Interoperability among Semantic Resources in Construction: Is it Feasible?

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ABSTRACT: This paper discusses the semantic interoperability in the Construction sector, from the viewpoint of the FUNSIEC project. Shortly, FUNSIEC project aimed to answer the following question: is it feasible to establish semantic mappings amongst Semantic Resources (SRs) specifically created for the Construction sector? This quest has been answered positively through the development of the Open Semantic Infrastructure for the European Construction Sector (*OSIECS*). FUNSIEC work relied in a methodology that supported the development of the OSIECS triad, which is formed by the OSIECS Kernel, the OSIECS metamodel, and the OSIECS model. This paper presents the OSIECS triad, discussing the approach adopted, the challenges faced, the problems overcome, and the results achieved. The work to be done to continue this work is also discussed.

1 INTRODUCTION

Semantic heterogeneity has been recognised initially in the field of databases as one of the toughest problems to bring out semantic interoperability (Kashyap & Sheth 1997). Semantic interoperability is the ability to exchange information and use it, ensuring that the precise meaning of the information is understood by any other application that was not initially developed for this purpose (Hughes 2004). Semantic interoperability enables systems to process (i. e. use it isolated or combined with their own information) in a meaningful way the information produced by other applications. Therefore, semantic interoperability is an important requirement for improving communication and productivity.

In Europe, the construction sector is largely fragmented. A construction project is characterised by several temporary associations of different actors, which apply mainly weakly explicit and poorly codified practices (Hannus et al. 2003). These actors have different viewpoints (e.g. technical and cultural) over the projects and sometimes they have also to consider specific regulations from different countries, which lead them to have different interpretations over the (shared) project-related information. Several initiatives have tried to facilitate the interoperability of information exchange, such as the models and tools related to the Industry Foundation Classes (Wix & Liebich 2003) set up by the International Alliance for Interoperability initiative. Other related contributions are the LexiCon from Stabu (Woestenenk 2003) and the CEN/ISSS eConstruction Workshop (Böhms et al. 2004)), the e-COGNOS IST project (Lima et al. 2003a), the eConstruct project (Lima et al. 2003b) and the ISO 12006 suite - Organization of information about construction works (ISO 12006-2 2001, ISO/DIS 12006-3 2004). Whilst the ISO 12006-2 standardises a model for classification systems by suggesting various terminological Construction specific items, the ISO/PAS 12006-3 suggests a generic standard framework for object-oriented information. Thus, the ISO 12006-3 complements the ISO 12006-2 by providing a generic organisation model that is Construction-domain independent, for the ISO 12006-2 specific Construction terminology.

Notwithstanding these collective efforts from researchers and industrialists the semantic heterogeneity among Semantic Resources (SRs) – in the construction sector – remains a very interesting challenge. Each one of the abovementioned initiatives specify or have associated SRs (ontology similar-entities, such as taxonomies, dictionaries, thesauri, etc.) that describe and arrange the conceptualised work domain. Since distinct groups built these SRs independently, they are semantically heterogeneous. Enforcing a single standard SR – or a set of standard ones – could attenuate the problem, but history of Information Technology in the construction sector has shown that this can be a long process with questionable results. Taking into account that SRs are necessary for expressing and organising the knowledge created and managed by the Construction organisations, there is a strong reason to deal with several SRs (semantically heterogeneous) that have to be shared, which also means, semantically linked. This was the quest motivating the FUNSIEC project that aimed at evaluating how feasible is to build and maintain OSIECS, an Open Semantic Infrastructure for the European Construction Sector (Lima et al. 2005). The FUNSIEC goal was to create a harmonised environment where each SR is clearly characterised (in terms of content, scope, usage, etc.) and situated in the overall map of resources, where semantic links are created among them. The focus of this paper is on the results achieved by the project, namely the FUNSIEC methodology to create the OSIECS *triad*, i. e., the OSIECS Kernel, the OSIECS meta-model, and the OSIECS model.

The paper is structured as follows. Section 2 shows FUNSIEC vision on interoperability matters. Section 3 describes the FUNSIEC approach and discusses on the feasibility question. Section 4 presents the OSIECS triad, emphasising the OSIECS Kernel. Section 5 introduces the *ideal scenario* pursued in FUNSIEC. Section 6 describes how to extend OSIECS through the integration of new SRs. Section 7 concludes the paper and points out the future work to be done.

