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Review

Semantic web technologies in AEC industry: A literature overview

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ABSTRACT

Over the recent years, the usage of semantic web technologies has notably increased in the domains of architecture, engineering and construction (AEC). These technologies are typically considered as complementary to existing and often used Building Information Modelling (BIM) software. The usage of these technologies in the AEC domains is thereby motivated by (1) a desire to overcome the interoperability issue among software tools used in diverse disciplines, or at least improve information exchange processes; (2) a desire to connect to various domains of application that have opportunities to identify untapped valuable resources closely linked to the information already obtained in the AEC domains; and/or (3) a desire to exploit the logical basis of these technologies, which is currently undisclosed in the AEC domains. Through an extensive literature study and survey, this article investigates the development and application progress of semantic web technologies in the AEC domains in accordance with these three primary perspectives. These examinations and analyses provide a complete strategical map that can serve as a robust stepping stone for future research regarding the application of semantic web technologies in the AEC domains. Results show that semantic web technologies have a key role to play in logic-based applications and applications that require information from multiple application areas (e.g. BIM + Infra + GIS + Energy). Notwithstanding fast developments and hard work, challenging research opportunities are situated in (1) the creation and maintenance of the links between the various data sets and in (2) devising beneficial implementation approaches that rely on appropriate combinations of declarative and procedural programming techniques, semantic and legacy data formats, user input, and automated procedures.

1. Introduction

1.1. Building Information Modeling (BIM) and beyond

For two decades now, the concept of Building Information Modeling (BIM) [1] has had a tremendous impact on the architectural, engineering, and construction (AEC) industries, resulting in the generation and broad employment of BIM authoring and application tools. This emerging trend has led to a paradigm change of the industries in ways to define, tailor, and manage the semantics of product models closely linked to geometry. As a result, industry domains and software developers have become more interested in organizing and sharing the 'semantics' of a building. This interest is developed for the entire building life-cycle, including not only design and construction, but also facility management (FM), operational building management, building engineering, HVAC design, simulation, renovation, and demolition. Rather than just adopting software applications, which simply display geometric perspectives and views of a building, or lengthy textual descriptions and spreadsheets of unstructured data, the industries have made significant progress towards the development of a robust semantic structure and a well-organized semantic connectivity map.

The semantics advanced by BIM technology has also led to a significant shift in research and development in the AEC industries. A number of the more recent outlook and review articles give an indication of the latest research directions and themes in BIM research. For example, Yalcinkaya and Singh [2] provide a list of 12 research themes, carefully obtained through a latent semantic analysis (LSA) study (which is a Natural Language Processing (NLP) technique) of papers with BIM as a topic. The following 12 research themes are outlined, giving an indication of what is the main interest in current BIM research.

1. Implementation and adoption
2. Energy performance and simulation
3. Academy and industry training

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4. Information exchange and interoperability
5. Safety management
6. Urban/building space design and analysis
7. Construction and project management
8. Design codes and code compliance
9. As-is, as-built data
10. Promotion and technology development
11. Maintaining and managing facilities
12. Architectural design process

This list clearly shows how interests in BIM research expands towards the entire building life-cycle, including areas like energy performance and simulation, safety management, urban space design and analysis, design code compliance checking, facility management, and architectural design. As BIM research in itself has a lot of focus on 'information', research in the areas listed above tends to stress on the ways in which information can be made available for addressing the core research challenges in any of the twelve given research areas. In addition, this significant focus on information has led to increased attention on efficient usage and smooth exchange of data and information, across the various application areas in the building life-cycle.

As an example, Dave et al. [3] gives an insight in the technology requirements for construction management, which is the 7th research domain in the above list. They point towards the Internet of Things (IoT) as a possible means to improve lean construction management, which is typically based on many ad hoc decisions and methods. Clearly, there is a high focus on information exchange and flows in this study. IoT standards have been proposed to allow and improve communication between the multiple devices and systems available in the construction sites and offices, regardless of the system or application features.

