AN ENHANCED VR INTERFACE FOR ONTOLOGY-BASED INTEGRATED CONSTRUCTION INFORMATION

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ABSTRACT

This paper presents the mapping of an existing OSCON integrated object model into construction domain ontology within semantic web. For the main reasons that web semantic ontology further improve construction integration and accessibility through sharing reusable semantic construction information through the web. Furthermore the paper present enhancements of the interactive Virtual Reality Interface by integrating VR with the semantic web ontology to further improve the interface usability, interactivity and its intelligence allowing all construction partners not only navigate and interrogate 3D building components but also managing and making changes to construction building in terms of planning, construction schedule, costs, etc...

KEYWORDS
Integrated Object Database, Ontology, UML, VRML and Semantic Web

1 INTRODUCTION

Information in construction project is scattered in an uncontrolled and uncoordinated way, on a variety of information systems and media, so that the design cannot be viewed as a complete entity. Such obstacles to the free flow of information between parties to the construction process lead to data re-entry and the consequent inaccuracies, which prejudice future design 'migration paths' and operational flexibility. Over the life time of a construction project, the process of architectural design and its associated supports become divorced from the manufacturing of the product (i.e. building) for which it exists. This creates problems for the organisation of both the design and construction processes and also communication between stake holders becomes difficult. As shown in Figure 1, the large number of IT interfaces results in breakdown, misunderstanding, frequent litigation, time consumption and additional costs and delays to the project. These reduce the quality of construction products with addition costs and delays of construction projects.

To solve these problems, many companies have selected their own CAD systems and applications and have developed specific ad-hoc interfaces between them. Many of these systems have been utilised effectively within object-oriented building application areas to form local "islands of automation” as shown in Figure 1 below.

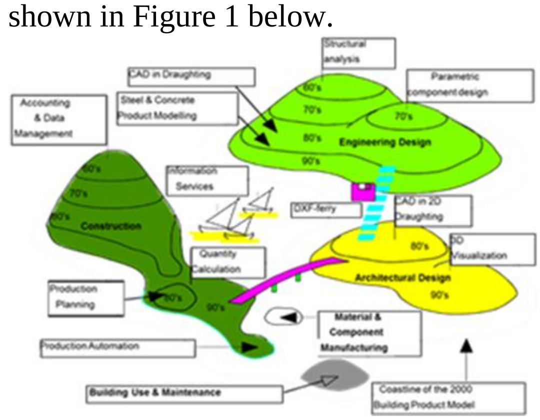

Figure 1. State of AEC Industry

However, in the Architecture, Engineering and Construction (AEC) industry, it is usually more productive to integrate information along the paths through which work flows between project stages or specialists. This is supported by research in the construction domain, which has shown that there is a general agreement for the need for integrating design and construction especially Latham report [1] which recommended the development of systems which aid a more harmonious relationship within the design/construction team.

However, the main difficulties of integration are exacerbated by the fragmentation of design information. The drawings are expected to provide the experts from different areas of interest the information they require and serve as the main medium for integration. Despite the fact that computer-aided design (CAD) systems are extremely powerful, they are not being utilised thoroughly in the AEC industry. Specialists in the AEC industry have used today's CAD systems as simply automated drafting tools, thereby automating their own narrow areas of specialisation. Each participant uses unique drafting conventions and their own CAD systems.

One of the integration project in which the author was involved in OSCON project [2] which used object technology to develop an integrated object database to address the problems of design fragmentation and the gap that exists between construction and design processes. It tightly integrate architectural design data model with construction management, planning and cost data models through an OSCON core object model that maps CAD basic geometric design constructs like lines and circles into construction objects like windows and doors.

This paper presents an enhancement of the OSCON integrated object model with semantic web ontologies to allow construction partners share and manage their data and their construction processes semantically through an interactive semantic web interface. Furthermore the paper present enhancements of the OSCONVR Virtual Reality (VR) Interface [3] by integrating VR with semantic web ontology to further improve OSCONVR VR usability, interactivity and its intelligence allowing all construction partners navigate and interrogate building components. The reasons for using web semantic ontology is to further improve construction integration and accessibility through sharing reusable construction information and knowledge on the web. Also, due to the closeness of ontology modelling and object modelling in software development as reported in [4] comparison review between object modelling and ontology modelling.

