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Knowledge engineering approaches for building materials domain

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SUMMARY: Architecture, Engineering, Construction, Ownership and Operation (AECOO) industry collects Big Data during the entire lifecycle of a building or infrastructure. First phases in the lifecycle account for majority of static design data (i.e. architecture, constructive elements, equipment) while later phases contribute more dynamic data (construction site, operation). The industry efficiently utilizes common information engineering approaches for storing, updating and processing of the data. However, the traditional information management approaches (i.e. SQL databases and queries) are not efficient enough in the digital construction era where a growing amount of semantic content is available as Linked Open Data. The AECOO projects will have to upgrade traditional databases to knowledge bases. This will enable semantic reasoning about project data beyond the capacity of an expert (i.e. construction foreman) in situations where project documentation is incomplete. In the paper, an overview of existing research in knowledge engineering technologies appropriate for AECOO projects with focus on building materials domain is given. In the second part, usage of knowledge base for building materials is demonstrated with a use case from the heritage building domain.

KEY WORDS: Architecture, Engineering, Construction, Ownership and Operation, Knowledge Engineering, Knowledge Base, Linked Open Data, building materials

1 INTRODUCTION

1.1 Motivation

In reality, documentation for AECOO projects (i.e. Technical Data Book) is often incomplete, not available or non-existent. Also, information that is exchanged between stakeholders throughout the lifecycle of a

construction project does not necessarily have an understood meaning [1]. In such situations, additional steps are needed outside the project's information system to search for specific technical information. Additionally, such additional searches are costly. There is also a cost for not finding information. Although it's impossible to measure the exact cost of employees not finding information on a company's intranet, the Intranet Cost Analyzer [2] gives a ballpark figure of over 17.000 EUR for a company with 50 employees (50 page visits per day per employee, 20 confusion seconds and average employee annual salary of 50.000 EUR). This is huge cost for not finding information.

It is known that traditional information management approaches correspond to the concept of "closed world assumption" where failed data search assumes that data does not exist. For example, consider the task [3] of designing a minimal concrete cover for a reinforced concrete beam placed outside a residential building situated close to the coast. To obtain an adequate concrete durability for the exposure class XS1, an information system is required to query the Eurocode 2 table for appropriate concrete strength class (i.e. C30/37). If the table is not part of the system, the information is considered non-existent. But, the information does exist outside of the information system.

Another explanatory example has happened on construction site where workers were in charge to connect new reinforcement to existing cured concrete using specific (Hilti) injection adhesives in drilled holes as designed by structural engineer (Post-installed rebar connections [4]). The workers replaced the planned system with (cheaper) alternative adhesive. At that moment, depth of the drilled hole had to be checked against the requirements of the alternative adhesive material. This is an unpredictable event and the information about the required depth of the hole for the rebar was not available. The goal is to transform such unpredictable events into predictable ones because, again, the information does exist outside of the information system.

1.2 Building materials

For any construction project to succeed, it is very important to select the materials accurately during the project's initial stage. Trying to choose the best-performing materials is a crucial task for the successful completion of a construction project [5].

Building materials can be standard, alternative, composite, and smart materials. The availability of 4000 different types of the metallic alloy and 5000 varieties of plastic, ceramics, and glass reveals that building materials data are highly diverse [6]. Furthermore, these materials possess thousands of unique properties of their physical, mechanical, thermal, chemical, optical, acoustical, and physiochemical characteristics [7]. Apart from the challenging task of capturing the semantics of large and complex properties of the building materials, another major challenge is associated with the strenuous data management issues related to the storage and maintenance of building data [8].

The materials industry is highly innovative and produces materials with different properties over the period to meet the current design, production and construction needs [5]. Because of the continuous development

distributed across multiple producers, data about any materials used in AECO projects could be integrated directly from the producers' data sources [9].

1.3 Knowledge bases

In an organization, knowledge exists in tacit, explicit and implicit form [10]. Tacit knowledge refers the personal knowledge of an individual which is gathered through experience, personal belief, instinct and values. It is a dynamic form constantly updating and changing. Tacit knowledge is difficult to extract for an organisation and is an extremely valuable asset. Explicit knowledge is ideally what tacit knowledge needs to become. Explicit knowledge takes the form of structured language and is easily transferred to others through IT techniques. Implicit knowledge on the other hand is unstructured and difficult to explain and share with others. Knowledge can be described in terms of "know what", "know how" and "know why". In **Erreur ! Source du renvoi introuvable.** [11] the creation of knowledge is shown as a pyramid beginning as data gathered from experience and organised into information which can be shared and analysed to become knowledge used in decision making.