2 INTEROPERABILITY IN THE FUNSIEC CONTEXT

When handling the semantic heterogeneity problem, the FUNSIEC project considered the untouchable need of preserving the SRs already existing. As such, the FUNSIEC approach to handle semantic heterogeneity can be stated as the problem of discovering, expressing and using (semantic) mappings among the SRs currently available for the sector. FUNSIEC considers that the mapping is a formal expression that states the semantic relation between two entities (an entity being a concept or a property) belonging to different SRs. The mapping should have an explicit and formal semantics, as this is the minimal condition for their usability in any semantic-based application (Bouquet et al. 2004).

Several methods can be used in order to compute mappings, such as terminological, structural, extensional (i.e. based on instances) or semantic methods. Those methods come from different disciplines such as data analysis, machine-learning, language engineering, statistics or knowledge representation. On one hand, their applicability depend on the type of SRs features (e.g. labels, structures, instances, semantics) to be compared and, on the other hand, they depend on the type of results expected. For instance, machine-learning techniques work better when large sets of instances are available. In turn, terminological methods are mainly based on string comparison, i. e., they compare only the terms used to name the concepts without comparing the semantics defined by the concepts. As such, the terminological methods do not fulfil the needs of FUNSIEC in terms of semantic interoperability.

FUNSIEC relies on *semantic methods* (Benerecetti et al. 2004) to tackle the semantic heterogeneity problem. Shortly, semantic methods aim at discovering relations between (pairs of) entities belonging to different schemas, *based on the meaning of the two entities*. It is worth noticing that these methods being semantically exact do only provide an absolute degree of similarity for entities considered equivalent.

FUNSIEC work is based on Description-Logic (DL). This technique was selected for two reasons: (i) it ensures the original semantics of the SRs entities is preserved; and (ii) it provides an explicit and formal interpretation of both entities being compared, and the relation produced. Details of the utilisation of this technique are explained in section 4.

3 IS IT FEASIBLE?

The FUNSIEC project focuses on the interoperability of SRs through the design of the OSIECS infrastructure in order to stimulate complementarities among SRs and promote the emergence of new electronic services. Additionally FUNSIEC also evaluates the work required by other SRs not initially considered in the OSIECS infrastructure, in order to integrate them into OSIECS.

Several ontology development methodologies are reported in the literature (Corcho et al. 2003, Corcho et al. 2002, Fernández-Lopez 1999) and the choice of the 'proper' methodology to be used is very much dependent on the nature and characteristics of the targeted domain and its various applications. In the case of an open semantic infrastructure, such as OSIECS, the applied methodology has to satisfy the following requirements:

• Enable collaborative, multi-user building of the unified infrastructure;

• Take into account the multi-national (including multi-lingual) and multi-disciplinary dimension of construction projects. A typical medium-sized project involves up to 100 stakeholders and generates thousand of documents;

• Make use of already established and recognised semantic resources;

• The unified infrastructure should be flexible and comprehensive enough to accommodate different business scenarios;

• The infrastructure should be developed incrementally involving the end-users; and

• The unified infrastructure is a living system and should allow for future expansion.

A new methodology was developed – the FUNSIEC methodology – which draws on the strengths of the methodologies previously mentioned. The proposed methodology, illustrated in figure 1, comprises the following phases: domain scoping, candidate semantic resources identification, conversion and mapping detection (OSIECS Kernel), OSIECS meta-model and model construction, testing and validation, and maintenance.

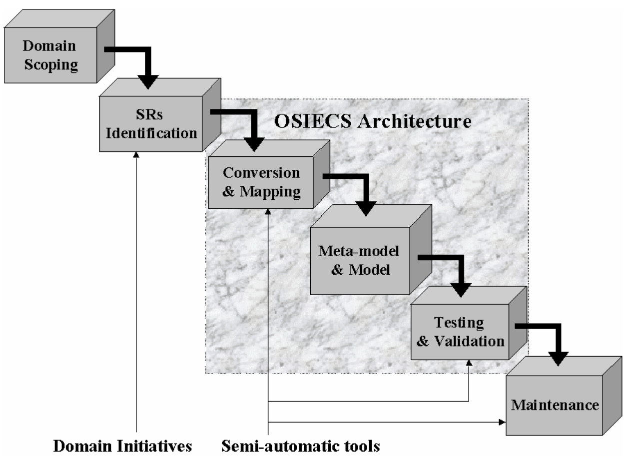

Figure 1. The various phases of the FUNSIEC methodology.

In the first phase, a strategic decision was made regarding the domains that were going to be covered by the unified infrastructure (e.g. knowledge management, e-procurement, etc.).