The content of the paper is organised as follows. The second section reviews and analyses related research in the area of design-construction integration and virtual reality interfaces for construction projects. The third section is devoted to the enhancement of the OSCON integrated object model with semantic web construction domain ontologies. The fourth section will be devoted to the description of construction application running through the interactive VR semantic web interface.

2 PREVIOUS WORKS

A great deal of work has been carried out in 90’s in the area information modelling for construction IT to support sharing information across participants in a construction project. Efforts in this area include projects such COMBINE [5] (for HVAC and building design) and OSCON [6] which uses object model that integrates architecture design construct and construction related applications. Two detailed application built on top of the OSCON object database were reported in OSCONCAD [2] which details how AUTOCAD architecture design were directly saved in OSCON object database rather than AUTOCAD own standard file e.g. dxf files to facilitate construction application access construction data in that database. OSCONVR [3] described a Virtual Reality application that provides 3D interface for navigating through construction products. Further work were undertaken using methodologies similar to OSCON methodology like [7] which describes an application oriented research project which seeks to apply the integrated project database technology to the design and construction of water treatment plants. [8] Presented a methodology to implement integrated project systems through the use of a model-based approach that involves developing integrated "smart AEC objects." [9] Presented an implementation of the Industry Foundation Classes (IFC) classes to support the full integration of AEC projects data and processes. [10] Highlights the need to bridge the gap created by the level of satisfaction provided by ICT applications through the development of an augmented process model which will enable integrated databases to support collaborative extranets at the tender stage. [11] Integrated time and schedule data of construction projects using object-oriented method based on Building information modelling.

Still few of these integrated data models has a universal acceptance except those built with compliance to Industry Foundation class like OSCON reported by [2]. This is due mostly to the fact that developed data models were neither accessible to all AEC construction-related applications nor related industries applications. Furthermore as reported in [12] which reviewed a large number reported that most of the work on computer integrated construction (CIC) for approximately 20 years was focusing like OSCON integration approach on data and application integration and little work was undertaken on the semantic aspect of such integration that typifies the multi-disciplinary and multi-cultural working environment in the construction sector. To answer the need for enhancing the integration of construction data and applications with some elements of semantics and take advantage of the semantic web that promotes sharing and managing data on the web, this paper presents the extension of OSCON integrated object model and its related construction applications like OSCONCAD [2] and OSCONVR [3] with semantic web ontologies. This is to integrate OSCON architectural design and related construction applications through semantic web concepts to allow constructions partners share and manage data and construction processes through semantic web interface. The paper also presents how semantic web interface is merged with virtual reality to improve the intelligence and the interactivity of the initial OSCONVR [3] interface that was built on top of the OSCON object database.

3 SEMANTIC WEB ONTOLOGY-BASED INTEGRATION

The root cause of the different problems in construction projects is the information or data upon which all participants depend. Because of fragmentation within the construction industry as shown in Figure 1, there are many different interpretations of the semantics of the data in use. Formalism to model information is referred to as data models and to model information and its semantics is referred as ontology. Although the Initial OSCON integration approach which used object technology and methods to make construction application share data, it did not completely address the different interpretations of the semantics of the shared data. This work builds on the OSCON integrated model and enhances it with semantic web ontology to unify the semantic interpretation of the OSCON objects and allow construction users and application share and manage construction information and knowledge on the web.

3.1 The Ontology-Based Integration Approach

The OSCON core model was built by grouping basic architectural design drawing primitives like lines, squares and circles into meaningful construction components like windows, doors and roof as classes of that core model. These objects are also enhanced with construction rules and constraints. To achieve integration, the OSCON core classes are further enhanced with other domain ontologies related to costs, planning and management as shown in the inner three layers in Figure 2 below.

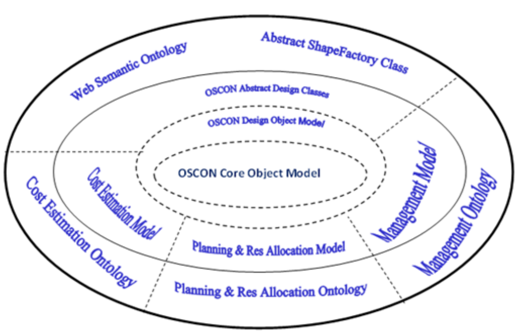

Fig. 2. Ontology-Based Integrated Object Model

Also, the core model classes encapsulate a set of operations, which are invoked externally from custom applications using the OSCON core model. They allow the existence of two different views of the drawing: the graphic view, which is the usual three-dimensional CAD drawing, and the textual view which is the collection of all design information captured. Moreover classes within the core model are enhanced with the concept of separation of the design data from the specific CAD package used to manipulate it. A consequence of this new CAD product will be much easier to incorporate and also other non-CAD applications can have direct access to the design data from such a database.

