INTEROPERABILITY IN SEMI-INTELLIGENT CIVIL ENGINEERING AGENT

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ABSTRACT

Fragmentation is one of the major problems in the UK construction and civil engineering design. It causes mistakes and misunderstandings partly because of the insufficient interoperability. Fragmentation is not only a geographical issue, also the distributed information management system should be taken into account. This research studied the process of information management in the UK civil engineering and its findings emphasized the need for an efficient semi-intelligent engineering agent.

In the course of model exchanging many authors use the term 'agent' (Anumba et al, 2002) rather than 'participant'. There is much discussion about whether a particular design system is an 'intelligent agent' or merely software system. The term "intelligence" is used to describe a system which behaves as an actor by percept of the environment and provides action to the environment. The actions should support the overall system aims. In this research 'semi-intelligent agents' mean a combination of programmed IT systems and human actors; communication is not completely based on IT systems replacing human users. This research argues that the key factor that could solve the misunderstandings between participants is enhanced interoperability. The previous studies in this area have categorized interoperability between design participants in four levels: 1- File level 2- Syntax level 3- Simulation level & 4- Semantic level (Steel et al, 2012). In this research the semi-intelligent structural agent will be used to improve the interaction, communication and understanding by describing the solutions and limitations in an accessible way to all shareholders. The amount of interviewees is relatively small although the position of participants in the design management in large international civil engineering companies who have several years' experience in the UK would support the validation of interoperability challenges in integrated design. This system is expected to reduce significantly the degree of mistakes and errors in structural and civil engineering design coordination.

This research reviews the state of the art and is based on interviews of civil engineers in the UK construction industry. Based on the findings the key challenges for semi-intelligent civil engineering agents are unstructured data, data mapping, unstructured evaluation and data consistency. Based on the findings a process map has been developed and it will be tested and expanded in the future research to find a solution for these challenges.

Keywords: interoperability process map, semi-intelligent agent, unstructured data

1. INTRODUCTION

The design process in the construction industry involves multiple stakeholders who may carry out their jobs from widely distributed locations (Caballero et al., 2002) Therefore, the interaction between those participants is often the cause of mistakes and misunderstandings due to a lack of interoperability (Serror et al., 2008). In previous research (Sacks et al., 2010) BIM is acknowledged as a solution for reducing errors by introducing some concepts, which are improving integration, constructability, information exchange, production plan and cost control. This research will consider BIM in a structural design by relying on two main philosophies; 1 - set-based design

(Parrish, 2009, Bavafa et al., 2012), and 2 – information-based design (Froese, 2002), and views design as a mechanism which requires obtaining information and knowledge, creating new information and finally sharing information and knowledge for the project. According to Ren and Anumba (2004) "*Fragmentation is one of the major problems in the construction industry*" due to different participants who are distributed in different places, who are required to collaborate and co-operate with each other. Nwana and Ndumu (1999) argued that in the centralised agent, most of the information resources are limited for that single agent and in the process of design, problem solving will not be efficient. Therefore the main objective of this research is to develop a process map in the process of civil engineering design to consider in integrated environment by minimum misunderstanding and maximum interoperability.

2. DESIGN AGENT

Inputting and managing data is still mostly carried out by collecting and translating from paper into a database or vice versa. Ford et al (1995) argued that this approach is inefficient in construction design due to the huge amount of processes and information.

Structural BIM (S-BIM) is the part of the BIM procedure, where the major and mainstream structural information is refined to provide the actual structural design (Robinson, 2007). In this process, the design is object-based and all objects are machine readable (Eastman, 2007). At the start of construction projects, the information is missing and designers and other participants produce a massive amount of information to populate this void (Robinson, 2007). Collaboration between construction participants is usually not enabled via on central database or model (Scherer and Schapke, 2011).

