INDUSTRY DRIVEN INNOVATIVE SYSTEMS DEVELOPMENT FOR THE CONSTRUCTION INDUSTRY: THE DIVERCITY PROJECT

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Collaborative working has become possible using the innovative integrated systems in construction as many activities are preformed globally with stakeholders situated in various locations. The integrated VR based information systems can bind the fragmentation and provide communication and collaboration between the distributed stakeholders in various locations. The development of these technologies is vital for the uptake of these systems by the construction industry. Therefore, requirements engineering can be a key aspect for the effective development and implementation of these technologies. The research project called DIVERCITY was a European consortium of researchers and practitioners from the construction industry who developed a virtual environment that enables the industry to better undertake the client briefing and design reviews. The project had the acronym DIVERCITY for "Distributed Virtual Workspace for Enhancing Communication within the Construction Industry". The paper starts by establishing the importance of requirements engineering in the Construction Information Technology (CIT) community, as well as explaining some of the current methods and trends in requirements engineering. Then, the research methodology is described to establish a base for the findings and results in the research. This is followed by an explanation of DIVERCITY's requirements engineering approach and exploration of some of its strengths & weaknesses. Finally the results and findings in regard to requirements engineering from the DIVERCITY case study project are represented and discussed about how to improve the requirements capture & testing process in the CIT research community.

Keywords: contextual design, industrial uptake, requirements engineering, incremental prototyping, unified modelling language

INTRODUCTION

In the last decade, construction companies have spent a great deal of effort and resources in improving their business processes. New forms of innovative project management, construction management, supported by recent IT developments, have appeared in response to ever-growing pressure from owners to complete projects on time and deliver high quality buildings (Sarshar et al, 2004).

Researchers and industrialists have attempted to utilise IT as an enabling technology in order to reduce the problems of communication and information sharing within the construction industry. More recently, in the area of construction IT, researchers have identified the need for an integrated virtual construction environment, which acts as a project repository, during all stages of the lifecycle (Aouad et al, 1997). This aims to improve the communication between the different stakeholders and improve productivity. This environment has proved complex to develop and implement.

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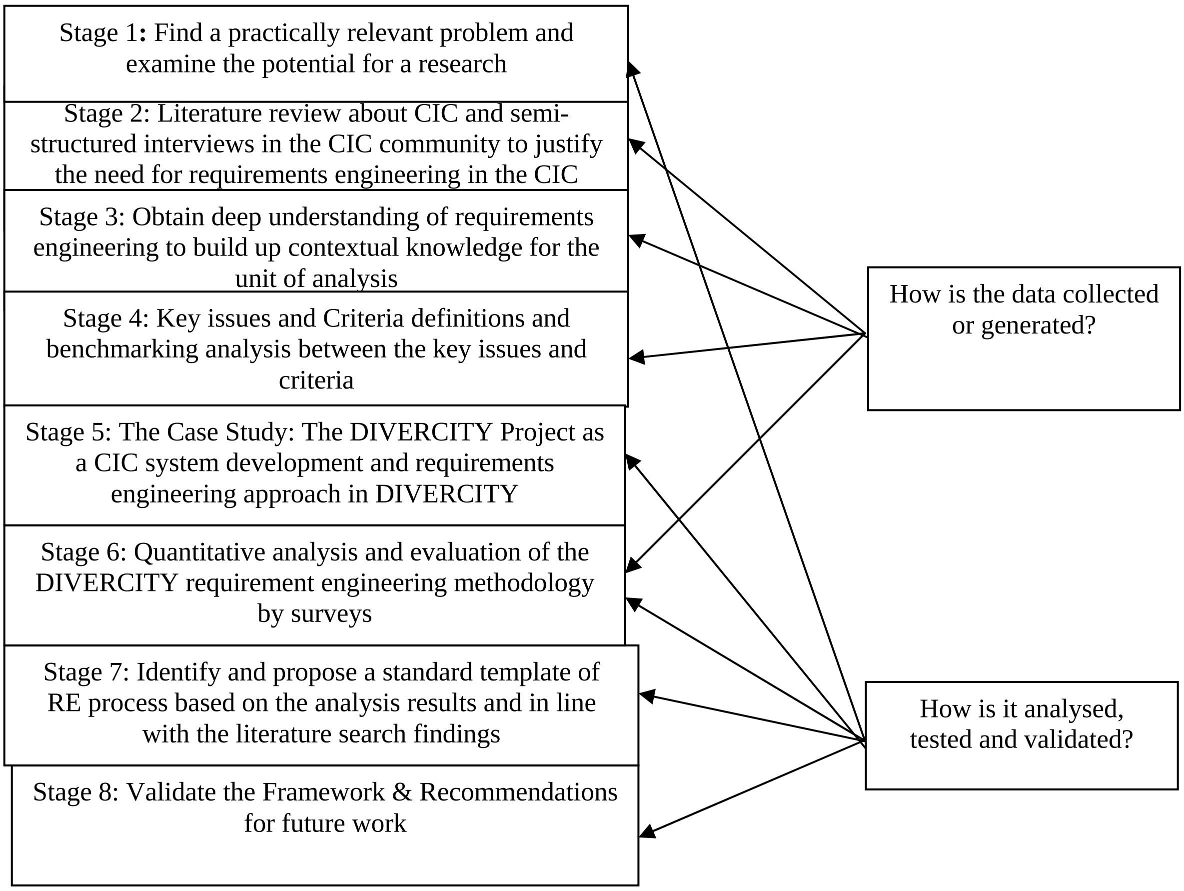
Although the concept of virtual prototyping and integrated computer environment has been the subject of research for many years, the uptake of this technology has been very limited due to the development of the technology and its effective implementation (Alshawi & Faraj, 2000).
In its early years, the CIT research community mainly focused on technology based issues, trying to implement lessons learnt from the IT community in the construction industry. Early prototypes in many research projects investigated data standards and common information models through which heterogeneous computer systems could exchange project information. Many different technologies have been explored. However, in the early projects there was little attention and consideration to the user requirements capture and subsequent implementation of the prototypes (Tanyer, 2003), (Arayici, 2004).
The discipline of requirements engineering, which is the branch of systems engineering for technical management and requirements capture test and validation of software systems under development, is related to the issues of the development of the technology and its effective implementation. Requirements engineering is a major factor in determining the success of the entire development. It can influence not only the attributes of the systems but how well it is targeted to user needs, the accuracy of the design and specification, the ultimate cost and quality of the final product (Cooper and Wootton, 1998). This is relevant to the development of the technology and the effective implementation (Alshawi & Faraj, 2000).
In the following section, the research methodology of the research is explained to establish a base for the succeeding sections in the paper.

