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A STATE-OF-THE-ART REVIEW ON INTEGRATION OF BUILDING INFORMATION MODELING AND ONTOLOGY FRAMEWORKS TO ENHANCE ECOLOGY

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ABSTRACT

Building Information Modeling is an intelligent 3D model-based process which plays a vital role in Architecture, Engineering and Construction (AEC) Industries. Around 40% of the total energy consumption and CO2 emissions is produced from energy used in buildings. BIM is used to eliminate areas of energy waste, such as building heat losses and improves energy efficiencies by introducing energy efficiency measures, such as smart controls. The BIM reduces the need for workforce and controls the onsite Green House Gas (GHG) emissions. BIM provide tools to conduct the process of planning, designing, constructing and managing building and infrastructure in an efficient manner. It serves as a reliable basis for decision making in all the phases of construction project life cycle. The buildings should be environmentally responsible and resource efficient. However, to be sustainable throughout their lifetime, buildings also need to be smart and intelligent by integrating high technology. It requires the reestablishment of link between the information and the building object model for every change in project information which makes the task tedious. This could be overcome by incorporating the ontology based approaches in BIM environment using which the building information is integrated in a dynamic and flexible manner. The use of ontology also enables sharing and reuse of domain knowledge and improves interoperability. In this paper detailed review on various ontological approaches are adopted in construction industry and also provides an audit on the Methontology approach of ontology engineering and E-COGNOS ontology to enhance Ecology through BIM.

KEYWORDS: BIM, Building Information Modeling, Information Sharing, Ontology, Semantic interoperability, METHONTOLOGY, E – COGNOS.

INTRODUCTION

The global warming caused by greenhouse gas (GHG) emissions has become a focus of concern to international society. The Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (AR4) has shown that global GHG emissions due to human activities have grown since preindustrial times, with an increase of 70% between 1970 and 2004. In the 100 years between 1906 and 2005, the average global temperature has increased by 0.74°C, while in the most recent 50 years the average temperature increase has been approximately 0.13°C every 10 years, double the temperature increase of the past 100 years. Model experiments show that the average global temperature will continue to increase at a speed of 0.2°C every 10 years in the next 20 years. Life-cycle analysis (LCA) is able to quantify energy consumption and environmental pollutant emission, by defining a scope of analysis for each type of building or fabrication method, for types of manufacturing or building material, and for each stage of its life cycle.

LCA has been applied to building systems on a variety of levels, such as building materials, building products, or the entire building. Most building-related LCA studies have focused on a specific part of the building life cycle, and few have addressed the whole building throughout its life cycle due to the difficulties of acquiring accurate building material quantities and building performance indicators such as energy use and indoor climate, especially in the design stage. Building information modeling (BIM) is used in providing the effective platform for removing the difficulties of building data in LCA. As a result, LCA can be used in enabling early-stage decision-making through feedback in BIM design choices. Basbagill et al. have identified approach for applying LCA to early-stage decision-making which gives the information to the designers about the impact on environmental and importance of dimension choices of building component materials.

Building Information Modeling (BIM) allows professionals to explore the functional and characteristics digitally .Various participants are integrated at different levels of project life cycle in BIM. Across the entire project life cycle, BIM model serves as the base for decision making starting from the project inception. It provides a knowledge resource for facility information which also enables the knowledge to be shared. In construction industry, BIM shifts the construction industry's paradigm from the two dimensional (2D) based drawing information systems to a three dimensional (3D) object information systems Mihindu.S., (2008). Since time is logically at higher priority to cost, time is added as 4th dimension in BIM modeling, and cost is added as the 5th dimension. This process is known as nD modeling. An nD model is an extension of a building information model that incorporates multi-aspects of design information required at each stage of the life cycle of a building facility Lee. S. (2005). 4D model is used for scheduling, 5D for cost estimation, 6D for Sustainability and 7D for facility management applications. Fig.1. exhibits the various dimensions of Building Information Modeling.

In recent times, semantic web faced a rapid development, in which ontology El-Gohary.N. M (2010).El-Gohary.N. M. (2011). is used to formally represent the knowledge and rules in the web domain to make the computers to process information in the websites automatically (W3C 2009). The use of ontologies to improve the semantics in construction industry is increasing day by day Lee. S. (2005.). Using ontology Lima.C (2003) and semantic web technology Nepal.M.P, Azhar.S, Bouchlaghem.N.B(2013a,2011b,2005c), the domain knowledge could be represented semantically which could be reused later (Anumba et al. 2008; Elghamrawy et al. 2009) Lee. S. (2005.). Even though BIM provides potential for many analysis and simulation processes which is impossible using traditional 2D design approaches, the information link to the building object model needs to be reestablished again and again for any update in project information. To avoid this problem, more information is to be integrated into building object models and also the integration must be carried out in a dynamic and flexible way. Thus ontology could be incorporated in BIM environment to organize, store and reuse the domain knowledge.