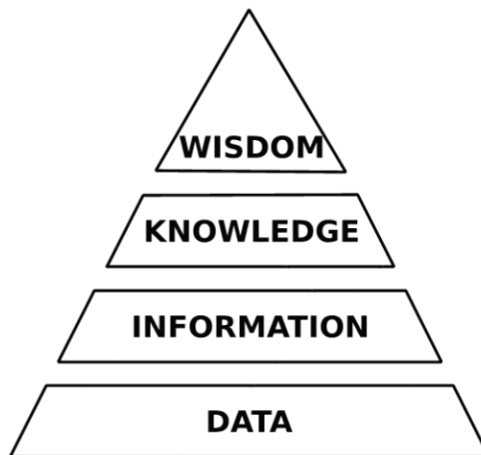


Figure 1. The pyramid of knowledge [11]

The two motivation examples above demonstrate the need for move from the concept of "closed world assumption" (information management) to the concept of "open world assumption" (knowledge management) for building materials domain. The change of concept technically corresponds to the migration from traditional databases (DB) to knowledge bases (KB) [12]. The advantages of KBs are:

- distributed KBs can be integrated by design,
- data stored in KBs can be used in reasoning mechanisms,
- in KBs data is converted to semantic information (i.e. C30/37 is minimal concrete strength class for exposure class XS1)
- Big Data [13] collected during building lifecycle can be stored in KB

Knowledge bases are intrinsic part of Semantic Web (or Web of Data technologies (RDF, OWL)) where a growing amount of semantic content is available as Linked Open Data (LOD) [14]. LOD enables linking of

entity mentions in text (i.e. inside Technical report or Data Book) with their corresponding entities in a knowledge base [12]. Generally, there is a manifest lack of AECOO projects leverage to utilize knowledge engineering approaches. But, there is a growing research community for LOD for Building Information Modeling (BIM) [15].

1.4 Contribution

Contribution of the paper is a short overview of the literature related to research and application of knowledge engineering technologies in the context of building materials. The overview is complemented with real use case as an example of knowledge engineering for building materials domain.

Therefore, in the first part of the paper, we shortly overview existing research in knowledge engineering technologies appropriate for AECOO projects with focus on building materials domain. In the second part of the paper, usage of knowledge bases for building materials is demonstrated with a use case from the heritage building domain.

2 LITERATURE REVIEW

2.1 Knowledge engineering for building materials domain

From a construction engineer's point of view proper identification of building materials knowledge assets and their modelling is very important for correct elements design and construction details, because together with a proper maintenance schedule, materials can reach levels of nominal life of the structure prescribed by the regulations [16].

From the knowledge engineer's point of view availability of the computer-readable building materials data and their specific properties is fundamental to performing different engineering analysis [9]. Another important feature is possibility for linking data. Linked data approach means that a knowledge base (i.e. ontology) can reference (integrate thru linking) complementary remote knowledge bases specializing in specific building materials (i.e. only insulation).

In the use case [5] authors demonstrated the use of support vector machine model for selection of suitable materials in a construction project in South Korea. They reported about 87.5% accuracy against highly experienced decision maker. This case study indicates that the support vector machine model appears feasible to be the decision support model for selecting construction methods.

In [7] authors had similar overall goal as in [5] but used different, more knowledge engineering oriented approach (semantic inference, ontology). They developed material name matching system to find a standardized material name and its associated material properties from BIM model in IFCXML format. One of the results was a knowledge base (ontology) for building materials. The system was applied for building energy analysis domain. Using the proposed system, engineers will be able to increase their efficiency in entering required data into building energy analysis tools and to reduce the possibility of erroneous data input.

In [9] authors demonstrated use of ontologies for developing building material database capturing highly accurate and semantically conflicting data of building materials. Authors see the database as the first step to

the development of a simulation tool for the building waste analysis. The proposed system provides syntactical homogeneity while accessing the diverse and distributed data of building materials. Following knowledge engineering technologies were used: knowledge engineering technologies: Resource Description Framework (RDF), Web Ontology Language (OWL), Protégé and Oracle RDF Graph database.