Ontology provides a shared and reusable piece of knowledge about a specific domain and has been applied in many fields, such as Semantic Web, ecommerce, and information retrieval [13]. And constructing ontology from different data source becomes a research focus. The method in [14] distinguishes different ontology constructing approaches based on the input type: text, dictionary, knowledge base, semi-structured schema, or relational schema as reported in recent work in [15].

The presented ontology-based object model uses OSCON core and construction do-main object models (cost estimation, planning and management) as input data to construct an integrated ontology-based object model as shown the external layer of Figure 2 shown above. This kind mapping of object to ontology was reported by [16] which uses rules-based approach for constructing ontology from object-relational database. They paper presented the development of an ontology based on constructing 3-tuple model: Ontology = (ORDB, rules, OWL) where ORDB denoted the data source of ontology construction; rules denote a set of rules used by ontology construction and the OWL (Web Ontology Language) which is a knowledge representation language for authoring for instance Semantic Web ontologies. By using XML, OWL information can easily be exchanged between different types of computers using different types of operating system and application languages. Similar approach used in [16] has been used to construct OWL ontologies shown in the external layer of Figure 2 for both OSCON core model (that includes architecture design model) and also Constructions domain models (costs, planning and management) shown in the two internal layers of Figure 1. Furthermore, the individual ontologies representing the OSCON core model and the domain models have been integrated in a global ontology using the approach reported in [17]. That global ontology provides shared design and construction vocabulary for the specification of the semantics and all information sources i.e. OSCON core model and domain models are related to that one global ontology represented as OSCON OWL ontology.

3.2 Designing the Integrated Ontology

OSCON core models was designed to comply with the IFC to facilitate data exchanges between construction-related applications and to allow common interpretation of the design objects amongst the applications in a consistent and interoperable manner. It derive classes from the IFC Generic classes and enhance them with knowledge about the detailed design stage that can be shared with other construction applications, such as cost and time planning. To achieve this and comply with IFC classes, it used object modelling approach and UML standards notation to design this core model that incorporate graphical and non-graphical information such as weight, colour, electrical or thermal properties, cost, as well as a definition of how it should appear in space (from which applications software can derive an appropriate display representation). Also the classes of the OSCON core model encapsulate procedures that can be used to describe how it should behave and how it relates to other construction classes. Thus, for instance, an object describing a light switch might give its height above a floor and the distance from a door and an object describing a window might 'cut itself' into a wall and create cavity closures and lintels automatically. The detailed design model is a description of the design components and their specifications with very limited topological properties incorporated as shown in Figure 3. The model offers the representation of several structural members e.g. Raft, pad and strip for foundation, ground slab, floor slab for Slab, columns, beams, solid and cavity walls, roof, and non-structural members, such as Windows and Doors.

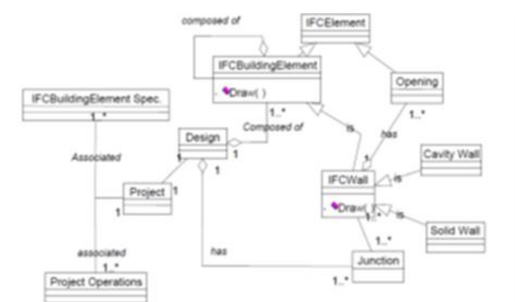

Figure 3. A Subset of OSCON Core Model

Each class and relationship of the above OSCON core model is translated into OWL like for instance the classes IFCWall and its subclasses Cavity Wall and Solid Wall are represented in OWL/RDF as shown in Figure 4 below:

```
<owl:Ontology rdf:about="">
 <owl:versionInfo>$Id$</owl:versionInfo>
 <rdfs:comment>
 </rdfs:comment>
</owl:Ontology>

<owl:Class rdf:ID="Wall">
  <rdfs:label>Wall</rdfs:label>
  <rdfs:comment>
   Solid and Cavity Wall
  </rdfs:comment>
  <owl:Class rdf:ID="Solid Wall">
    <rdfs:label>Male</rdfs:label>
    <rdfs:subClassOf rdf:resource="#Wall"/>
  </owl:Class>
  <owl:Class rdf:ID="Cavity Wall">
    <rdfs:label>Female</rdfs:label>
    <rdfs:subClassOf rdf:resource="Wall"/>
    <owl:disjointWith rdf:resource="Solid Wall"/>
  </owl:Class>
</owl:Class>
</rdf:RDF>
```

