A METHODOLOGY USING DOMAIN ONTOLOGY AND SOA FOR BETTER INTEROPERABILITY IN AEC MASS CUSTOMIZATION

Antonio Grilo[1], Ricardo Jardim-Goncalves[2], Adolfo Steiger-Garcao[2]

[1] *Faculdade Ciências e Tecnologia da Universidade Nova de Lisboa, DEMI, Campus FCT/UNL, Portugal*

[2] *Faculdade Ciências e Tecnologia da Universidade Nova de Lisboa, Dep Eng. Electrotécnica - UNINOVA, Campus FCT/UNL, Portugal*

ABSTRACT: *Today, the OMG's Model Driven Architecture (MDA) makes available an open approach to write specifications and develop applications, separating the application and business functionality from the platform technology. As well, the Service-Oriented Architecture (SOA) establishes a software architectural concept that defines the use of services to support the requirements of software users, making them available as independent services accessible in a standardized way. Together, these two architectures seem to provide a suitable framework to improve construction company's competitiveness through the adoption of a standard-based extended environment, challenging and enhancing the interoperability between computer systems and applications in industry. Nevertheless, Domain Ontologies (DO) have been recognized more and more as a challenging mechanism to bridge knowledge. The paper, after illustrating the general motivations the construction companies have to adopt open architectures to achieve interoperability for extended and collaborative enterprise practices, presents the emerging model driven and service oriented architectures. Then, it describes an innovative methodology for better interoperability in AEC mass customization. The paper finishes with discussion and concluding remarks concerning the empirical results obtained from the pilot demonstrator.*

KEYWORDS: *interoperability, mass customization, domain ontology, SOA, MDA.*

1 CONVERGING MASS CUSTOMIZATION AND LEAN CONSTRUCTION

As companies reverse their traditional market push systems to market pull systems, it is the consumer who drives product configuration requirements (Robertson 1998, Simpson 2005). Mass customization requires that the value chain's primary and secondary activities are linked together dynamically according to the product and customer profiles. These links need to be seamless established and error free. Since clients require highly specific product or specific requirements, companies must be able to design products that both satisfy clients and are easily manufactured (Liker 2004, Cusumano 1998). Thus, products must be designed to manufacture.

Mass customization principles promote the individual possibilities and unique features for the customer, and this must be supported accordingly by design, production and sales processes. To compete in a mass customization strategy, companies must have capacities, competencies and resources to cope with evolving product configurations, variable output frequency and dynamic customer profiles, providing thus product and services that will differentiate from commodity type of products (Pine 1993, Guilmore 1997). Diverse solutions have been considered to sustain these business demands, like product platforms, modularity, commonality or postponement (Anderson 1997, da Silveira 2001, O'Grady 1999). These solutions imply greater efficiency of internal business processes, and effective coordination mechanisms between its different functions.

Lean construction is a research field that aims to reduce waste and maximize value in AEC projects that has been adopted mainly by contracting firms (Arburu and Ballard, 2004). Work on lean construction field has tended to focus on process tools and IT solutions to identify and minimise uncertainty and hence improve the workflow of production (Soini et al, 2004). Indeed, the effective information communication between the various parties of the construction project, necessarily requiring information integration between the various functions and specialties during the project life-cycle, is seen as fundamental to support the deployment of lean construction approaches. For the past ten years, several product-oriented approaches have been advocated to fulfil the goal of IT integration in AEC projects (see e.g. Alshawi, 1996). However, recent studies have shown that the level of IT integration within companies' value chains is not achieved properly yet (Prodaec, 2004), if the wide scale information integration required for a systematic true lean construction approach.

Lean management and mass customisation pose business processes that can only be fulfilled if not supported by specialised computer applications, together with automation in the production line. To achieve agile and flexible response, these applications need to be integrated. Com-

mercial ERP systems promise this integration, but real world practice shows that too often companies choose fragmented, vertical and functionally oriented specialised applications rather than complete commercial ERP solutions (empírica GmbH 2005). This poses challenges for information integration and therefore systems interoperability, as many applications run on disparate operating systems and using heterogeneous reference models and technologies.

As the AEC sector seeks to improve its productivity records, lean construction is being poised as a body of knowledge that aims to eliminate waste through the introduction of many mass production principles and approaches, but maintaining the customised nature of the industry. Indeed, the lean construction philosophy shares many of its main themes with the parallel movement of mass customization in the industry. Thus, the argument poised in this paper is that if there is similarity between the two approaches, than lean construction must also address the recent interoperability developments that can support the implementation of mass customization.