Ford et al (1995) argued that building modelling during the design phase is divided into three categories: 1 - data modelling, 2 - product modelling, and 3 - activity modelling. In the structural design process, there are some data that could not be modelled through the product visualization or graphical standards, such as codes and methods; these are categorized into data modelling. In the course of product modelling, the structural components and relationships between components will be modelled. Through activity modelling, the construction process will be simplified and made in order. All of these modelling types involve three main levels of computer system procedures: 1 – input, 2 – storage, and 3 – output; after outputting the models and before delivering them to contractors, it is required to evaluate the models by expert disciplines to reduce the errors and risks (Lopez et al., 2010). The agent technology can support design experts as a mediator to provide requirements and resources. The philosophical definition of construction design, which could contribute in this research, is "Agent", and the key issue of this paradigm is to "encapsulate humans as peer agents to computer processes using common language and protocols to integrate people and machines" (Ren and Anumba, 2004). Agents in the environment of integrated design have been classified into two categories: "Generator Agents" and "Critics Agents" (Fenves et al., 1994) The "generator agents" are the agents that directly affect design descriptions and are often knowledge-based systems that develop the emerging design. On the other hand, "critics agents" do not directly contribute to descriptions. However, they evaluate and make endorsements for design, for instance constructability assessment. According to Ren and Anumba (2004) the agents can be classified to either generator or critics based on their input and output and role in the overall project. In addition, this research seeks to add the principle of data evaluation during the production of the design model in an integrated environment.

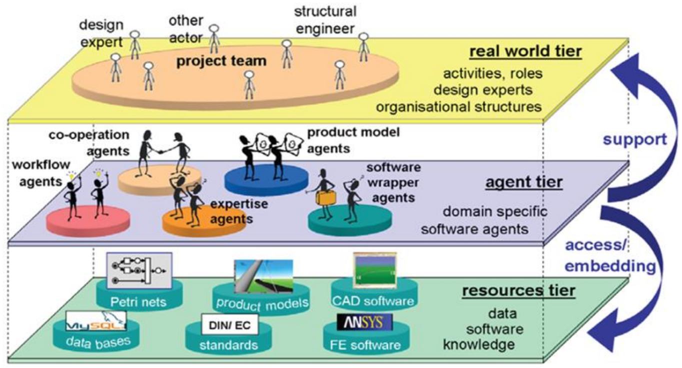

Figure 1: Three tier model for collaborative structural design from (Bilek & Hartmann, 2006)

The structural engineer agents coordinate their requirements through negotiation. According Ren and Anumba (2004) agent negotiation has two phases: in the first phase, data which are relevant to negotiation should be communicated to participating agents; in the second phase, "agents try to reach a deal through relaxation of initial goals, mutual concessions, lies or threats". This research has applied the first phase of Ren and Anumba's theory. However, the second phase has been described in this research as an effort to put solution models into design environment by those agents.

3. INTROPERABILITY IN SEMI-INTELLIGENT CIVIL ENGENEERING AGENT

Organizational information management has a critical role in project's scope. According to Hansen et al. (1999) there are two types of strategies for managing organizational information: 1- Personalization & 2- Codification. Personalization strategy portrays the transferring information from one person to another person by several ways such as meeting, face-to-face interaction etc. Codification supports capturing and storing of information to provide it in more accessible and accurate methods through IT or non-IT tools. In the course of model exchanging many authors use agent rather than participant. Therefore this keyword in this research needs to be specified. There is much discussion about whether a particular design system is agent and is that an intelligent agent or merely a programme (Anumba et al., 2002). According to (Nwana, 1996) agents could be defined in three behavioural options; 1- Autonomy, refers to the attribute how an agent needs human guidance, on the other words is an agent able to carry out the organizations tasks on behalf of their users or not. 2- Co-operation, refers to ability of an agent to interact and communicate with other agents. 3- Learning, refers to ability of an agent to learn before reacting to external environment. In the course of integrated construction design each agent has its responsibility to configure their model and interact with others' models outside their agents. Therefore communication takes place both inside and outside the agent (Chiou and Logcher, 1996). In this research the communication has been defined as communication between semi-intelligent agents because it is not implemented completely by IT system on behalf of their human users and will not take place completely by users without intelligent IT systems. In this study communication either inside or outside the semi-intelligent agent is composed of two phases. First one refers to exchanging a created model (inside the agent or to other agent) and second one refers to communication related to that model for evaluation or changes.