Figure 4. OWL-RDF Code for Wall class and its sub classes

3.3 The Abstract Classes for CAD Interface

The OSCON core model is designed to be generic and abstract enough to allow separation between the design model and the specific implementations of commercial CAD tools. For this it uses the Abstract Factory Design Pattern which provides an interface for creating families of related objects without specifying their concrete classes [18]. As shown in Figure 5., the OSCON model defines:

- An Abstract ShapeFactory Class that declares the interface for creating each basic kind of design element,
- An Abstract Design Class (IfcBuildingElement) that represents an abstraction for each kind of architectural design element and provides abstractions that the OSCON design model classes can use to draw and render themselves in any CAD environment, and
- A set of client classes that encapsulate the commands the users will want to issue. Instances of these classes can then be used to implement command functionality in an environment independent manner.

The ShapeFactory's interface has an operation that returns a new design object for each Abstract Design Class of the design component. The client class (from the user application) uses the IfcBuildingElement Abstract Design Class, which calls operations to obtain instances of a design element and draw themselves without being aware of the Concrete Classes they are using. In other words, the client class has to commit to an interface defined by the Abstract Design Class, not to a particular Concrete Class.

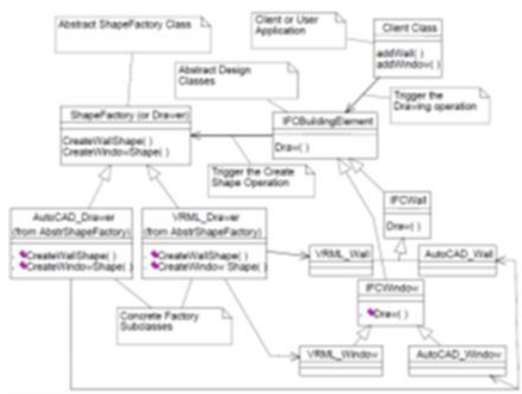

Figure 5. OSCON Abstract and Factory Classes

A set of Concrete Subclasses of the ShapeFactory Class which implement the design elements for a specific CAD or graphical display environment is shown in Figure 6. These subclasses can be used by the model classes to `draw' themselves without knowing which application is actually doing the drawing. For instance, in OSCON model a concrete sub classes CAD_Drawer and VR_Drawer have been designed specifically for communication between CAD system (e.g. AUTOCAD) and Virtual Reality (e.g. VRML) interface with OSCON core model (i.e. OSCON Object database) respectively.

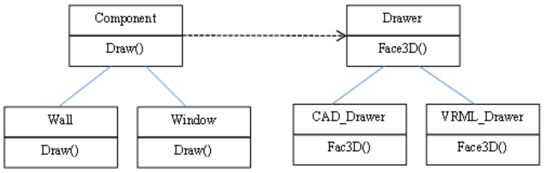

Figure 6. CAD and VR Concrete Classes

4 OSCON Applications

In order to demonstrate how an integrated approach can benefit construction projects, a number of construction applications have been developed, e.g. OSCONCAD application [2] and OSCONVR [3]. The OSCONCAD application allows a user to create and manipulate architectural components of a building in AUTOCAD and stored them directly in OSCON object oriented database rather their own files like dxf and dwg files. Instances of the building product received from CAD design interface and stored in OSCON object database are then mapped into web semantic ontology-based objects and then read by the OSCONVR interface in order to create a 3D view of the building which gives the user a better environment for navigation, walkthrough and interaction. The OSCONVR interface is not only limited to navigation and querying but also running other construction application like communication between partners, planning, scheduling tasks, costing and management the construction project. OSCONCAD and OSCONVR applications are being developed on PCs running under Microsoft Windows NT and are implemented in C++ and OBJECTIVITY/DB in conjunction with UML which is useful for designing and generating OSCON C++ code. The overall architecture of the OSCON system is shown in Figure 7 below