In the second phase, a set of SRs was identified and the most appropriate were selected regarding the following variables: availability, cost, formalism, and underlying natural language. The SRs that initially form OSIECS are the *bcBuildingDefinitions* taxonomy, the e-COGNOS ontology, ISO 12006-3, and the IFC model. Their meta-schemas and schemas are succinctly described afterwards.

The *bcBuildingDefinitions* is the bcXML taxonomy developed by the eConstruct project (Lima et al. 2003b) in order to demonstrate the power of bcXML[1], an XML-based language tailored to the representation of products/services in the construction sector. The bcXML taxonomy holds 3 000 terms in six European languages and is used to construct electronic catalogues of construction products. The bcXML meta-schema is the model of bcXML taxonomy.

The e-COGNOS ontology (Lima et al. 2003a) focuses on construction concepts related to the *consistent knowledge representation of (construction) knowledge items.* The e-COGNOS ontology comprises two taxonomies containing 17 000 concepts and relations covering several domains of the construction sector. Those concepts and relations are grounded on top of the IFC model, which form the highest-level of the e-COGNOS ontology. Such ontology is used to support Knowledge Management functionalities.

The IFC classes are defined according to the scope and the abstraction level of software systems dealing with Construction specific content (Wix & Liebich 2003). The entities of the IFC model are grouped in layers where the kernel and core extension layers deal with general, abstract concepts whilst the shared elements and domain layers deal with specialised concepts of the real world (IAI).

The ISO 12006-3 defines a schema for a generic taxonomy model, which enables concepts to be defined by means of properties, the grouping of concepts and defining relationships between concepts. *Objects*, *collections* and *relationships* are the basic entities of the model (ISO/DIS 12006-3 2004; Kees 2003).

Third, fourth, and fifth phases are about developing the OSIECS triad. Once identified the SRs to form OSIECS, syntax-related problems (data heterogeneity) were solved by converting each SR meta-schemas and schemas into a *neutral* language, the Web Ontology Language (OWL), produced by the W3C Web Ontology Working Group (Connolly et al. 2004). The OWL was selected due to its expressiveness and the explicitness of its semantic representation, which allows some automated deduction.

The conversion process produced the translation rules from original formalisms into OWL, which is used to create the OWL version of SRs meta-schemas and schemas. At this stage, human intervention was required in order to:

i) Identify formalism used in SRs,

ii) Study semantics of the formalism and

iii) Identify syntactic elements in OWL corresponding to the syntactic elements of the formalism used in the SRs.

The next step required for the construction of the OSIECS meta-model and model was to firstly detect and validate the correspondences (i.e., the mappings) existing among SRs meta-schemas and subsequently the ones existing among the different

[1] The bcXML primarily supports simple eCommerce communication of products (materials, components, equipment, documents) and services within or across borders.

SRs schemas. This step involved two different components: a detector of mappings and a validator. The detector of mappings used an inference engine to compare SRs meta-schemas and schemas and to create lists of equivalent concepts. The validator component was then used to check the mappings detected. The latter was a semi-automatic process, which required the intervention of human experts to ensure that the results of the validation process were correct.

In order to test and validate the OSIECS infrastructure a series of dedicated services and scenarios were implemented. The testing process aimed at:

i) Verify the completeness of the infrastructure in terms of conceptualising the targeted domains.

ii) Assess the relevance of concepts and relationships.

iii) Verify consistency and coherency of concepts.

The final phase of the methodology aims at correcting and updating the open semantic infrastructure during its life cycle. Maintenance is necessary to eliminate errors or deficiencies in the infrastructure as well as to update, enrich or extend the domains covered by OSIECS through the integration of new SRs. During this phase it might also be considered to re-integrate already included SRs. The latter process could be needed in the case in which these resources have been updated or modified.

The results of the application of this methodology allow us to say that yes, it is feasible to establish semantic mappings among SRs construction-oriented. Details about the construction of the OSIECS tool as well as about the semantic mappings results are presented in the next section.

4 OSIECS TRIAD: INTEROPERABILITY FROM FUNSIEC VIEWPOINT

The major result of FUNSIEC is the OSIECS triad, which is composed of the OSIECS Kernel, the OSIECS meta-model, and the OSIECS model. The Kernel is a semi-automatic tool that produces both OSIECS meta-model and OSIECS model. The operation of the OSIECS Kernel is shown in figure 2, which is the transformation process leading to the creation of both OSIECS meta-model/model. The Syntax Converter, the Semantic Analyser, the Converter, the Detector of Mappings, and the Validator (Fig. 2) form the OSIECS Kernel. Experts are required to 'feed' properly the OSIECS Kernel and, as such, make the best use of it.