RESEARCH METHODOLOGY

The strategy for the research is the case study that encourages in-depth investigation of particular instances within the research subject. Case study research typically combines data collection methods such as literature search, interviews, questionnaires and observations (Fellows and Lui, 1997). Yin (1989) defined case study strategy as an empirical inquiry that investigates a contemporary phenomenon within its real-life context when the boundaries between phenomenon and context are not clearly evident; and in which multiple sources of evidence are used. Eisenhardt (1989) stated that case studies can be used to accomplish various aims such as providing description, test theory or generate theory, exploratory and explanatory.
The research is a single case study research and the case study is the DIVERCITY project (1999-2002). Therefore, the research results mainly rely on the data collected from the DIVERCITY case study and the proposed requirements approach mainly reflects DIVERCITY's requirements engineering approach.
When research questions focus mainly on "what" questions, they can lead an exploratory research, such as "What is the requirements engineering process for the development of the CIC systems?". This type of question is a justifiable rationale for conducting an exploratory study, the goal being to develop pertinent hypotheses and propositions for further inquiry. However, as an exploratory study, any research strategy can be used such as an exploratory survey, an exploratory experiment or an exploratory case study. However, "why" questions, such as "why is there a need for identifying a requirements engineering process for the CIC developments?", are more explanatory and likely to lead to the use of case studies as the preferred research strategies (Yin, 1989). Therefore, the case study research strategy was chosen to investigate the research questions of the thesis. Both Yin (1989) and Eisenhardt

(1989) also stressed that case studies can involve qualitative data only, quantitative data only or both types of data.

Figure 1: Research Methodology Diagram (Arayici, 2004)



Because the research questions are “what” and “why” type of questions, the research is both exploratory and explanatory research involving both qualitative and quantitative data. It subsequently brings about the research approach embracing both positive and interpretive research approaches in this study.

Qualitative research is explorative and interpretive and is especially suitable for the examination of systems and processes where there are interactive relations between variables (Krathwohl, 1998). The qualitative method is also useful for inductive and exploratory research as it leads to the understanding of phenomena and theory generation, (Read, 2000). Furthermore, a qualitative approach helps to analyze and compare and contrast the main findings, directions, and shortcomings of the research. The result will be a synthesis of the research to arrive at a statement of the current status of innovation research, its implications for management, and suggestions for the direction for future research (Read, 2000).