With the advance of BIM-centric approaches, semantics contained in BIM-models [17] is subject to knowledge engineering tasks. One such task is verification of objects from a BIM-model against semantical rules. In such cases knowledge engineering technologies are needed (i.e. knowledge base referring to the concept of “open world assumption”), which basically introduce general knowledge (i.e. meta description) about domain (i.e. building materials). Another ITC concept that supports interoperability and upgrades the concept of a knowledge-base is linked data (LD). Linked data utilizes Semantic Web standards and technologies [18] so that knowledge-bases from diverse domains can be interlinked [19].

New and innovative semantic applications (i.e. Semantic MediaWiki [20]) can utilize knowledge-bases with the advanced searching and querying mechanisms provided by SPARQL [19]. One such SPARQL example is to query knowledge-base for historical buildings where specific type and dimension of brick was used for walls. Since masonry brick is found on nearly every continental historic building, the query results can be used during a restoration project to learn from another previously completed restoration projects.

In addition to that, semantic applications can also employ reasoning mechanisms to infer logical consequences from asserted facts in knowledge-base. Semantic reasoning is an advancement to what was previously referred to as case-based reasoning approach [21]. For semantic reasoning a knowledge base composed of ontology (or many interlinked ontologies) and semantic rules [22][23] is needed.

In consequence, proper knowledge engineering in construction projects [24] results in knowledge-based system (KBS) acting as a consultation system [25], which supports more effective management of projects and application of building materials.

3 RESEARCH EXAMPLE: Knowledge base for concrete production

Our research was focused to concrete production process. Figure 2 shows a process diagram (notation is IDEF) of concrete production which we developed as part of our research.

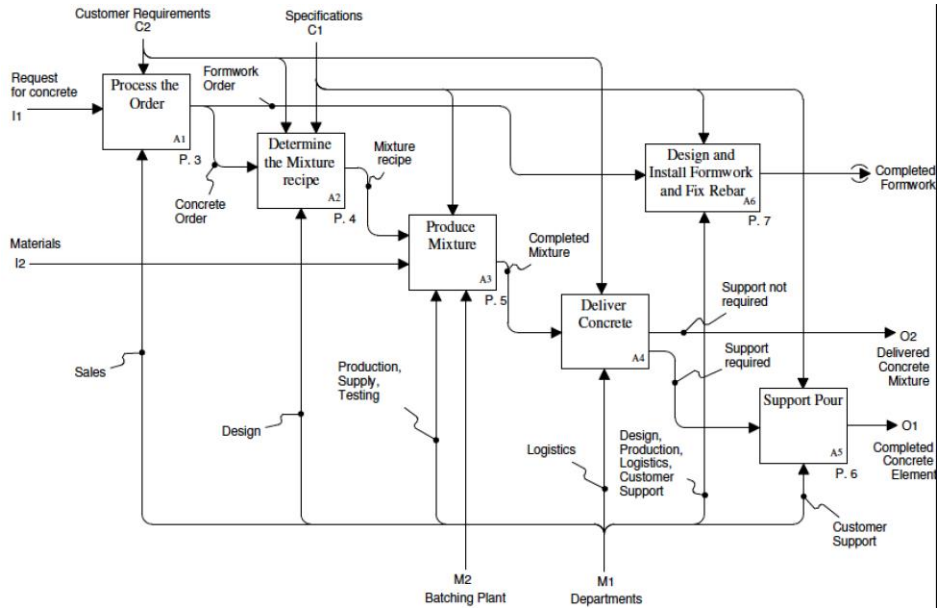


Figure 2. Concrete production process diagram (IDEF)

The process diagram shows following activities in concrete production:

- Order processing
- Specification of mixture recipe
- Mixture production
- Concrete delivery, and
- Pour support

For the process a knowledge base (Figure 2, left) with 49 concepts, 15 object properties and 15 data properties (Figure 2, right) was designed. The knowledge base was implemented as an ontology in Protégé. The ontology also contains SWLR rules that infer fine aggregates, coarse aggregates, Mortar, MediumSand, CoarseSand, FineSand, Pebble, Pebble, Cobble. Some of the rules are deined in Table 1.