The Syntax converter and the Semantic analyser work together using the respective *SR input* (for example XMI/EXPRESS meta-schemas, or XSD schemas) in order to produce the conversion rules to be used by the Converter to guide the production of the OWL meta-models and models for each SR. The Converter is a software tool based on the JavaCC[2] compiler, which takes the production rules and generates the Transformers. The Transformers are pieces of software used to automatically convert a given SR (written in its original formalism) into OWL. Two transformers are currently available, namely the XMI → OWL and the EXPRESS → OWL.

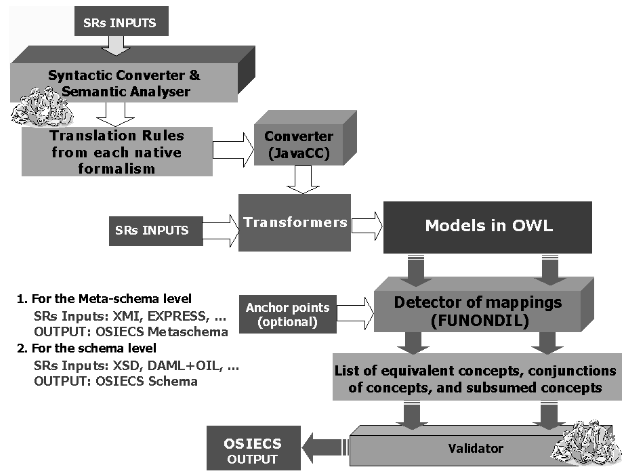

Figure 2. The operation of the OSIECS Kernel.

In the next step, the Detector of Mappings works with the OWL-converted entities to create lists of equivalent or subsumed entities, which are then analysed and assessed by the Validator.

The FUNONDIL[3] system is responsible for the detection and establishment of the mappings among meta-schemas and schemas. As previously mentioned, FUNSIEC adopted a method based on DL techniques to create mappings among the SRs. It uses the 'reasoning services' of FUNONDIL to identify and create semantic mappings, i.e., relations between pair of entities belonging to different SRs. The FUNONDIL inference engine uses two ontologies (O and O') and a set of axioms (A), producing a set of inter-ontology axioms (A') that represents the mappings. The set of axioms A is a list of predefined mappings that represent anchor points among entities of the SRs. If necessary, an expert on SRs may manually define these anchor points. It is worth noticing that this is an optional action that leads to better mapping results. Inferences were carried out a priori in order to optimise the processing time.

Finally, the Validator relies on the expert's manual work that assesses and validates the quality of the produced mappings (this is the best indicator

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[2] JavaCC stands for Java Compiler and is available https://javacc.dev.java.net/

[3] The FUNONDIL system is available at http://195.83.41.67/ondil/connect.html

of the quality of the achieved results). The output of this process is the OSIECS meta-model and the OSIECS model.

All in all, both OSIECS meta-model and model are mapping tables that identify and establish the semantic mappings among the entities forming the SRs.

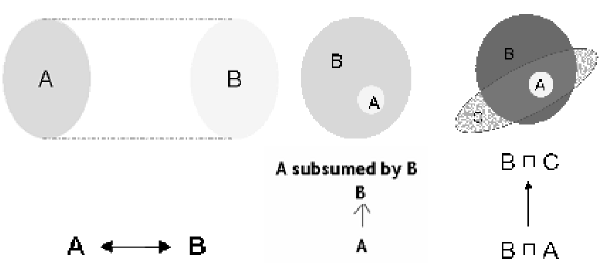
4.1 *Analysis of mappings results*

The mapping search is performed between each pair of SRs producing semantic correspondences considered *equivalent* and *non-equivalent*. The former refers to absolute equivalences among the concepts mapped. The latter refers to partial mappings where only a part of the concepts mapped is common – this is the case of *subsumption* and *conjunction*. Shortly, there are three types of mappings, namely *equivalence*, *subsumption* and *conjunction*, described as follows:

i) Equivalence: the concept A is 100% equivalent to the concept B, considering the semantic expressed in each ontology (Fig. 3a).

ii) Subsumption: Subsumption is a rank relation that defines the relation subconcept → superconcept between concept A and concept B (Fig. 3b).

iii) Conjunction: Conjunction mappings are a consequence of the mappings obtained in the previous stage (Fig. 3c). Note that the conjunction is represented by the constructor ⊓ in the figure 3c.