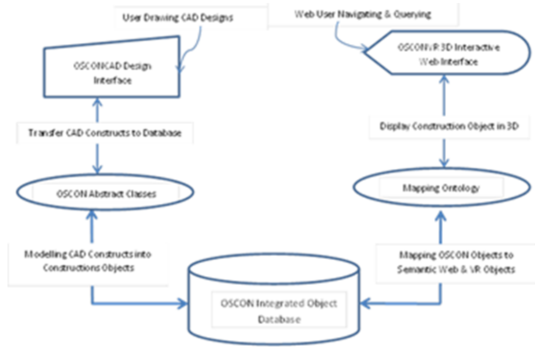

Figure 7. Architecture of OSCONVR

4.1 The Abstract Classes for CAD Interface

The OSCONCAD Application is built using AUTOCAD Application Development System (ADS) prototype, which is loaded by a user of an AutoCAD session. As shown in Figure 8 below, AUTOCAD is enhanced with OSCON menu items to allow the user to design and manipulate architectural components of a building. The created components are stored directly in the OSCON object database which is mapped into the web semantic ontology-based repository and made available for OSCONVR web semantic interface to display and manipulate. The design primitives are walls, windows, doors, columns, beams, foundations etc. As design objects are created through the AutoCAD interface, corresponding objects are created in the OSCON object-database. Also, the information that is used to draw these objects on the AutoCAD screen via an instance of the Drawer class comes directly from the instances in the OSCON Object database. This ensures that the screen reflects the content of the OSCON object database. This also means that changes in a design can be immediately propagated to other areas of the project database. For instance, if an on-line project-planning package or OSCONVR application were accessing the OSCON object database then it would be possible to change a part of the design and immediately see the impact these changes would have on the project schedule.

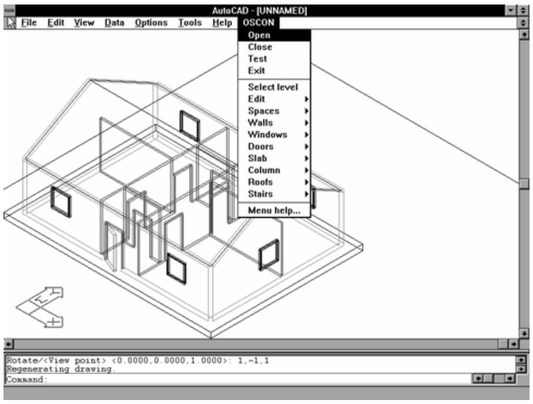

Figure 8. Enhanced AUTOCAD Interface

4.2 Enhanced OSCONVR Application

Traditionally, the user interface provided within databases has been used to query information stored in these databases. This has proven to be difficult in browsing through the many records of instances of entities developed within the scope of a certain construction application, particularly the design and construction management information. One way of browsing and querying is through the use of VR interfaces. It is a more natural way of interfacing with information as the user can visually identify the objects of interests and retrieve information about them using the VR interface.

Several work have been undertaken to integrate virtual reality with ontology. [19] Used virtual reality to improve the retrieval of pages on the web by focussing on pag-es semantic connectivity grouping (referring to the similar pages) rather than their content grouping. As the development of VR interface is complex, [20] developed new approach based on ontology to ease modelling and the development of Virtual World on the web. [21] Combined geometrical analysis of point clouds and semantic rules to detect and build 3D building objects. [22] Presented a 3D Internet research platform, called ISReal, for intelligent 3D simulation of realities. It integrates application of semantic Web technologies, semantic services, intelligent agents, verification and 3D graphics for this purpose. OSCONVR [3] application usually reads information about the design produced through OSCONCAD object database and displays it in a virtual reality environment. This provides better visualisation using the web-based VRML (Virtual Reality Modelling Language). It was limited to navigating and interrogating 3D building components to get information like cost, dimension of the building components from the remote OSCONCAD object database.

This paper enhances the OSCONVR 3D interface with not only navigation and querying 3D construction components but also interaction and manipulation capabilities (updating, removing and adding) like updating the costs, change design of the building change planning and scheduling these 3D construction components lively on the web. This is achieved through mapping of the OSCON integrated object model with Semantic web construction domain ontologies to provide shared and reusable piece of knowledge about construction project design and building on the web and more importantly. More importantly the new versions of OSCONVR VR objects draw themselves from the ontology-based object rather the OSCON object database (deep web). The architecture of the enhanced OSCONVR interface linking VR to the ontology-based objects is shown in Figure 9 below.