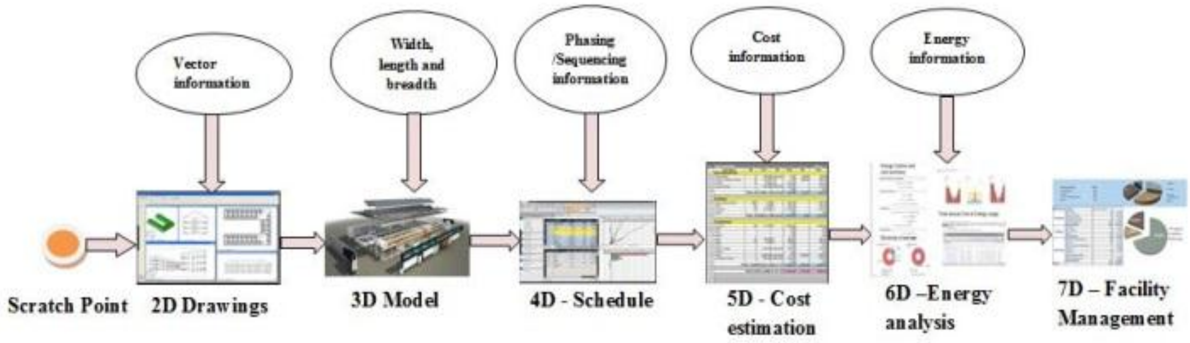

Figure 1: BIM Dimensions.

This paper provides an extensive review on various ontological approaches that are adopted in the construction industry. It also presents an overview on the METHONTOLOGY approach of developing ontology Ayimdji.A (2012) Elghamrawy.T. (2009) and the E-COGNOS ontology to adapt future environmental changes.

Ontology in a Nutshell

Ontology

People, organizations and software systems must communicate between and among themselves.Each uses different jargon, and each may have differing overlapping and or mismatched concepts.This lack of shared understanding leads to poor communication between people and organizations. This limits interoperability and the potential for reuse and sharing. The term Ontology Abanda.F.H (2017) refers to the shared understanding of some domain of interest which can be used as a framework to solve the above mentioned problems.Ontology is an explicit, formal representation of concepts and the relationships among them within a particular domain that expresses human knowledge in a machine readable form.

The intended purposes of using ontology are as follows:

- Ontologies are mainly intended to be used as a manner of re-use.
- Ontologies are used as a means to structure a knowledge base or even used as a part of knowledge base.
- Major motivation of ontology is to integrate models of different domains into a framework. This usually happens in a distributed multi-agent architecture in which the communication between the agents plays an important role.

Ontology Mapping

Mapping of one ontology to another is expressing of the way how to translate statements from one ontology to the other. It involves translation between concepts and relations. In the simplest case it is mappingfrom one concept of the first ontology to one concept of the second ontology.The mapping between the concepts of Ontology A and B is shown in Figure 2.

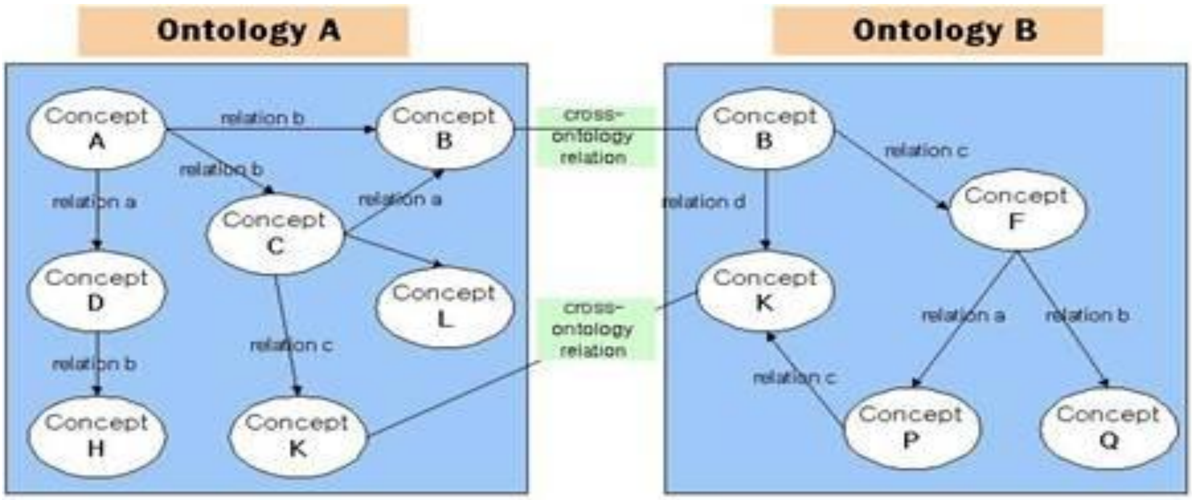

Figure 2: Ontology A and B.

Ontology mapping is carried out in order to specify matching relations among concepts from different ontologies. Such a rich set of semantic relations for expressing alignment is useful in ranking. This matching relies on similarity measures to establish alignment. In other word, ontology matching or alignment is the process of finding the closest semantic and intrinsic relationship between the existing ontologies of corresponding ontological entities.

Ontology based approaches in civil and construction Engineering

e-CKMI* (e-COGNOS *Knowledge Management Infrastructure)

"The e-COGNOS Project" (Consistent knowledge management across projects and between enterprises in the construction domain) was one of the initiatives taken in the construction domain to develop a comprehensive ontology – based system.Lima et al. (2003) presented the development of Knowledge Management (KM) environment, e-CKMI (e-COGNOS Knowledge Management Infrastructure), tailored the Building and Construction (BC) sector in Europe. The e-CKMI is a Web-centred and ontology-enabled solution that has been implemented following the Web services model Lima.C (2003). The functional, architectural, and technical requirements adopted to guide the development of the e-CKMI design and implementation were developed based on input from a number of leading construction organizations. It paid special attention to the ontology-related matters in e-CKMI, including guidelines, methodology, and the incorporation of already existing taxonomies and product models into the ontology.