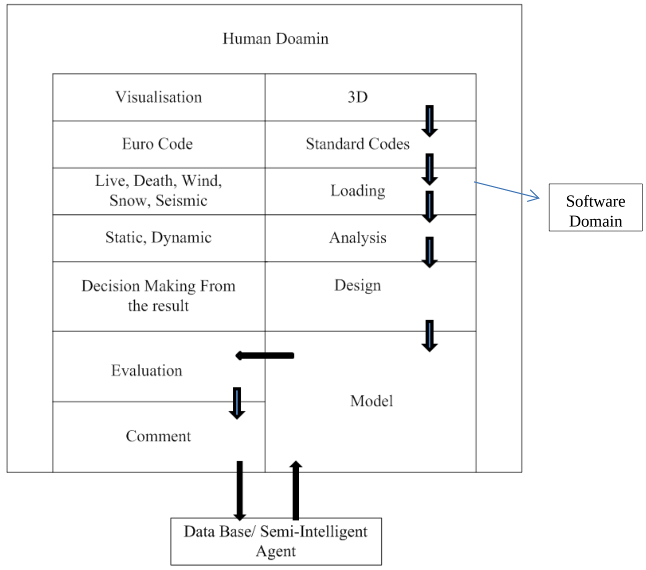

Figure 2: Semi-Intelligent Structural Agent

In the course of integrated design an appropriate information management system is necessary to aid project partners handle information digitally. The target of the system is to reduce the space of document storage and time for delivery to multiple agents and to enable system to track the documents by search engine (Pan, 2006) However, this research seeks to develop a process and technology map to move structural semi-intelligent agent forward to `Pan's targets and enhanced interoperability.

For conducting a process map for information management system inside the semi-intelligent agent, first the features of the product (information) should be identified. According to Leeuwen and Zee (2005) the value of product information for design is categorized in four aspects; 1- Format (Can the information be accessed and applied directly in the design context?), 2- Validity (Is the most actual information available?), 3- Semantic (Is the meaning of the information sufficiently defined and understood?), and 4- Timelines (Is the information found and available when needed?). From another point of view according to Steel et al. (2012) interoperability is considered in four levels; 1- File level interoperability (The ability of two tools to successfully exchange files), 2- Syntax level interoperability (The ability of two tools to successfully parse files without errors), 3- Visualisation level interoperability (the ability of two tools to faithfully visualise a model being exchanged), and 4- Semantic level interoperability (The ability of two tools to come to a common understanding of the meaning of a model being exchanged). However, in this research interoperability between structural semi-intelligent agent and client's, architectural and building services semi-intelligent agents will be a combined theory from Steel et al. (2012) and Leeuwen and Zee (2005). In addition, two new levels of interoperability are proposed; access control level and evaluation level.

4. PILOT STUDY IN THE UK CIVIL ENGINEERING INDUSTRY

Pilot study is used in social science as a method to refer to feasibility study and could be a part of the research method to pre-test or try out the research questions (Baker, 1994). The main advantage of conducting a pilot study in this research is a potential warning about failing the research scope and questions. It is necessary to verify sufficient elements for the conceptual framework. In the other words, before starting case studies, the research will conduct 5 interviews of engineers and design managers who have experience in BIM design environment within 2 different cases. It will increase the validity of the research by addressing the relevant issues in the engineering BIM design in the UK.