Quantitative techniques in the research are employed for the analysis and the evaluation of the DIVERCITY requirements engineering (RE) approach based on the results of the questionnaire based survey. This is because the systematic numerical analysis of the data in the form of tabling, graphs, etc assists in structuring the analysis and expressing the strengths and weaknesses in the RE approach while helping to visually represent the evaluation (Hussey and Hussey, 1997) and (Read, 2000).

According to Yin (1989), a common pattern can be established: case study design; data collection; conducting case studies; analysing data; and finally reporting. For case

studies, (Yin, 1989), five components of a research design are especially relevant: (i) a study's questions; (ii) its propositions; (iii) its unit of analysis; (iv) the logic of linking the data to the propositions; and (v) the criteria for intepreting the findings. As a result, the research methodology that is designed according to Yin (1989)'s instructions is depicted in figure 1 above.
To check the quality and reliability of the research, following tests recommended by Yin (1989) are applied to the research methodology, which are indicated in table 1 below.

Table 1: The case study tactics to test the quality of the research

Tests	Case study tactics	Phase of research in which tactic occurs	The adoption of the tactics in the research
Construct validity	-Use of multiple sources of evidence	-Data collection	-Adopted
	-Establish chain of evidence	-Data collection	-Adopted
	-Have key informants review draft case study report	-Composition	-Adopted
Internal validity	-Do pattern matching	-Data analysis	-Adopted
	-Do explanation building	-Data analysis	-Adopted
	-Do time series analysis	-Data analysis	-Not adopted
External validity	-Use replication logic in multi-case studies	-Research design	-Not adopted
	-Use generic assessment models	-Data analysis	-Adopted
Reliability	-Maintaining chain of evidence	-Data collection	-Adopted
	-Use case study protocol	-Data collection	-Adopted
	-Develop case study database	-Data collection	-Adopted

The rest of the paper focuses on the stage 5 of the research methodology in which the DIVERCITY project and its approach to requirements engineering is elaborated.

THE DIVERCITY PROJECT

DIVERCITY was an EU funded project that used IFC (Industry Foundation Classes) standards in order to develop a toolkit for shared virtual briefing and design, in the construction industry. This toolkit allows construction companies to conduct client briefing, design reviews, simulate what if scenarios, test constructability of buildings, communicate and co-ordinate design activities between teams.

DIVERCITY developed virtual workspaces that improve communication and collaboration. DIVERCITY allows users to produce designs and simulate them in a virtual environment. The designs are IFC based and can be viewed by all stakeholders within the project team.
DIVERCITY uses a distributed architecture, and enhances concurrent engineering practices during briefing and design. It allows teams based in different geographic locations to collaboratively design, test and validate shared projects. DIVERCITY embraces seven applications. These are as follows:

1. Client Briefing: This supports clients and designers during briefing. It provides tools for capturing strategic and spatial requirements and allows experimentation with alternate spatial layouts, in a visual format.
2. Acoustic simulation: This application automatically reads CAD drawings (in an IFC format), and allows changes to building materials on-line, in an interactive manner. The use can listen and analyse the acoustic qualities of the building, and change the design to achieve desired noise levels.

3. Thermal Simulation: This application automatically reads CAD drawings (in an IFC format), and allows changes to building materials online, in an interactive manner. The user can simulate the energy consumption of the building (/or rooms) and select appropriate material for energy efficiency.
4. Ligting simulation: This provides a realistic simulation of lighting. The user can change and move objects or lights in the building and see lighting simulation in an interactive manner.

   One novel characteristic of this application is the mathematical algorithms, which are used for simulation. Lighting simulations generally take a long time (several hours). In most cases, DIVERCITY algorithms allow real time simulation and only take a few seconds. This facilitates interactive and collaborative simulation.
5. Site Planning: The site planning and analysis application aims to evaluate the space use and safety in the construction site, and provide ways to generate enhanced construction site layouts with respect to time and safety criteria.
6. Visual Product Chronology: This Visual Product Chronology application provides visualisations over the various data and their interdependencies. In these visualisations the “Time” aspect is crucial. The application links the time tags with the appropriate building components and their data. This results in the visualisations of the status of the building and its components at the selected point of time.
7. Communication Layer: Stakeholders in different geographical locations can share an application via communication layer, which provides (i) communication between heterogeneous systems, architectures and languages, (ii) robust and secure messages transfer, (iii) time performances to allow real time collaboration, (iv) multi-user management including identifications and access control

In the following section, requirements engineering and DIVERCITY’s approach for capturing the requirements of construction stakeholders are described.