Knowledge Management optimization

The e-COGNOS platform presents the first comprehensive ontology-based portal for knowledge management in the construction domain. The main features of the platform are an ontology (to encapsulate human knowledge) and a set of web services to support the management of ontology (creation, updates), user management (profiling) and handling knowledge management requirements (indexing, documentation, retrieval and dissemination). Implementation of e-COGNOS platform (at leading European construction organizations) by Lima et al. (2005) has proven the benefit of semantic systems as they provided adequate search and indexing capabilities, allowed for a systematic procedure for formally documenting and updating organizational knowledge (through the ontology) and enhanced the customization functions in a knowledge management systems (through user profiling). The functional architecture of e-COGNOS is shown in Figure 3.

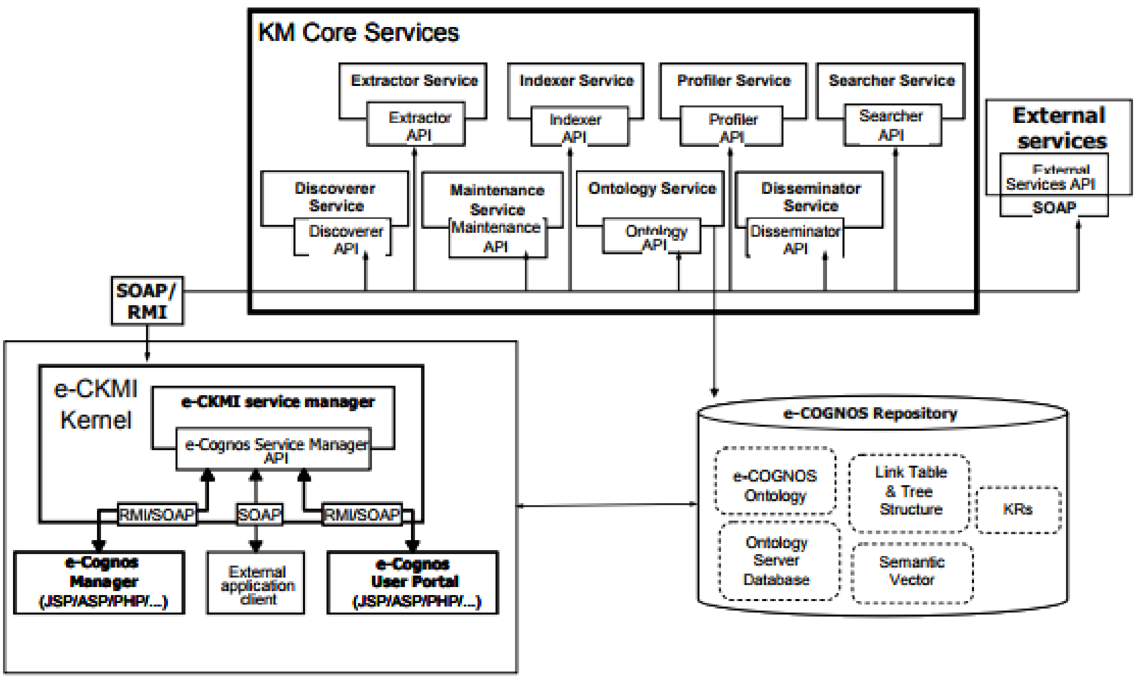

Figure 3: e-COGNOS Functional Architecture.

The e-COGNOS platform implemented an ontology-based system for knowledge management in construction Lima. C., (2005). A set of web services have been developed to support the creation and update of the ontology, support frequent knowledge management activities (such as dissemination and discovery), and managing users (profiling their needs and roles).Some of the previously-developedclassifications and taxonomies (e.g., the IFC model, the BritishStandard Glossary of Building and Civil Engineering terms, the Uniclass, and the W3C DAML+OIL language) were adopted andreused to support the consistent knowledge representation of construction items.

The use of semantic (ontology-based) systems for knowledge management provides two fundamental advantages:

- The development of the ontology itself provides a formal (and machine-readable) representation of domain/organizational knowledge
- Using the ontology for supporting knowledge management activities provides users with an effective and semantic means for accessing and documenting knowledge.

Semantic blogging system for construction professionals

To improve the effectiveness of blogging technology in information and knowledge sharing, an ontology-based semantic blogging system is proposed by Wang and Xue(2008). Semantic blogging is an extension of conventional blogging and ontology is the key enabling technology for it. Domain-ontology-based semantic blogging site is composed of a network of concepts, which are clearly defined and interlinked according to their context and bound to certain behaviors. The e-Cognos ontology was implemented into the blogging system and the behavior of the system while processing its contents is reported. It is found that using ontology-based semantic blogging site can greatly enhance information sharing between construction professionals and it is a very promising tool for construction communities to publish and share their experience Wang.C. (2008).

Extraction of partial building Information model

Le Zhang and Raja R.A.Issa (2011) established ontology-based method to extract a partial model from a complete BIM Elghamrawy.T. (2009). El-Diraby.T (2011). model. The partial model, as well as the complete model, should be defined in industry foundation classes (IFC) format, which is the widely supported open standard data exchange format for BIM Le Zhang, (2011). The system structure is shown in Figure 4.