Table 1: Description of the organisations Case study

Organisations	Description
Company 1	A civil engineering department in northern England of a multinational infrastructure group operating in over 80 countries with capabilities in professional services, construction service, support service and infrastructure investment.
Company 2	A civil engineering department in northern England of a multinational professional service, which provides engineering, design, planning, project management and consulting services for all aspects of the built environment.

The researcher interviewed 2 members in company 1 and 3 members in company 2 as following role description. Those members have a holistic view of the civil engineering industry and the use and challenges of BIM, not only in their own firms but also across the UK.

Table 2: Description of interviewees

Participant	Participant Position	Years of Experience	Interview Method	Company
A	Structural Eng.	14	Telephone	1
B	Civil Eng.	16	Face to Face	1
C	Structural Eng.	17	Face to Face	2
D	Design manager	17	Face to Face	2
E	Sustainability developer	15	Face to Face	2

The overall results are dominated by the people who have substantial experience and understanding about the progress of civil engineering information management. The company 1 supports general design service, design management service and BIM and company 2 supports feasibility study, design information management, detail design, construction and operation maintenance. The key findings from the interviewees in terms of interoperability in their organization are Unstructured Data, Data Mapping, Unstructured Evaluation and Data Consistency. All of the interviewees highlighted that Unstructured Data is the key issue in creating the model. Four interviewees argued that Data Consistency is their concern in the interoperability design, and three and two interviewees mentioned Unstructured Evaluation and Data Mapping between different BIM tools as the key elements in interoperable process.

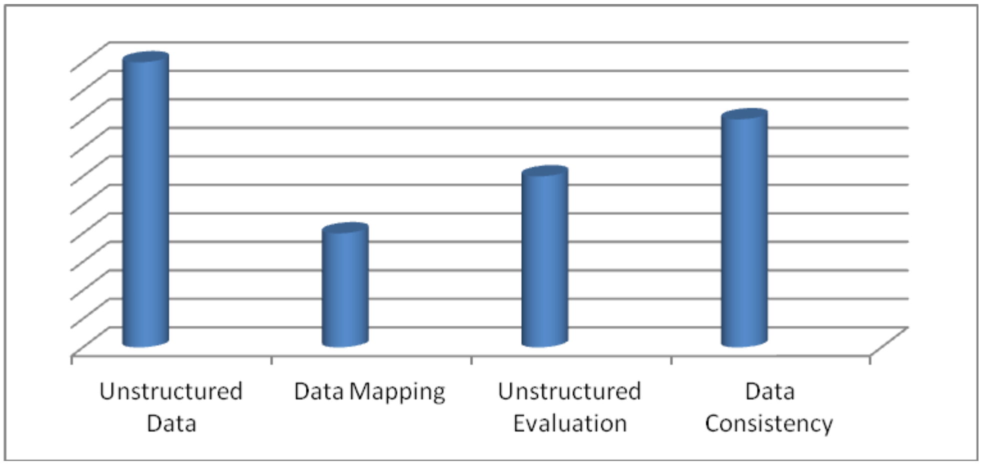

Figure 3: Key findings in interoperability design

The first tier of interoperability for the semi-intelligent agent in the UK civil engineering is simulation tier. In this tier the modelling procedure is conducted by four kinds of structures of data; 1- unstructured data 2- semi-structured data 3- structured data and 4- advanced structured data.

Unstructured data is the data that often do not have transparent description or in other words, there is no platform or placeholder for metadata, such as description. Most of the participants argued that they have many meetings, video conferences, text, photos of site, but there is no efficient place in the final model to support inclusion of these data. Therefore users need to transcript and transfer these data by their interpretation and this causes missing data, loss of the key descriptions and misunderstandings of client requirements.

