organisational ontologies is a general issue for any industry and concerns defining the concepts such as actors and their relations, hierarchies in projects and organisations, interorganisational relations, etc. They enable administration of rights to information and context dependent information delivery to users. In the Inteligrid project (Gehre et al. 2006) an organisational ontology is developed based on actor and project definitions from the IFC standard, developed by the IAI (IAI 2006), authorisation from the RBAC standard (Ferraiolo et al. 2001) and supplemented with additional concepts from the CIM model (Distributed Management Task Force 2006). It is assessed that this ontology will cover the user needs in relation to the scenario described in section 3. However, it is also recommended to consider using the Web Service Business Process Execution Language (WS-BPEL) extension designated BPEL4People (Agrawal et al 2007). BPEL4People enables the modelling of human interaction processes using BPEL but does not contain a complete organisational ontology. A combination of BPEL4People and the Inteligrid organisational ontology is therefore recommended by the authors for developing interoperable applications.

In relation to Semantic Web the Friend of a Friend (FOAF) Vocabulary gradually developed since 2000 is a different approach to an organisational ontology. Because of its simplicity and roots in the fast expanding world of social networking, FOAF is a potential candidate for the first widely accepted organisational ontology while it also should be considered used in the construction industry. FOAF uses the Resource Description Framework (RDF) for defining persons, their ongoing projects, organisations, interests, personality, relationships etc. (Brickley and Miller 2007)

8. BUSINESS PROCESS ONTOLOGIES

By use of the organisational and resource ontologies the business process ontologies specify services for interorganisational communication and enable a direct relationship between business processes and business requirements. They also support workflow management, but currently no mature ontologies exist ready for use in construction. The Inteligrid project describes a framework for developing interoperable business services, which can be implemented using service oriented business architecture (SOBA) and Business Process Executions Language (BPEL) (Gehre et al. 2006). The framework describes high-level business process objects but when it comes to more detailed ontologies about actual information delivery, reference is made to the on-going IDM project of the BuildingSMART initiative (cf. Wix 2005).

In Denmark the national Digital Construction project has worked with information delivery to the construction site and to the client in a digital project hand-over process. The use of a production card has been proposed to represent the information needed to conduct a given task, and a XML-schema has been specified for representing the information needed in the project handover to the client. Knowledge from these projects can be valuable in relation to developing future business process ontologies based on functional building systems but they are currently not considered to be mature enough for industrial use. See also Christiansson (2007).

9. CONCLUSION

This paper describes a review and assessment of existing ontologies relevant in relation to linking virtual models with physical objects in construction. It has been found useful to categorize the ontologies after their applicability to specify meta ontologies, technological services, resources, organisations and business processes. The ontologies applicability to fulfil future requirements have been evaluated from informal questioning against a proposed future user scenario. Up until now the proposed ontologies structure seems to be well-founded.

The conclusions are; 1) the meta ontologies developed for the Semantic Web and the InteliGrid Ontology Framework will be important for developing future IT infrastructures for information handling in construction. 2) Many technical service ontologies are already mature and used widely for communication through the Internet and mobile phones. Therefore the barriers in these domains are integration of these ontologies with the remaining ontologies. When it comes to RFID technology there is also a number of available technical ontologies, e.g. ISO 14443 and ISO 15963 for HF RFID technology and EPC (ISO 18000) for UHF. These standards enable interoperable access to data stored in the RFID tags. Here the critical task is to select the right ontology because they are not compatible. 3) The resource ontology IFC supports representation of identification numbers from RFID tags. However, there is a need for modifications to IFC allowing object information retrieval based on registered RFID tags. It is proposed to use a combination of meta-tagged information based on specified ontologies with the use of search-engines using automatic full-text indexing and key word tagging. This would function as a way to quickly provide users within construction with widely used information such as work instructions, documentation, schedules etc. 4) Various proposals exist for organisational ontologies such as the Business Process Execution Language for People (BPEL4People), the Semantic Web based Friend of a Friend (FOAF) and project and actor definitions in IFC but none of them have gained wide acceptance. FOAF is simple and originates from the widely expanding social networking world and is therefore expected to be the first general used organisational ontology. 5) Business process ontology development is a new discipline requiring new development and specification of e.g. functional building systems before they can be used in relation to linking virtual models with physical objects.

Development of new ontologies starting on meta-levels and increased use of internationally accepted ontologies will enable the structuring and reuse of information to greatly benefit for the whole industry. Nevertheless, it is also one of the most complicated hurdles to overcome for the industry while an increased focus from major universities, companies and property owners is needed for progress in this area.

10. ACKNOWLEDGEMENTS

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