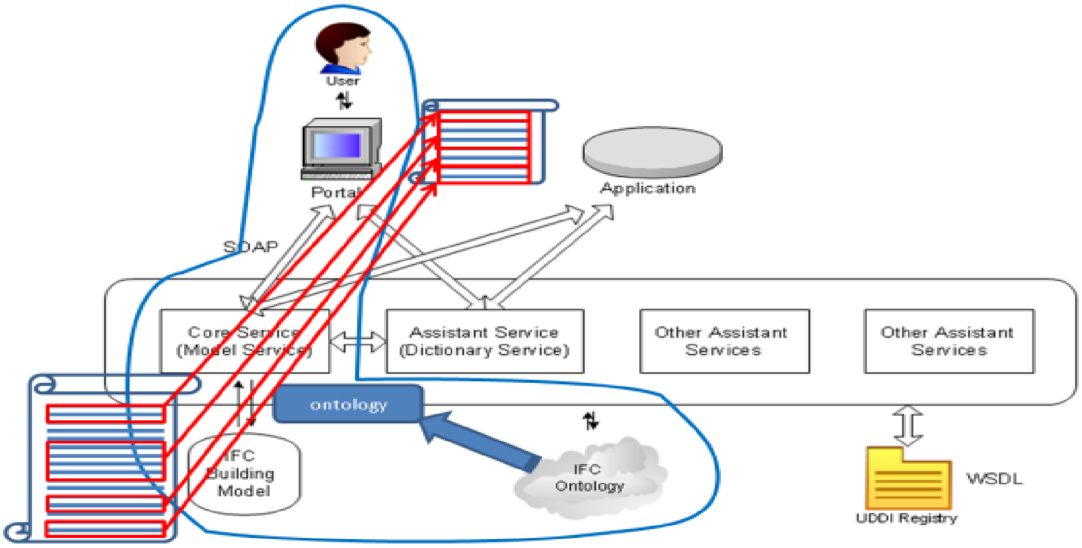

Figure 4: Partial model extraction framework using the ontology.

The extraction is based on an IFC-based ontology which defines the necessary building blocks of a valid IFC model and the rules of extraction. The IFC model is stored remotely on the company's datacenter while the extracted partial model is transmitted to the construction site. The whole process is to be implemented as a Web service allowing remote accessibility from various computing platforms. The Web service system could also be linked to other construction software applications for automating construction management functions.

Automated construction quality compliance checking

Zhong et al. (2012) proposed CQIE Ontology for improving the support for the construction quality compliance checking against regulations. Based on CQIE ontology, the regulation constraints are modeled into OWL axioms and SWRL rules. By these OWL axioms and SWRL rules, the regulation provisions imposed on construction quality inspection can be translated into a set of inspection tasks, and get associated with the specific construction tasks.

Once the construction starts, the applicable inspection tasks, including a series of quality checking and evaluation, will be reminded and recommended Zhong.B., (2012). . The proposed approach enables theconstruction quality compliance checking to be performed as a parallel activity during the construction process. Finally, the approach is demonstrated in Protégé 3.4.6 through case studies based on regulation examples taken from "Code for Acceptance of Construction Quality of Building Foundation (GB50202-2002).

Ontology-Based Building Information Modeling

Karshenas and Niknam (2013) proposed an ontology based approach for building information modeling to facilitate information exchange among different knowledge domain applications. The results of an on-going research on an ontology-based approach to building information modeling to facilitate information exchange among different knowledge domain applications is presented. The proposed approach is based on a shared building ontology that models building domain element types and element relationships. Shared ontology is used to model the information systems that are to be integrated; each knowledge domain adds its own element properties to the shared building ontology Karshenas.S., (2013).

SWRL rules are used for mapping element properties from one domain to another. An example is demonstrated to show how the developed approach facilitates project information sharing between designs and estimating domains.

BIM and ontology-based approach for building cost estimation

Lee et al. (2014) proposed an ontological process to automate the searching process using BIM data to find the work items suitable for building elements and materials with greater ease and consistency.

The authors established,

- A work condition ontology that consists of the determinants required to select work items,
- A work item ontology, which consists of the factors defining the tiling method, semantic reasoning rules.

By conducting a case study to demonstrate the proposed ontological inference process in a real-world situation, it is confirmed that the proposed process can provide consistent results Lee.S. (2014). however, since work items differ depending on construction type and technological advancement, the work item ontology should be continually revised and updated. The ontological inference process removes the need for the intervention of a cost estimator's subjectivity in searching for an appropriate work item. Also, if ontology is elaborately defined by the knowledge of experienced engineers, then accurate and consistent results can be obtained. In addition, the proposed process will assist cost estimators to use BIM data more easily, and it will help the expansion of BIM-based construction management.

Construction risk knowledge management

LY. Ding et al. (2016) established an ontology-based methodology/framework for construction risk knowledge management in BIM environment. The framework for managing and reusing the construction risk knowledge in the BIM environment to facilitate the construction risk analysis process is shown in Figure 5.