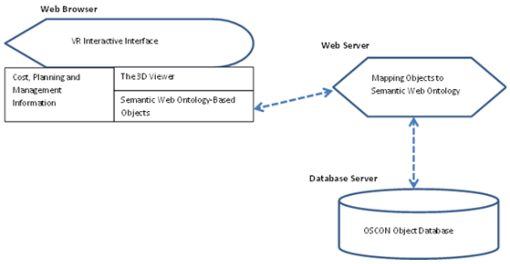

Figure 9. OSCONVR Architecture

Figure 9 depicts OSCONVR interface 3D Object mapped to semantic web ontology-based objects that draw themselves in 3D with the possibility of interacting and manipulating any construction component viewed in the OSCONVR 3D interface. It uses Virtual Reality Modelling Language (VRML) for describing interactive 3D scenes developed across the web. In OSCONVR, VRML browser load VRML objects that contains nodes that describe shapes of OSCON construction objects like windows and doors and also indexes to related ontology-based construction domain knowledge like costs, planning and scheduling information etc….to allow the user navigate and manipulate these objects.

In OSCONVR, the user can navigate through the VR model and identify elements by clicking on them. Information is then obtained about the specific objects depending on the view or requirements of a particular participant of the construction process. For instance, the designer can retrieve information about the specifications of a cavity wall, the QS can obtain cost information about the same cavity wall, and the time planner queries the model to retrieve information about the duration of building this cavity wall as shown in Figure 10.

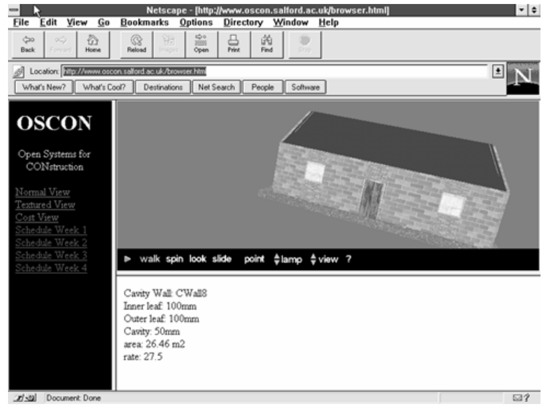

Figure 10. OSCONVR Interactive Interface

As shown in Figure 10 above, the cost of building components stored in the ontology-based repository could be viewed and manipulated through VR environment.

Furthermore, project planning information could also be read from the ontology-based repository of objects and displayed in the VR environment. As construction tasks stored in the repository contain information about durations, start dates, end dates and dependencies, this will allow the VR environment to be used as the medium for checking the status of construction plans. Figure 11 below shows the status of construction plans in VR on days 1, 5 and 10. This will allow a better access to planning information through the interactive VR capabilities.

Figure 11. Planning in OSCONVR

5 CONCLUSIONS

This paper presents a new approach of integrating construction information through domain ontology and sharing it through semantic web interface. This approach maps the OSCON integrated object model into semantic web ontology-based object model to allow construction users and application share and manage construction information and knowledge on the semantic web interface. Furthermore it enhances the OSCONVR interface with a combination of virtual reality and web semantic interface to not allow 3D navigation and interrogation of construction components e.g. windows, walls and roofs but also to manipulate and make changes which will captured in the underlying ontology-based repository and the underlying object database.