(a) (b) (c)

Figure 3. Representation of (a) an equivalence mapping, (b) a subsumption mapping and (c) a conjunction mapping.

Let us consider the ontologies O_1 and O_2, the concepts C_1, C_2, A and B, and the constructor ⊑ that represents subsumption. It is worth emphasising that subsumption mappings depend on the sense in which the mappings are established. In other words, the subsumption mappings of (O_1,O_2) may be different from the subsumption mappings of (O_2,O_1). This difference comes from the asymmetry of the subsumption relationship between two concepts. A subsumption mapping $C_1 \sqsubseteq C_2$ (where $C_1 \in O_1$ and $C_2 \in O_2$) belongs to the set of mapping (O_1,O_2) while the set of mapping (O_2,O_1) may not contain the subsumption mapping $C_2 \sqsupseteq C_1$.

Another interesting conclusion of the mapping process is the fact that an equivalent mapping intersection depends on the SR point of view and is not totally symmetric. For instance, considering the OSIECS meta-model and from the e-COGNOS viewpoint (Fig. 4), the inference service for mapping intersection will return the following set of couples among others:

[Relation_Relation (e-COGNOS -MS), Relationship (bc-MS)];

[Relation_Relation (e-COGNOS -MS), IfcRelationship (IFC)]; and

[Relation_Relation (e-COGNOS -MS), xtdRelationship (ISO)]

By the transitivity property we can state that *Relationship* (from the bcXML meta-schema) is equivalent to *IfcRelationship* (from IFC meta-schema) and to *xtdRelationship* (from ISO12006-3 meta-schema), which is true.

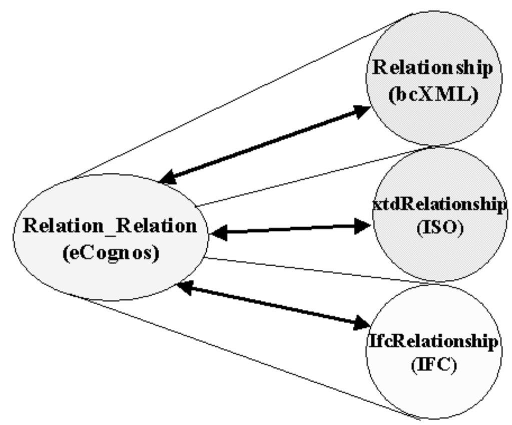


Figure 4. Mapping intersection: looking through the perspective of Relation_Relation concept of eCognos.

However when we take another SR viewpoint the results of mapping intersection will not necessarily be the same. Indeed, the mapping intersection corresponds to the set of all entities that have at the same time (*n-1*) equivalent mappings with other SRs entities, *n* being the number of SRs that belong to the OSIECS kernel (*n*=4 in this case).

Finally, we mapped each SR with itself in order to prove the correctness of the OSIECS Kernel. As expected, mapping a SR to itself produces equivalences between the same concepts and only that kind of equivalences. In addition, results for subsumption and conjunction are also presented, but this means only redundant information, because if A ⊑ B and B ⊑ A then A is equivalent to B. This exercise helped us to be sure that the mapping process was working properly.

Wrapping up analysis of mapping results we should say that the mapping discovery process grants semantic interoperability improvements by enabling us to express what type of relation holds among concepts, but nothing can be said regarding the degree of subsumption that stands between two concepts.

5 THE IDEAL SCENARIO

In the FUNSIEC ideal scenario (Fig. 5), there is an 'integration' of the OSIECS components (including SRs, the extended version of OSIECS Kernel, both enriched OSIECS meta-model and model) together with the tools used to manage the SRs, namely:

a) The eConstruct tools: bcXB, RS/SCS, and TS (Lima et al. 2003b),
b) The IFC tools: IFCViewer and IFCEngine,
c) The e-COGNOS tools: e-CKMI and e-COSer (Wetherill et al. 2002); and
d) The LexiCon Explorer (Woestenenk 2002).