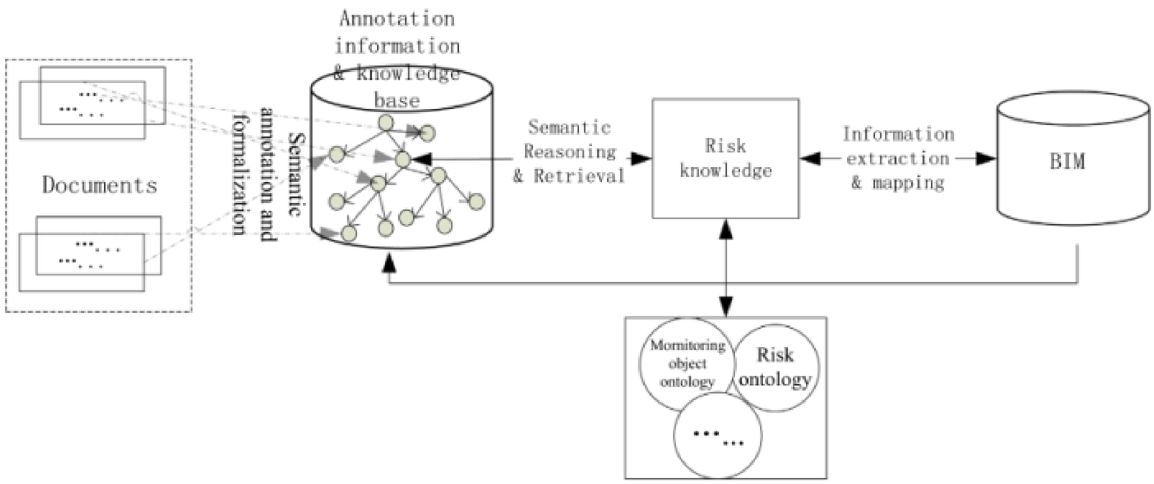

Figure 5: Framework for managing and reusing construction risk knowledge.

The risk knowledge is modeled into an ontology-based semantic network to produce a risk map, from which the interdependences between risks, risk paths can be inferred semantically Ding.L.Y (2016). Based on the semantic retrieval mechanism, the applicable knowledge is dynamicallylinked to the specific objects in the BIM environment. Based on the methodology, a prototype systemis developed as a tool to facilitate the construction risk knowledge management and reuse to indirectly improve the construction risk analysis process.

Ontology-Based Representation and Reasoning in Building Construction Cost Estimation

Xin Liu et al. (2016) established the ontology representation model including concept model ontology, work item ontology and construction condition ontology and developed a reasoning mechanism that automates the process of reasoning if building construction cost estimation satisfies a set of these reasoning rules. The framework for the automated cost estimation reasoning is shown in Figure 6.

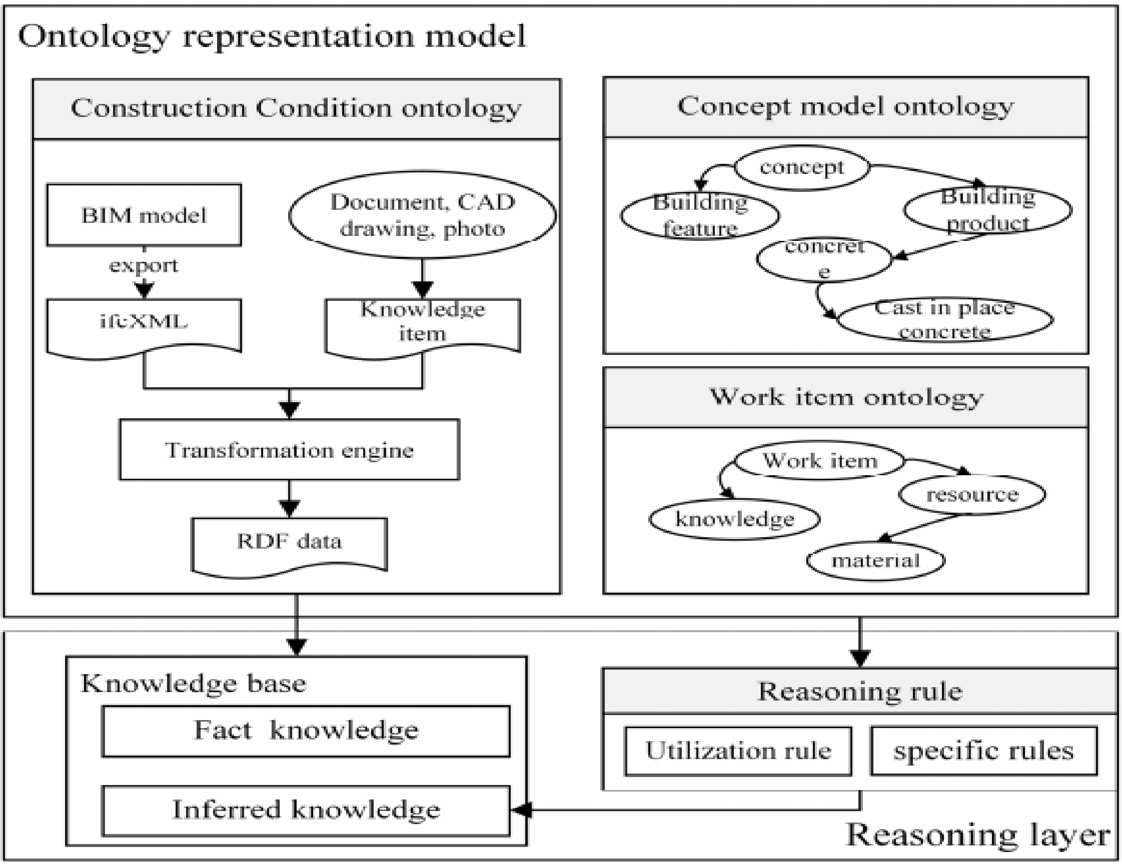

Figure 6: Overall Framework for automated cost Estimation Reasoning.