Semi-structured data is the data that illustrate the description and entity separately. However, users still need to map descriptions from semi-structured format to the civil engineering model. The examples, which most interviewees mentioned, are Excel sheets and statistical sheets. Unstructured and semi-structured data are understandable by human only, and mapping the data and its description is not understandable by machine. Structured data present for example the geometry of model and the construction and infrastructure components and could be presented by lines and spaces. The interviewees used dwg and dxf for this kind of data format. Interviewees used also IFC file format for advanced structural data to exchange models of structural system and components defined by their placement and physical representation.

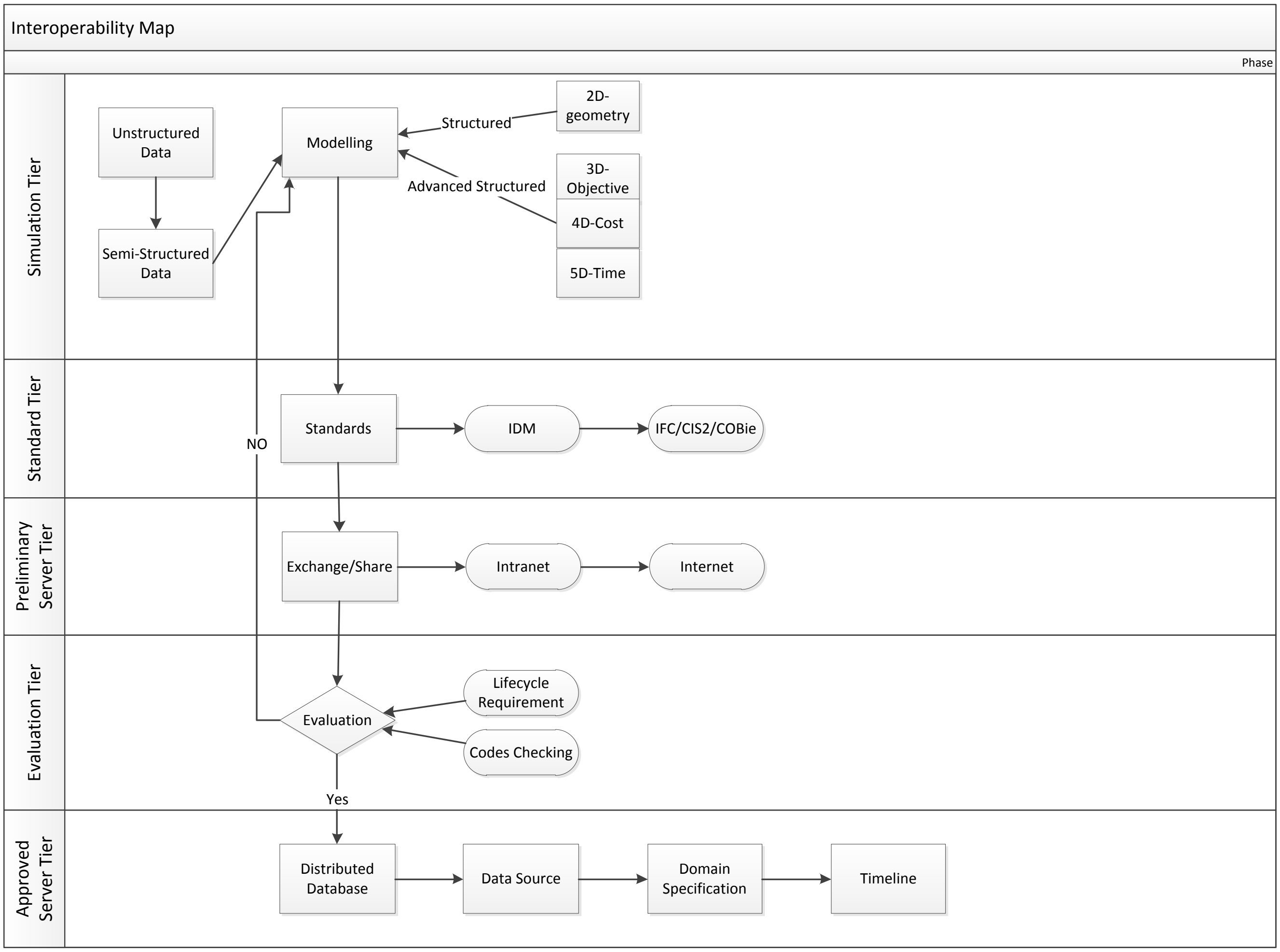

Figure 4: Interoperability Process Map

Two companies highlighted their ambitions to share their data with local authorities because most of their project funding comes from the government authorities and as the Cabinet Office (2011) argued “the UK government will require all engagement in the design construction, management and infrastructure of publicly funded to share that process by 2016”.

Most of the participants argued that interoperability in design phase is more efficient in their internal information management system. They argued that their company interest is in internal information system although in many projects which are funded by local authorities, their company have been forced to use an external information system.

Most interviewees argued that one of the main key issues in interoperable design is providing information consistently. They mentioned that their information are distributed in different formats, different databases and timing of information transfer is not specified in the system. Therefore they need a more efficient system and specific format(s) to be available for future. The solution for the interviewees’ concerns has been illustrated in Preliminary Server Tier and Approved Server Tier (Figure 4) Because of the practical process needs the first exchange/share process must happen before evaluation. Each participant creates their structured and advanced structured model and exchanges it in IFC format on the Preliminary Server Tier. Unstructured and semi-structured content must be interpreted and mapped to IFC files and some of these data can be shared without any interpretation by the computer for human communication. The evaluation and clash detection have not conducted yet on this tier. In the next stage design manager combines the preliminary models using IFC viewer tools and after appropriate assessment on the Evaluation Tier the final models can be exchanged or shared on the Approved Server Tier by specifying the required transactions and access rights for each internal participants and external authorities. In the evaluation tier, design management team consider the local authorisation codes and project