2 INTEROPERABILITY FOR AEC MASS CUSTOMIZATION

Recent observations state: "30-40% of companies' IT budget is spent on integration (Gartner and AMR), 30% of entire IT budget is spent on building, maintaining, and supporting application integration (Forrester), 61% of CIOs consider integration of systems and processes a key priority (CIOMagazine), $29 billion by 2006 for application integration by IT professional services (Gartner Group)".

Recent studies have uncovered the cost of interoperability barriers of the IT systems used in engineering and manufacturing in the US auto industry, estimated to be of the order of $1 billion per year. Similarly, for the construction industry, a study prepared for NIST by RTI International and the Logistic Management Institute, to identify and estimate the efficiency losses in the U.S. capital facilities industry resulting from inadequate interoperability among computer-aided design, engineering, and software systems estimates the cost of inadequate interoperability in the U.S. capital facilities industry to be $15.8 billion per year (Gallaher 2004). These studies are an indication of the industry's inability to exploit IT to realize its full benefits. It is in this context that standards for information exchange are also critical in the mass customization paradigm.

Many standard-based Application Protocols (APs) and Business Objects (BOs) are available today, e.g., ISO 10303-225, IAI/IFC. They cover most of the major manufacturing and business activities, and come from ISO, UN, CEN or OMG. However, most of these standards are not widely adopted, either by lack of awareness or due to private commercial interests of the software developers. Moreover, when they are selected, they are frequently used inadequately in most of the situations, due to an imprecise interpretation of the scope. This results in difficulties in achieving interoperability with others and introduces limitations in potential future reuse and model extensibility when creating new components (Jardim-Goncalves 2002).

Recently, XMI, one of the most promising tools for meta-model representation, revealed very able to assist on integration based on the concept of extending and reusing existent objects, and also on the development of compilers and code generators to assist in the development of new components (Jardim-Goncalves 2002). Complementing this, ISO13584 PLib is the standard suggested for representation of catalogues of objects and components (e.g., Units of Functionality, Application Objects and Assertions, Integrated Resources, Data Access Interfaces, Object Business Data Types, etc.), with direct link with a multi-level multi-language ontology system. This multi-level characteristic also assists with the development of hierarchical components, while the multi-language mechanism will provide the adequate description of the objects and components in many native languages, for an easier understanding and better usage. However, most of the standards for data exchange contain a framework that includes a language for data model description, a set of application reference models, libraries of resources, mechanisms for the data access and representation in neutral format. Examples are the DOM for XML, or the Part 21 of standard STEP (DOM 2006, ISO10303-1 1994).

Ontology is the study of the categories of things within a domain and reflects a view of a segment of the reality. Its definition comes from philosophy and provides a logical framework for research on knowledge representation, embracing definition, classification and relationships of concepts (IDEAS 2003).

Therefore, an interoperable system that seamlessly communicates and understands each other requires the comprehensive understanding of the meaning of the data exchanged within the domains involved. This can be realized, if the communication process is supported by an ontology developed under global consensus (Jardim-Goncalves 2004, JTC 1/SC 7/WG 17 2006). To obtain this consensual model, it is necessary to classify and merge the concepts from the different sources within the domain of applicability, describing them in a unique harmonized structure of classes, attributes, relationships, knowledge components and definitions. Through a combining procedure, the harmonized classification is defined, structuring the various suppliers' information from different sources and for diverse product categories.

Despite the availability of technologies supporting interoperability to sustain management challenges like increased flexibility and efficiency, there is a need a more systematic approach if companies are likely to widely adopt inter-organizational information systems across the value chain.

3 A METHODOLOGY FOR IS INTEGRATION FOR AEC MASS CUSTOMIZATION

Generally, the standard data access interfaces are described at a very low level. Moreover, they are made available with all the complexity of the standard's architecture to be managed and controlled by the user. This circumstance requires a significant effort from the imple-

menters to use it, and is a source of systematic errors of implementation, for instance when there are functionalities for data access very similar with slight differences in attributes, names or data types (Pugh 1997, Vlosky 1998, ENV 13550 2006).