Some common concrete research challenges in the other areas of research are given below:

- Enable vendor-neutral model exchange
- Combine different information representations
- Support use case based information exchange
- Manage and share information
- On-site visualization of building information
- Combine product manufacturer data with building data
- Support building performance analysis and optimization
- Generate BIM models from point cloud models
- Model change management (versioning)
- Efficient combination of multiple models
- Connect BIM and GIS
- Enable automated regulation compliance checking
- Check model consistency and completeness
- Logical inference for building energy performance, construction safety, cost estimation, home automation, etc.

1.2. *The advent of semantic web technologies in the AEC domain*

Each of the research challenges presented above requires the presence of building information in some form. Various information sources (e.g. BIM and GIS) need to be combined and federated for improving the availability and efficiency of information. Considering this high focus on combinations of information and data, it comes as no surprise that there has been an increasing interest in the use of semantic web technologies and linked data technologies. Semantic web technologies namely allow to represent information in structured graphs and efficiently integrate building information of an entirely different nature (e.g. GIS data, FM data, city data, material repositories, regulation data, cadaster data). As a result, the development of software applications that rely on multiple information sources is within reach.

Researchers started to propose the use of semantic web technologies in the AEC industries in the early 2000s. One of the earliest proposals for applying semantic web technologies in the AEC industries is outlined in Pan et al. [4] and Elghamrawy and Boukamp [5]. Early articles focusing on the added value of semantic web technologies similarly see these technologies as one of the diverse sets of web technologies that can bring improvements to *information exchange* in the construction industry. For example, Aziz et al. [6,7] consider semantic web technologies together with web services and multi-agent systems.

Secondly, semantic web technologies were found useful to increase the value of BIM by enabling *data integration and complex search queries across several data sources*. An interesting viewpoint on the added value of semantic web technologies to the construction industry can be found in Shen and Chua [8]. They see semantic web technologies as one of three web technologies (semantic search, cloud computing and mobile computing) that are not commonly used in the construction sector, but that could provide considerable value in addition to the already existing technologies (such as BIM).

With the increase of the application of sensing technology in the construction site, the third added value brought by semantic web technology is to *incorporate sensing technology to manage construction document information in the field*. Elghamrawy and Boukamp [9] first incorporate sensing technology into semantic web technology and present a use case in the field for managing construction document information using RFID-based semantic contexts.

Furthermore, Rezgui et al. [10] and El-Diraby [11] present invaluable discussions and overviews on the reasons to shift from a model-centric approach towards a more distributed semantic approach. As Rezgui et al. [10] indicates, a shift towards the usage of semantic web technologies implies that we need to *"try to interpret, accommodate and model what is, rather than trying to change reality to fit a single model. This inevitably results in different ontologies for different communities, but the challenge then is to find ways to allow those communities to collaborate effectively with one another whilst maintaining their existing, efficient, effective separate world views."*

This tendency of using semantic web technologies is recently also embraced in the technical roadmap of BuildingSMART, which is displayed in Fig. 1. This figure illustrates the three long-standing levels of the technical roadmap, and this is supplemented by a fourth level to the right with 'semantic search in the cloud' and a 'cloud library'. To realize this part of the technical roadmap, the Linked Data Working Group (LDWG) [12] has been launched, aiming to support the usage of semantic web technologies in the construction industry, such as the Resource Description Framework (RDF [13]) and the Web Ontology Language (OWL [14]).

1.3. *Promises and expectancies*

The primary question this article investigates is what has been and can be obtained by adopting semantic web or linked data technologies for the AEC industries. In this investigation, we consider three main topics that are often used in arguing for the usage of semantic web technologies in the design and construction industry.

1. *Interoperability:* The usage of semantic web technologies has been considered as an opportunity to improve interoperability in the AEC industries [16–21], thus resulting in an integrated and successful data exchange environment. Namely, semantic web technologies appear to provide a way to describe information in a computer-understandable manner. To rephrase Berners-Lee et al. [22]: *"the Semantic Web will enable machines to comprehend semantic documents and data"*. So, from this hypothesis, one can assume that it should be possible to apply these technologies in the construction industry and thus enable computers in this industry to understand the

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