lifecycle requirements with the created model. If the created model is accepted by design management team, the model will establish in approved tier server nevertheless,the model would not establish and will transfer to simulation tier by attachment of evaluation comments. Some interviewees argued that the evaluation process is often established using unstructured method and does not use IFC files. However, one case utilized cloud-based collaboration for Evaluation Tier and the system could record who accessed, edited, uploaded and downloaded any document and when they did with it. If the model does not pass the evaluation it will be sent back to its original author on simulation tier for corrections before it can be delivered to the Approved Server Tier.

5. CONCLUSION

Design process in the construction industry involves multiple stakeholders who may carry out their tasks in widely distributed locations. Therefore the interaction between those participants is often affected by insufficient interoperability. In a semi-intelligent civil engineering agent, a programmed system would carry out part of the information creation, retrieval and delivery on behalf of the users who would also conduct part of the process. In the integrated civil engineering design each agent would have its responsibility to configure their model and interact with others. Hence communication takes place on different levels of interoperability. This research identified the key barriers against the interoperable civil engineering design including: Unstructured Data, Data Mapping, Unstructured Evaluation and Data Consistency. The research also highlighted the key challenges in the process of interoperable civil engineering and developed a process map (Figure 4) to illustrate rational relationships between the key barriers and other components of the civil engineering design process.

The research also identified that there is a lack of rational platform on the first level of interoperability (Simulation Tier) to link unstructured and semi-structured data to structured data efficiently to minimise misunderstandings and mistakes. Lack of data consistency of data was identified as one of the key challenges in the UK civil engineering industry. Distributed data in different databases and different formats and lack of specified timing of data transactions leaded to the development of two tiers of servers. The first exchange or share process must happen before evaluation to enable fluent work processes before combining domain specific models for assessment and coordination. If any of the domain models does not pass the evaluation, it must be sent back to its original author on Simulation Tier for corrections and further assessment. The final, approved models can be exchanged or shared on the Approved Server Tier by specifying the required transactions.

In the future research the process map will be tested to verify the capability and validity of the framework created in this study.

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