Using this ontology representation model, the cost estimation information is modeled into OWL axioms and SWRL rules. The cost estimation information is translated into a set of concept models, work items and construction conditions based on OWL axioms and SWRL rules. The proposed framework is implemented in Protégé 3.4.8. The proposed method enables faster and easier extraction of information helpful for the building construction cost estimator and also eliminates the need to manually update the cost database.

New rules of measurement ontology for construction cost Estimation

F.H. Abanda et al. (2017) discussed various challenges faced by construction cost estimators. To overcome those challenges, Ontology based approach is proposed. The proposed approach includes following activities.

- The appropriate knowledge engineering tools and BIM software systems is identified.
- Ontology modeling based on new rules of measurement (NRM) is undertaken based on the chosen knowledge engineering tools. In this stage, the existing IFC domain ontology is reused. IFC facilitates the abstraction of building components necessary for cost estimation.

- Protégé 3.5 is used to implement the developed ontology.
- The ontology is syntactically checked using descriptive logic-basedreasoners. The 4D BIM modeling software is used to validate the ontology for consistencies and compliances.
- Finally the ontology is transformed by writing code for the purpose of cost estimation.

The entire system architecture is shown in Figure 7.

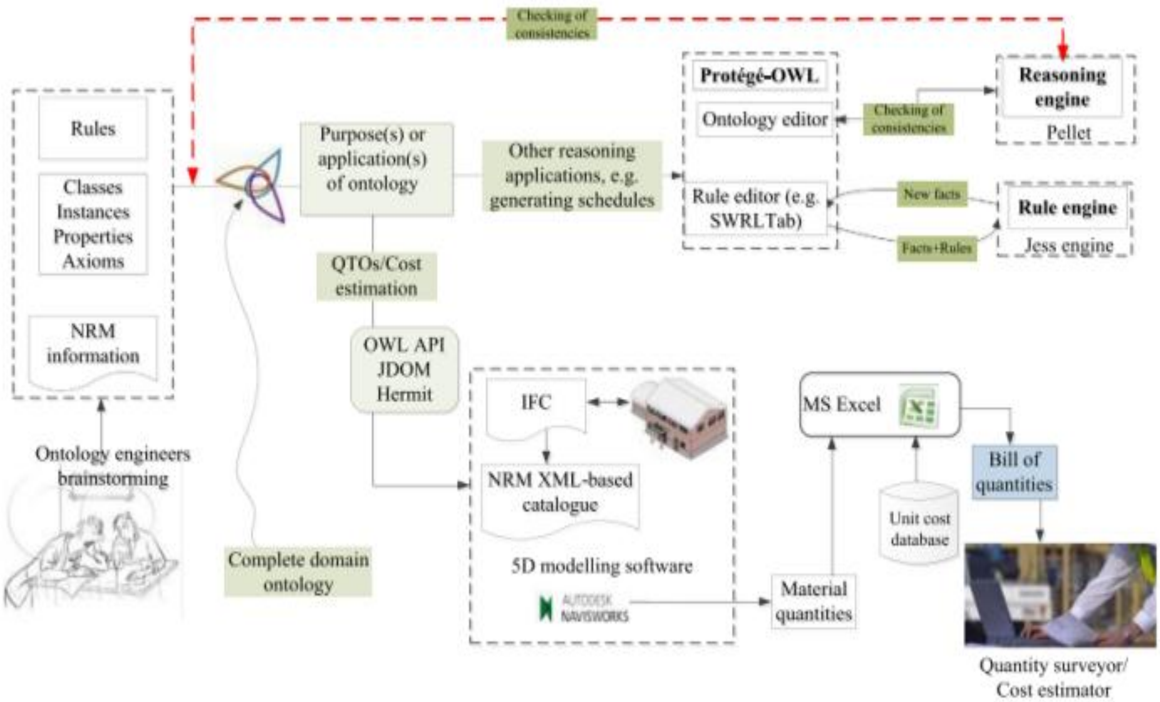

Figure 7: System Architecture.

Integrate LCA and BIM for Environmental Assessment

Environmental Assessment of the entire building is a complex procedure due to the multifaceted constructions, are made up of a wide variety of products. Each of these products has its own features and life span which means that they have varying relevance with regard to environmental impacts. To find an automatic and efficient link between BIM models and environmental information included in the lifecycle assessment databases. So incorporate the relevant environmental information to these objects with the other properties. In this way, it is possible in the pre design and design phase to include environmental criteria in decision making process regarding the selection of material and building elements.