6 REFERENCES

1. Latham, M. (1994). Constructing the team, H.M.S.O.
2. Marir, F. et al.(1998) 'OsconCAD: A Model-Based CAD system integrated with computer based applications', Electronic Journal of Information Technology in Construction, Vol. 3, 25-44.
3. Marir, F. et al. (2002). OSCONVR: An Interactive Virtual Reality Interface to an Object-Oriented Database System for Construction Architectural Design. In the 2002 International Conference on Computational Science (ICCS 2002), April 21-24, Amsterdam, The Netherlands.
4. Waralak V. Siricharoen (2009) "Ontology Modeling and Object Modeling in Software Engineering", International Journal of Software Engineering and Its Applications Vol. 3, No. 1, January, 2009
5. Dubois, A.M., Flynn, J., Verhoef, M.H.G. and Augenbroe, F. (1995) Conceptual Modelling Approaches in the COMBINE Project, presented in the COMBINE final meeting, Dublin
6. Aouad, G,.Child, T, Marir, F & Brandon, P (1997). Developing a conceptual model for an integrated database, Proceedings of intelligent information systems, Bahamas, December, pp 316-320.
7. Ming Sun et al. (2001) "Integrated Information Management and Exchange for Water Treatment Projects" The ASCE 8th International Conference on Computing in Civil and Building Engineering Standford University California, USA, August
8. Halfawy, M.; Froese, T. (2005a) "Building integrated architecture/engineering/construction systems using smart objects: methodology and implementation" Journal of Computing in Civil Engineering, v. 19, no. 2, April 2005, pp. 172-181
9. Halfawy, M.; Froese, T.(2005b) "Integration of data and processes of AEC projects using the industry foundation classes" 6th Construction Specialty Conference, Toronto, Ont., June 2-4, 2005, pp. 1-10.
10. Maher AL-AJAM (2008) "INTEGRATING COLLABORATIVE EXTRANETS WITH PROJECT INTEGRATED DATABASES TO IMPROVE THE CONSTRUCTION TENDER STAGE" PhD thesis, The Research Institute for the Built and Human Environment, University of Salford, UK, 14-17, 2000, pp130-137
11. Seungjun Ahn, Moonseo Park, Hyunsoo Lee and Youngjun Yang (2010) "Object-oriented modelling of construction operations for schedule-cost integrated planning, based on BIM" Proceedings of the International Conference on Computing in Civil and Building Engineering W Tizani (Editor), June 30- July 2nd, Nottingham University UK, Nottingham University Press, Paper 80, p. 159
12. Stefan Boddya, , , Yacine Rezguib, Grahame Cooper, Matthew Wetherilla (2007) "Computer integrated construction: A review and proposals for future direction" Advances in Engineering Software, Volume 38, Issue 10, October 2007, Pages 677–687
13. William S, Austin T. (1999) "Ontologies", IEEE Intelligent Systems, 1999(1): 18–19.
14. Maedche L, Staab S. (2001) "Ontology learning for the semantic Web". IEEE Intelligent Systems, Special Issue on Semantic Web, 2001(3): 72–79.
15. Wondu Y. Mallede; Farhi Marir; Vassil T. Vassilev; Yanguo Jing (2012) "Algorithms for mapping RDB Schema to RDF for Facilitating Access to Deep Web",The First International Conference on Building and Exploring Web Based Environments WEB

2013 January 27 - February 1, 2013 - Seville, Spain

16. Chen Jia & Wu Yue1 (2009) "Rules-based object-relational databases ontology construction" Journal of Systems Engineering and Electronics, Vol. 20, No. 1, 2009, pp.211–215
17. Arens Y., Chin Y. Chee, Chun-Nan Hsu, and Craig A. Knoblock (1993)."Retrieving and integrating data from multiple information sources". International Journal of Intelligent and Cooperative Information Systems, 2(2):127–158, 1993.
18. Gamma, E., Richard Helm, Ralph Johnson, and John Vlissides. (1994). Design Patterns: Elements of Reusable
19. David Cleary, Diarmuid O'Donoghue (2001) "Creating a Semantic-web Interface with Virtual Reality", Proc. SPIE Workshop on Commercial Applications for High-Performance Computing, Howard Jay Siegel, Editor, Vol. 4528, pp 138-146, Denver, Colorado,21-22 August 2001.
20. Wesley Bille, Olga De Troyer, Frederic Kleinermann, Bram Pellens, Raül Romero (2004) "USING ONTOLOGIES TO BUILD VIRTUAL WORLDS FOR THE WEB" IADIS International Conference WWW/Internet 2004
21. Yucong Duan, Christophe Cruz, Christophe Nicolle (2010) "Architectural reconstruction of 3D building objects through semantic knowledge management" International Conference on Software Engineering Artificial Intelligence Networking and Parallel/Distributed Computing (SNPD), 2010 11th ACIS,9-11 June 2010.
22. Patrick Kapahnke, Pascal Liedtke, Stefan Nesbigall,Stefan Warwas, and Matthias Klusch (2010) "ISReal: An Open Platform for Semantic-Based 3D Simulations in the 3D Internet"ISWC, Shanghai, China Nov. 7-11, 2010