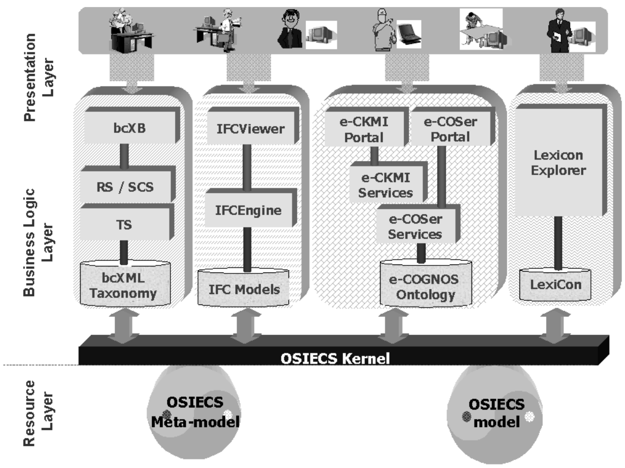


Figura 5. The ideal usage scenario for OSIECS components.

The vision is that the OSIECS Kernel, supported by both OSIECS meta-model and model, acts as a bridge amongst the different tools providing richer possibilities of using the SRs in a transparent way. For instance, an expert looking for knowledge (using the e-COGNOS tools) concerning problems related to the fire resistance of a given brick can, at the same time, find the information about alternative products, their suppliers, prices, etc., using the eConstruct tools in a totally transparent way. The OSIECS Kernel, extended version, is to be responsible for translating the need of the expert in the respective bcXML query, sending it to the bcXML server and getting back the right answers. Another example is for a designer developing a CAD drawing (IFC compliant) and, at the same time, needing to know about the regulations that must be followed in his/her project. In this case, OSIECS Kernel provides the link between the IFC tools and the e-COGNOS tools.

Let us consider another situation where a client asks the services associated to one specific SR. OSIECS associated tools can push knowledge to him, by sending information described in other SRs that represents knowledge related to that s/he asked for and that s/he is not aware of.

6 HOW CAN OTHER SRS BE INTEGRATED INTO OSIECS

The semantics of a given formalism is said explicit if it is expressed *without ambiguity* and represented in a format *interpretable by the computer*. Consequently, natural languages are the most expressive – we can express everything using natural languages – but their semantics are the least explicit; the semantics of natural languages are ambiguous and inaccessible for computer programs.

Since different encoding formats need specific processing, this section explains the required work to integrate new SRs into OSIECS meta-model/model. The formats considered in FUNSIEC were *free texts*, *semi-structured documents*, *Structured databases,* and *XML with DTD/XML Schema*.

Free texts, written in natural language, are essentially definitions of words and grammatical rules. These definitions and rules are described in dictionaries and grammars for human interpretation only and not for computers. *Free texts* have to be submitted to some preliminary treatments in order to capture formal and non-ambiguous semantics, using some Natural Language Processing (NLP) tools.

In order to make human language exploitable by software, NPL tools endeavour to understand it. The process can be summarised as follows: experts (from a given domain) collect some representative texts of the knowledge that constitute the corpus. Then those texts are submitted to several NLP specific processes, such as text segmentation and identification of specific grammatical expressions (like synonyms, morph-syntactical constructions, detection of most frequent verbs, nouns and expressions, *etc*.). Specific dictionaries can help some of the tools. Those dictionaries depend on the natural languages used to write the texts.

After this stage, those terms are considered as the candidate terms to form an ontology but likely all those terms could not be the most representative ones. Therefore, a manual phase is required where the experts are invited to remove some of those terms. Afterwards, the experts use the selected terms and relations to construct a formal ontology. Most of this work needs to be done by experts even if tools can help them. By using this approach some of the natural language expressiveness is lost, but this is the price to pay in order to obtain formal and non-ambiguous description of a given domain, which is precise and can be automated.

Semi-structured documents, such as Excel sheets and HTML files, contain more explicit semantic content than free texts. In fact, tabular structure and relationships among cells in an Excel sheet allow computer programs to understand partially the meaning of the sheet. In the same way, the tags introduced to HTML files help a navigator to parse and display them according to a predefined template. Apart from that, the remaining part of the semantics is expressed in natural languages making the meaning inaccessible for computer programs. A part of the semantics is represented through the structure. For instance consider a table entitled *products* with a column labelled *name* and another one labelled *number_of_components*. Even if for an expert the semantic is clear, it is difficult to design an algorithm that would automatically detect which kind of relationship links those two columns. Hence, even experts need to extract explicit semantics from semi-structured documents.

Structured databases are the representation formalisms of a large volume of SRs. The logic model of databases allows organise huge amount of data and formally express relationships among data. The semantics of these resources are implied from table structure and integrity constraints. However, to the best of our knowledge, a semantically well-defined format representing all integrity constraints in the context of an automatic transformation does not exist yet. Consequently, these integrity constraints help the designers to develop consistent databases rather than facilitate interoperability.