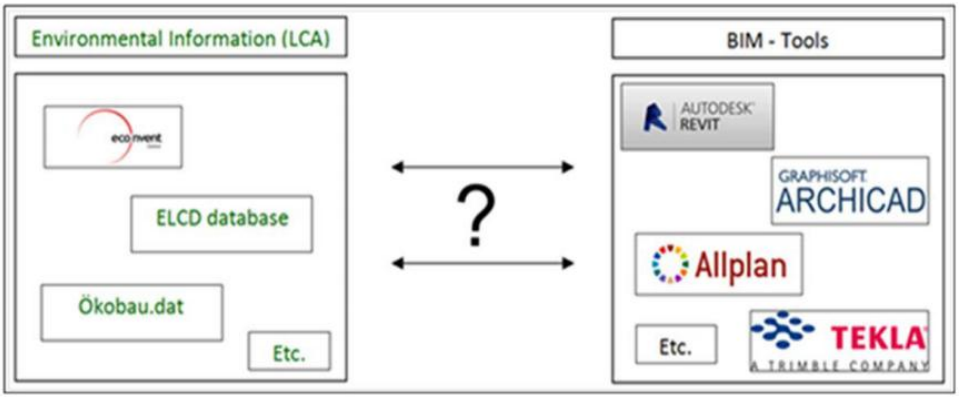

Figure 8: Efficient Link between BIM models and environmental Information.

Design Ecologies using BIM

BIM can certainly act as a significant catalyst for complex problems of sustainability in a changing world but it also requires the community that uses it to change. The scale, complexity and changing nature of these problems are hard to deal with but with a suitable conceptual framework and a catalyst, the BIM design ecology can offer a platform to start the process. But more needs to be done to enable and encourage the success of the process of BIM and the understanding of design ecologies. This will be all the more important as the industry moves towards Level 3 BIM maturity and the hardest part will be to move away from short-term 'add-on' fixes to seek long-term sustainable solutions – to 'create sustainability'. The opportunities of BIM and the affordances of the design ecology fit together quite well but how these two relate to one another – that BIM is acting as a catalyst for change and that this allows some of the key features that a design ecology requires to form. It is further argued that what might be termed BIM design ecologies are already emerging as a response to BIM Level 2 BIM maturity and it is entirely possible that this will develop further as a result of moving towards Level 3 maturity. Drawing on Ehrenfeld's creating sustainability approach, the design ecology addresses the system relationships within and between design values and activities and shifts away from focusing on single issues in isolation. It is a context-framing concept that identifies relational boundaries, effects and trade-offs. In creating a sustainability approach these boundaries are broad and thus the contexts of design strategies and practice inevitably encompass complex interactions at multi-scales and across timescales is depicted in Figure 9. This temporal element reflects long-standing concepts associated with sustainability such as the precautionary principle and inter-generational equity.

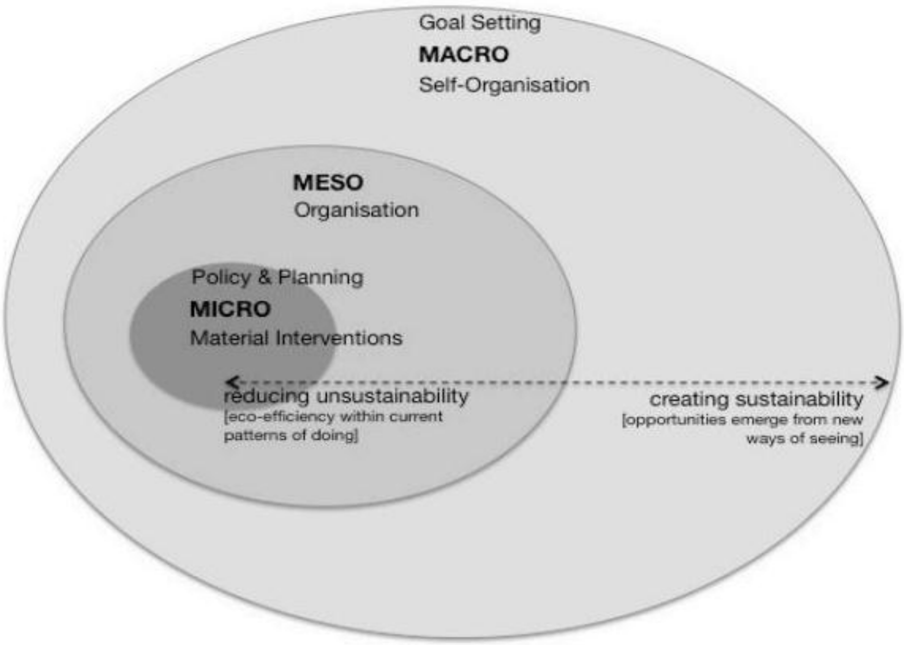

Figure 9: Shifting the Emphasis of approaches to sustainability.

CONCLUSION

This main focus of this work is on BIM and the need of a methodology to enable integration, sharing, and reuse of domain knowledge. Semantic web ontology is identified to serve for this purpose. AEC industry gains benefit from the advancements of semantic web technology. This paper provides a detailed review on several approaches integrating ontology and BIM that are implemented by various researchers of civil and construction engineering. The review shows that the researchers find it beneficial to integrate the ontology based techniques and building information modeling for the following reasons

i) Enhancement of information sharing between construction professionals.
ii) Effective retrieval, classification and the management of information
iii) Sharing and reuse of knowledge
iv) Faster and easier extraction of information
v) Automation of information updation.

Now a days BIM Level 2 is mandatory in public sector construction projects. Integration of BIM and Ontology can be used to understand collaborative building design models to remove the Environment barriers, design errors, reduce design conflicts, and provide more sustainable building designs. They are used to assess and improve the building's energy efficiency.