To avoid the explosion in the number of required translators to cover all the existent standard data models, this methodology proposes the use of standard meta-model descriptions, i.e., the meta-model, using a standard meta-language, and putting the generators to work with this meta-model information (Umar 1999, Jardim-Goncalves 2001). A proposal to contribute to face this situation considers the integration of SOA and MDA to provide a platform-independent model (PIM) describing the business requirements and representing the functionality of their services, supported by a Domain Ontology (DO) that models and describes the concepts as they apply in the domain. These independent service models together with the DO can then be used as the source for the generation of platform specific models (PSM), dependent of the web services executing platform.

Within this scenario, the specifications of the execution platform will be an input for the development of the transformation between the MDA's PIM and the targeted web services platform. With tools providing the automatic transformation between the independent description of the web services and the specific targeted platform, the solution for this problem could be made automatic and global.

An Integration Platform (IP) is characterized by the set of methods and mechanisms capable of supporting and assisting in the tasks for integration of applications. When the data models and toolkits working for this IP are standard-based, they would be called Standard-based Integration Platforms. The architecture of an IP can be described through several layers, and proposes using an *onion layer model* (Jardim-Gonçalves et al, 2006). Each layer is devoted for a specific task, and intends to bring the interface with the IP from a low to a high level of abstraction and functionality. The main aim of this architecture is to facilitate the integration task, providing different levels of access to the platform and consequently to the data, covering several of the identified requirements necessary for integration of the applications.

To produce accurate mapping, the mapping tool needs to have knowledge about the mechanism for interoperability between the standards that originate the model in XMI, in order to implement in the translators the inter-reference mechanisms, accordingly with such standards. This is where the access to the DO is of major relevance in this process. For instance, the reference from one model described in STEP to PLib should be done using the PLib services, as recommended by the ISO TC184/SC4 community (Staub 1998), and assisted by a DO described in OWL.

Therefore, the proposal for the methodology for the integration of Applications in IPs must be developed at three stages: i.e., Conceptual, ADT and Mapping. At Conceptual stage, first it selects the APs, the DO and the models to be used as support for the integration of the Application in the IP, then it selects the parser, meta-SDAI and Mapping module for each of the selected AP's language, and finally translates those conceptual models to XMI.

At ADT stage, first it selects the programming languages to be used for the implementation of the translators, then it selects the ADT generator, meta-SDAI and Mapping module for each of the selected programming language, and finally it generates for each AP the correspondent ADT in the set of selected programming languages.

At Mapping stage, first it selects the set of APs that is required the mapping, the DO described in OWL, and then it defines the mapping rules between them, using EXPRESS-X. Then it selects the ADT generator, meta-SDAI and Mapping module for each of the selected programming languages, and then it generates for each mapping the correspondent inter.-model mapping ADT, in the set of selected programming languages. Finally it can be Integrated the Application in the IP using the generated code.

This methodology supports the required dynamics and flexibility existing in construction supply chains and projects, allowing fast, re-usable and largely automation-generated interoperability between construction firms IT systems.

4 VALIDATING THE METHODOLOGY

To validate this methodology in the context of the application scenarios, it was considered the application of a PIM to ISO STEP APs using XMI. Construction industry cases representing common situations requiring interoperability in the construction process were analysed, where the adoption of the joint model-drive and service-oriented architectures is conceptually developed and evaluated. An example was with HVAC specialists and architects existing at different locations and using different business models. They need to interoperate, through a business model for cooperation, supported by integrated electronic exchange of information. In this case each company used its own platform, and different proprietary applications, though allowing external communication of data. Here is the point were MDA adds its great value to make a seamless integration of the services.

Their collaboration is bound to the use of Service Oriented Architectures. Each one has its own services available and with well defined different entry-points. Also, the services implementation is based on different underlying system architectures, with the HVAC specialist using web-services and the architect using CORBA. Regarding the type of information to be managed, the HVAC specialist needs the layout and properties of the rooms in the building, from the architect, in order to be able to produce the engineering analysis regarding air flows.

To achieve the aim as the proof of the concept, UNINOVA developed the STEP25 tool that translates EXPRESS-based models to XMI following the emerging ISO10303 Part25 directives. This tool is the first that we know of that implements and proves this concept for AP236 EXPRESS to XMI binding including AP225 standard modules, validating an ISO 10303 Application Reference Model.

```
XMI:

 (* ENTITY product_class; *)
<Foundation.Core.Class xmi.id="product_class.CLASS">
 <Foundation.Core.ModelElement.name>product_class</Foundation.Core.ModelElement.name>
 <Foundation.Core.ModelElement.visibility xmi.value="public"/>
 <Foundation.Core.ModelElement.isSpecification xmi.value="false"/>
 <Foundation.Core.GeneralizableElement.isRoot xmi.value="false"/>
 <Foundation.Core.GeneralizableElement.isLeaf xmi.value="false"/>
 <Foundation.Core.GeneralizableElement.isAbstract xmi.value="false"/>
 <Foundation.Core.Class.isActive xmi.value="false"/>
 </Foundation.Core.Class>
 (* END_ENTITY product_class; *)
```