A conversion from a database to an OWL ontology is an *ad hoc* transformation, highly dependent of each database schema (Barrasa et al. 2003). Some authors (Calvanese et al. 2001) suggested an approach to transform a database into a set of DL axioms. Such work is a preliminary stage to develop a generic method to convert a relational database into a OWL ontology.

XML language (with DTD/XML Schema) supports the creation of SRs that already consider interoperability matters. This provides a good background to build tools allowing to (semi)-automatically treat the semantics of these resources, coming essentially from the DTD or the XML Schema. Basically, these tools can read XML files and associated DTD/XML Schema and convert them into the DL axioms. A OWL ontology can be generated from these axioms by means of a compiler.

In synthesis, the human intervention plays an important role for capturing and formalising semantics of free texts, semi-structured documents and even structured databases. SRs of these types firstly need to be 'treated' before being integrated into OSIECS. After the formalism conversion step, the mappings discovery stage can be pursued by submitting the OWL SRs to the detector of mappings of the OSIECS kernel.

7 CONCLUSIONS AND FUTURE WORK

As presented in this paper, semantic interoperability is the reason behind the FUNSIEC project, which was entirely based in a methodology for creating the Open Semantic Infrastructure for the European Construction Sector (OSIECS). The development of such infrastructure was the mechanism used in FUNSIEC to answer one single question: *is it feasible to establish semantic mappings amongst SRs tailored to the construction sector*? Based on the assessment of FUNSIEC results, namely the OSIECS triad (Kernel, meta-model, and model), the answer is *yes*, it is feasible. The OSIECS Kernel generates both meta-model and model which, in turn, provide the required links to semantically map the SRs among themselves.

The FUNSIEC methodology covers the selection of the SRs, their transformation to the same (neutral) format, and the identification and establishment of the existing mappings among them. Two transformers were developed in FUNSIEC supporting the conversion XMI/EXPRESS to OWL. Three types of mappings were considered, namely *equivalence*, *subsumption* and *conjunction*. Technically speaking, FUNSIEC adopted an approach based on *semantic methods* to tackle the semantic heterogeneity problem using the FUNONDIL system.

FUNSIEC quest is not finished yet. The results achieved so far are going to be extended. Firstly, there is a need to discover new mappings and cope with the multi-lingual aspects of European SRs. In order to do that, other interoperability methods are to be evaluated, such as those underlying Natural Language Processing techniques.

Secondly, the semantic interoperability could be improved by associating annotations to the mappings, such as specific labels aiming to facilitate a better contextualisation of the links connecting the SRs. Thirdly, OSIECS Kernel needs to provide an Application Programming Interface to offer its service to third party applications.

Finally, it is necessary to optimise the current FUNONDIL reasoning process of mappings discovery since it is a time consuming task.

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[4] The interested reader can find more information at www.funsiec.org

REFERENCES

Barrasa, J., Corcho, O. & Gómez-Pérez, A. 2003. Fund Finder: A case study of database-to-ontology mapping. In A. Doan, A. Halevy & N. Noy (eds), *ISWC2003 Workshop on Semantic Integration*, *Sanibel Island, Florida, USA, 20 October, 2003.*

Benerecetti, M., Bouquet, P. & Zanobini, S. 2004. Soundness of Semantic Methods for Schema Matching. In P. Bouquet & L. Serafini (eds), *Workshop on Meaning Coordination and Negotiation (MCN-04) at the 3rd International Semantic Web Conference; Working notes, Hiroshima, Japan, 8 November 2004*.

Böhms, M., Lima, C., Storer, G. & Wix, J. 2004. Framework for Future Construction ICT. In R. Beheshti (ed.), *International Journal of Design, Sciences & Technology* 11(2): 153-162.

Bouquet, P., Euzenat, J., Franconi, F., Serafini, L., Stamou, G. & Tessaris, S. 2004. D2.2.1 Specification of a common framework for characterizing alignment. *Knowledge Web project EU-IST-2004-507482, realizing the semantic web*.

Calvanese, D., De Giacomo, G. & Lenzerini, M. 2001. A framework for ontology integration. *Proceedings of the 1st Internationally Semantic Web Working Symposium (SWWS), Stanford University, California, USA, 30 July – 1 August, 2001*: 303–317.

Connolly, D., Hendler, J. & Schreiber, G. 2004. Web-Ontology (WebOnt) Working Group, http://www.w3.org/2001/sw/WebOnt/

Corcho, O., Fernández-Lopez, M. & Gómez-Pérez, A. 2003. Methodologies, tools and languages for building ontologies. Where is their meeting point? *Data and Knowledge Engineering*, 46: 41-64.