REFERENCES

1. Abanda.F.H, Kamsu-Foguem.B, Tah.J.H.M, (2017) "BIM – New rules of measurement ontology for construction cost estimation", *Engineering Science and Technology, an International Journal*, 443–459.
2. Ayimdji.A.Koussoube.S, Fotso.L.P, Konfé.B.O,(2012) "Using Methontology to build a deep ontology for African traditional medicine: First steps"
3. Azhar.S, (2011) "Building Information Modeling (BIM): Trends, benefits, risks and challenges for the AEC industry", *Leadersh. Manage. Eng*., 241–252.
4. Bouchlaghem.N.B,Holmes.M, Loveday.D, Bennadji.A(2005)," The engineering dimension of nDmodelling" *Special Issue From 3D to nDmodelling.*
5. Ding.L.Y, ZhongB.T, Wu.S, Luo.H.B, (2016) "Construction risk knowledge management in BIM using ontology and semantic web technology", *Safety Science*, 87: 202–213.
6. Elghamrawy.T., Boukamp.F., and Kim.H.-S. (2009). "Ontology-based, semi-automatic framework for storing and retrieving on-site construction problem information—An RFID-based case study." Construction Research Congress, *ASCE, Reston*, VA, 457–466.
7. El-Diraby.T., and Osman.H. (2011). "A domain ontology for construction concepts in urban infrastructure products." *Autom. Constr.*, 20(8): 1120–1132.
8. El-Gohary.N. M., and El-Diraby.T. E. (2010). "Domain ontology for processes in infrastructure and construction." J. Constr. Eng. Manage., 10.1061/(ASCE)CO.1943-7862.0000178, 730–744.
9. El-Gohary.N. M., and El-Diraby.T. E. (2011). "Merging architectural, engineering, and construction ontologies."J. Comput. Civ. Eng.,10.1061/(ASCE)CP.1943-5487.0000048, 109–128.
10. Karshenas.S, and Niknam.M. (2013). "Ontology-based building information modeling." ASCE Int. Workshop on Computing in Civil Engineering, IoannisBrilakis, SangHyun Lee, and BurcinBecerikGerber, eds., *ASCE, Reston*, VA, 476–483.
11. Lee.S.-K., Kim.K.-R., and Yu. J.-H. (2014). "BIM and ontology-based approach for building cost estimation." *Autom. Constr*., 41: 96–105.
12. Lee. S. Wu. A. Marshall-Ponting, Aouad.G, Tah.J, Cooper.R, Fu.C, nDmodelling(2005.) - a driver or enabler for construction improvement? *RICS Research.*
13. Lima.C., Diraby. T., Fies. B., Zarli. A., and Ferneley. E. (2003). "The E-Cognos project: Current status and future directions of an ontology enabled IT solution infrastructure supporting knowledge management in construction." Construction *Research Congress, Keith R. Molenaarand Paul S. Chinowsky, eds., ASCE, Reston*, VA, 1–8.

14. Lima. C., El-Diraby. T., and Stephens. J. (2005). "Ontology-based optimization of knowledge management in e- construction." *J. IT Constr.,* 10: 305–327.
15. Le Zhang, Raja R. A. Issa,(2011), "Ontology Based Partial Building Information Model Extraction", Proceedings of the CIB W78-W102 2011*: International Conference –Sophia Antipolis, France.*
16. Ma.Z, Liu.Z, (2014) "BIM-based intelligent acquisition of construction information forcost estimation of building projects", *Procedia Eng*., 85: 358–367.
17. Mihindu.S., &Arayici. Y. (2008), "Digital construction through BIM systems will drive the re-engineering of construction business practices", *In Visualisation, 2008 International Conference,* 29-34.
18. Ma Zhiliang, Wei Zhenhua,(2012) "Framework For Automatic Construction Cost Estimation based On BIM and Ontology Technology", *Proceedings of the CIB W78 .29th International Conference –Beirut, Lebanon.*
19. Nepal.M.P,Staub-French.S, Pottinger.P, Zhang.J, (2013)" Ontology-based feature modeling for construction information extraction from a building information model", J. *Comput. Civil Eng.,* 27(5): 555–569.
20. Park.C.-S., Lee. D.-Y., Kwon. O.-S., and Wang. X. (2013). "A framework for proactive construction defect management using BIM, augmented reality and ontology-based data collection template." *Autom. Constr.,* 33: 61–71
21. Wang.C. C., and Xue.D. (2008). "Using domain ontology in a semantic blogging system for construction professionals." *Tsinghua Sci. Technol.,* 13: 279–285.
22. Wang.H.-H., Boukamp.F., and Elghamrawy.T. (2011). "Ontology-based approach to context representation and reasoning for managing context sensitive construction information." *J. Comput. Civ. Eng., 10.1061/ (ASCE)CP.1943-5487.0000094,* 331–346.
23. Xin Liu, Zhongfu Li, Shaohua Jiang,(2016) "Ontology-Based Representation and Reasoning in Building Construction Cost Estimation in China", *Future Internet*, 8: 39.
24. Yurchyshyna.A., and Zarli.A. (2009). "An ontology-based approach for formalisation and semantic organisation of conformance requirements in construction." *Autom. Constr.,* 18(8): 1084–1098.
25. Zhong.B., Ding.L., Luo.H., Zhou.Y., Hu.Y., and Hu. H. (2012). "Ontology-based semantic modeling of regulation constraint for automated construction quality compliance checking." *Autom. Constr.,* 28: 58–70.