EXPRESS:	DTD:

ENTITY product_class;
 name : OPTIONAL string_select;
 id : undefined_object;
 description : OPTIONAL string_select;
 level_type : OPTIONAL undefined_object;
 version_id : OPTIONAL undefined_object;
END_ENTITY;
	<!ELEMENT Product_class EMPTY>
	<!ATTLIST Product_class
	   id ID #REQUIRED
	   name IDREF #IMPLIED
	   description IDREF #IMPLIED
	   level_type IDREF #REQUIRED
	   version_id IDREF #IMPLIED>

ENTITY product_class_relationship;
 relating : product_class;
 related : product_class;
 description : OPTIONAL string_select;
 relation_type : undefined_object;
END_ENTITY;
	Product_class_relationship EMPTY>
	<!ATTLIST Product_class_relationship
	   id ID #REQUIRED
	   description IDREF #IMPLIED
	   relation_type IDREF #REQUIRED
	   relating IDREF #REQUIRED
	   related IDREF #REQUIRED>

Figure 1. ARM AP236 and respective meta-model representation in XMI.

The commercial Mega Suite platform is used to import the ARM model, described in XMI, into UML, and then the facilities of this platform are used to automatically generate code ready to assist in the implementation of the translators and repositories compatible with the reference model in specific platforms. The tool was also tested with subsets of ISO10303 AP214, AP225, AP236 and ISO13584 part 20 (automotive, building and construction, furniture, and parts library and product catalogues).

Figure 1 depicts a subset of the ARM and the respective meta-model representation in XMI resulting from the output of the execution of the developed STEP25 tool, and the DTD for the representation of the product data in XML format. It also depicts the UML representation when the XMI representation is imported into the MEGA Suite platform. STEP25 is available for use by anyone interested. Authors will be very pleased to receive EXPRESS input files to help validate the tool.

5 CONCLUSIONS

The advance of lean construction principles can only be sustainable if supported with changes in how business value is created, i.e. the way business define its goods and services, and how they design logistics, operations and consumer interaction. Changes must occur internally, within its value chain but also in the network wherein companies are embedded, further exploiting relationships with suppliers, distributors and consumers. All these changes in business can only occur if enabled by adequate information systems. This pose challenges in terms of meta-data, data and IT interoperability towards enhanced mass customisation practices.

Mass customization and interoperability can be identified as key factors for enterprise success on a constantly changing global custom-driven environment enabling companies to act in partnership strengthening their position facing the market. Based on these concepts and due to the difficulty of maintaining and integrating existing heterogeneous platforms, languages and applications, software development is urging to change to a more efficient and rapid process.

Applications developed using model-based processes present a systematic approach to enterprise application integration, promoting reuse and enabling interoperability among different enterprises. Several dedicated business models have already been developed covering many industrial areas and related application activities, from design to production and business. Most of these models were designed and developed using standard methodologies and techniques. The MDA (Model Driven Architecture) and SOA (Service Oriented Architecture) have been evolving and it is expected to prove as the standard way of handling middleware and infrastructure development for enterprise systems groups

The building industry is moving in a reverse trend of traditional consumer/manufacturing sectors. Indeed, the building industry has always had a very much customised approach. In recent years, authors working in the lean construction approach are advocating and developing mass customisation principles in order to increase the industry's productivity. Yet a major hurdle on the deployment of mass customisation principles is the interoperability between IT applications, since it is a very fragmented sector, mirrored in the information systems development. Moreover, this is a sector with a very poor record on ontology, requiring a sound DO development.

This paper described a conceptual information system framework to support mass customisation principles grounded in an interoperable environment in the construction sector, proposing a methodology to enhance construction enterprises' interoperability in the support of lean construction practices using DO and SOA, keeping the same organization's technical and operational environment, improving its methods of work and the usability of the installed technology through harmonization and integration of the enterprise models in use by customers, manufacturers and suppliers. The proposed framework aims to stimulate the adoption of lean construction concepts and improve those practices by enhancing enterprise's interoperability through proper integration and harmonization of model and data.

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