Corcho, O., Fernández-Lopez, M., Gómez-Pérez, A. & Vicente, O. 2002. WebODE: an integrated workbench for ontology representation, reasoning and exchange. In A. Gómez-Pérez & V.R. Benjamins (eds), *13th International Conference in Knowledge Engineering and Knowledge Management (EKAW'02), Lecture Notes in Artificial Intelligence*, v. 2473: 138-153. Berlin: Springer.

Fernández-Lopez, M. 1999. Overview of methodologies for building ontologies. *Proc. of the IJCAI-99 Workshop on ontologies and problem-solving methods, Stockholm, Sweden, 2 August, 1999.*

Hughes, G. 2004. A Guide to Interoperability for Regional Initiatives. Brussels, Belgium: eris@ European Regional Information Society Association.

IAI - International Alliance for Interoperability web site, http://www.iai-international.org/iai_international/

ISO 12006-2. 2001. Building construction -- Organization of information about construction works -- Part 2: Framework for classification of information.

ISO/DIS 12006-3 version 3. 2004. Building construction -- Organization of information about construction works – Part 3: Framework for object-oriented information.

Kashyap, V. & Sheth, A. 1997. Semantic Heterogeneity in Global Information Systems. In M. Papazoglou & G. Schlageter (eds), *Cooperative Information Systems: Current Trends and Directions*. London/San Diego: Academic Press.

Lima, C. P., Fiès, B., Lefrancois, G. & Diraby, T. E. 2003. The challenge of using a domain Ontology in KM solutions: the e-COGNOS experience. In R. Jardim-Gonçalves, J. Chan & Steiger-Garção (eds), *Concurrent Engineering: Research and Applications; Proceedings of 10th ISPE International Conference*, *Madeira, Portugal, 26-30 July, 2003*.

Lima, C. P., Stephens, J. & Bohms, M. 2003. The bcXML - Supporting eCommerce and Knowledge Management in the construction industry. In Bo-Christer Björk (ed.), *Electronic Journal of Information Technology in Construction; Special Issue eWork and eBusiness*, v. 8: 293-308.

Lima, C., Ferreira Da Silva, C., Le Duc, C. & Zarli, A. 2005. A Framework to Support Interoperability among Semantic Resources. *In Interoperability of Enterprise Software and Applications – Technical Sessions; Pre-proceedings of the First International Conference: Interop-Esa'2005, Geneva, Switzerland, 23-25 February, 2005*.

Wetherill, M., Rezgui, Y., Lima, C. & Zarli, A. 2002. Knowledge management for the construction industry: the e-Cognos project. In Bo-Christer Björk (ed.), *Electronic Journal of Information Technology in Construction; Special Issue ICT for Knowledge Management in Construction*, v. 7: 183-196.

Wix, J. & Liebich, T. 2003. IFC: Current Reality and Future Potential. R. Jardim-Gonçalves, J. Chan & Steiger-Garção (eds), *Concurrent Engineering: Research and Applications; Proceedings of 10th ISPE International Conference*, *Madeira, Portugal, 26-30 July, 2003*. The Netherlands: Balkema.

Wix, J. & Liebich, T. 2004. CWA3 – CEN Workshop Agreement, *European eConstruction Meta-Schema (EeM), eEurope Pilot Project SPICE,* 2004. Document published by the CEN/ISSS eConstruction Workshop, Brussels.

Woestenenk, K. 2003. Classification, taxonomy, ontology, what do we mean with it? In R. Jardim-Gonçalves, J. Chan & Steiger-Garção (eds), *Concurrent Engineering: Research and Applications; Proceedings of 10th ISPE International Conference*, *Madeira, Portugal, 26-30 July, 2003*. The Netherlands: Balkema.

Woestenenk, K. 2002. From LexiCon to XTD. In Z. Turk & R. Scherer (eds), *European Conference on Product and Process Modelling in the Building and Related Industries; Proc. eWork and eBusiness in Architecture, Engineering and Construction, Portoroz, Slovenia, 9-11 September, 2002.* The Netherlands: Balkema.

Hannus, M., Blasco, M., Bourdeau, M., Böhms, Cooper, G., Garas, F., Hassan, T., Kazi, A., Leinonen, J., Rezgui, Y., Soubra, S. & Zarli, A. 2003. Construction ICT Roadmap. *D52 - ROADCON project: IST-2001-37278.*