Table 1: Rules for concrete production ontology

Rule for	SWLR rule
Coarse aggregate	Aggregate(?a1), hasSize(?a1, ?dm), greaterThan(?dm, 4.0) -> CoarseAggregate(?a1)
Fine Aggregate	Aggregate(?a1), hasSize(?a1, ?dm), greaterThan(?dm, 0.063), lessThan(?dm, 4.0) -> FineAggregate(?a1)
Mortar	hasConcreteMixProportions(?c, ?x) ^ Concrete(?c) ^ hasSize(?a, ?sz) ^ lessThan(?sz, "4.0"^^xsd:double) ^ hasAggregate(?x, ?a) -> Mortar(?c)
Fine sand	Sand(?sd), hasSize(?sd, ?sz), greaterThanOrEqual(?sz, 0.063), lessThanOrEqual(?sz, 0.2) -> FineSand(?sd)

The concrete production ontology is an open and therefore scalable repository of knowledge, which server as a basis for development of further semantic applications for construction domain.

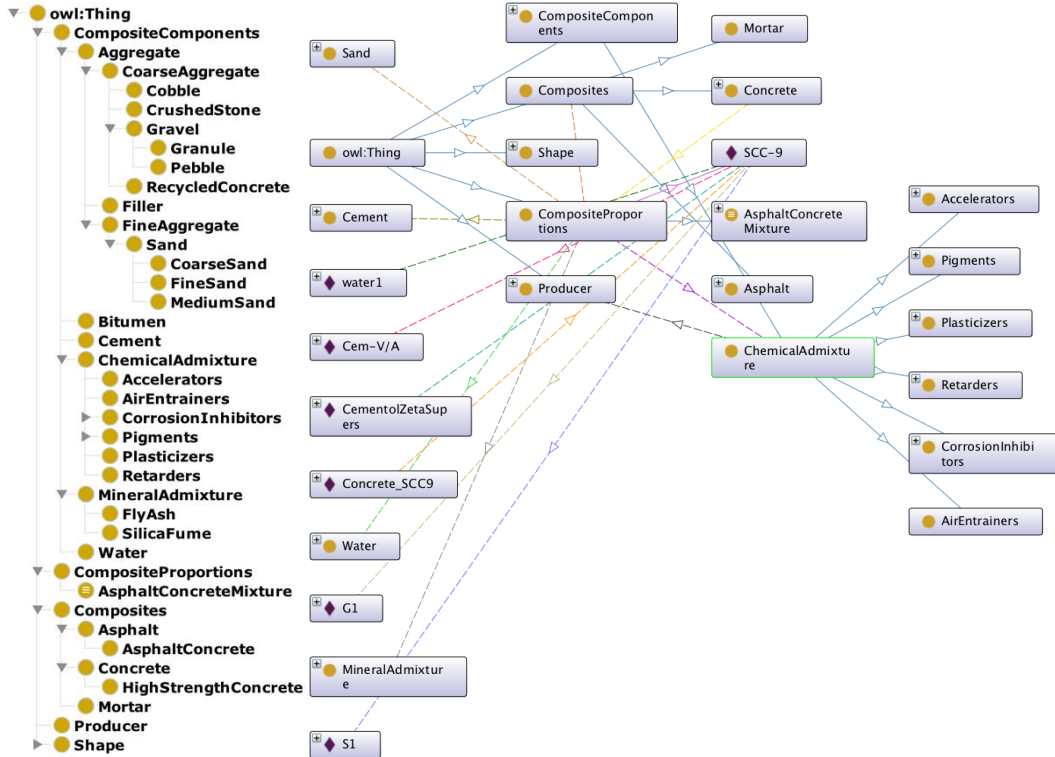


Figure 3. Hierarchy of concepts (left) and their relations (right) for concrete production ontology

4 CONCLUSIONS

In the paper, we reviewed research and application of knowledge engineering technologies in the context of building materials.

There is only little research literature published at the crossroad of building materials and knowledge engineering (keywords: linked data, semantic web, knowledge bases). One of the reasons for this is that, generally, application of knowledge engineering to building materials domain is out-of-scope for AEC researchers while IT researchers are more interested in basic IT research than applicative research. Luckily, construction informatics has growing interest in knowledge engineering in AEC.

Pioneering applications of knowledge engineering technologies for building materials can be found where linked data approach is utilized thru a knowledge base (i.e. ontology) that can link complementary remote knowledge bases specializing in specific building materials (i.e. concrete).

Research activities are most active in the following domains:

- building energy analysis,
- building waste analysis,
- building material catalogues,
- material name matching from BIM models,
- ontologies for verification of objects from a BIM-model against semantical rules
- concrete production.

Our research in concrete production ontology proved the usefulness and efficiency knowledge engineering.

Future research will include integration of different complementary ontologies from the AECOO domain.

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