REQUIREMENTS ENGINEERING

Requirements as defined by Dorfman (1997) is a software capability that must be met or possessed by a system or system component to satisfy a contract, standard, specification or other formally imposed document which is needed by the user to solve a problem to achieve an objective.
The process of requirements engineering must be planned and managed. There are a number of generic activities to all requirements engineering processes (Sommerville, 2000):

1. requirements elicitation
2. requirements analysis
3. requirements validation
4. requirements management

Elicitation is a definition of the system in terms the end user can understand. Analysis is a technical specification of the system in terms the developers can understand. Validation is concerned with showing that the requirements define the system that the users want. Requirements management is the process of managing changing requirements during the requirements engineering process and system development (Lundh 2002).

Although they seem to be separate tasks, these four processes cannot be strictly separated and performed sequentially. Some of the requirements are implicit in the working practices, while others may only arise when design solutions are proposed. All four are performed repeatedly because the needs are often impossible to realize until after a system is built. Even when requirements are stated initially, it is likely they will change at least once during development and it is very likely they will change immediately after development.

DIVERCITY'S APPROACH

DIVERCITY is a large-scale, highly innovative and interactive workspace. It is concerned with the development of interactive systems that cannot be treated simply as incremental improvements over existing construction IT solutions on the market. In such cases it is not possible to identify user requirements on the basis of empirical techniques, as there are no instances of the use of the product (or similar products) from which to collect data. Consequently, the developers of innovative products must proceed by envisioning the use of the proposed product (Dearden 1998).

The importance of requirements engineering was well understood amongst the project team. However, the processes and methods for requirements engineering evolved through the project. Initially team members had individual ideas and perceptions. Different methods were explored concurrently, but independently of each other. It took the team over a year to evolve a shared understanding of the processes and methodologies. There was then a learning period, for all team members to become familiar with all the deployed methods.

DIVERCITY reviewed a number of methodologies and finally used a combination of techniques. It is detailed down into three category; use case driven requirements analysis, contextual design, incremental prototyping with user tests, each of which are strong techniques to undertake the requirements elicitation, requirements analysis and requirements validation respectively.

UML (Unified Modelling Language) Phase

DIVERCITY initially intended to use use-cases and UML (Unified Modelling Language) as means of requirements capture. It provided object-oriented development and fits with well some other technical aspects such as IFC. In addition, technical team also supported to use of UML for requirements capture. Therefore, use case driven analysis were selected for requirements elicitation and analysis and rational rose enterprise edition software tool of UML were selected for the development of high level use cases and for the decomposition of these use cases into further detail object diagrams before committing them to code (Arayici, 2004).

In use case driven requirements capture, the requirements workflow proposed by RUP (Rational Unified Process) was intended to use in order to communicate the complex top-level industry requirements and progressively break into more detail. Furthermore, to manage the large scale and evolving industry requirements, three critical milestones, i.e. (i) lifecycle objectives (ii) lifecycle architectures and (iii) operational capability were defined (Shelbourn et al, 2001).

Contextual Design Technique

There are not so many well-formalised methods to support the entire design of a product like DIVERCITY. Due to its well worked out user centred approach the Contextual Design method (Beyer and Holtzblatt, 1998) is chosen to try to early take into account the end user work practice and interface requirements. Furthermore, because system developments which start with UML based object modelling takes too little account to early conceptual analyses of user requirements and user interface functionality. The risk is obvious that important properties of the final product with regard to end use are overlooked (Christiansson et al, 2001). Besides that, use case models are loose collection of use cases, which results in taking too little consideration to understand user needs and user interface design as well as quality requirements (Regnell et al, 1995). Therefore, contextual design technique was employed for the requirements elicitation.

Contextual Design methodology has five different types of Work Models. These are as follows;

- Flow, representing communication and co-ordination necessary to do work (roles, responsibilities, actions/communication topics, and spaces which are regarded in DIVERCITY as project internal or project external memories and virtual/physical spaces).
- Sequence, showing the detailed work steps necessary to achieve intent. Sequence models can reveal alternate strategies to achieve the same intent.
- Artefact, showing objects created to support the work
- Culture, representing constraints on the work caused by policy, culture or values, formal and informal policy of the organisation, business climate, self image, feelings and fears of the people in the organisation, possibility for privacy.
- Physical, showing the physical structure of the work environment as it affects the work

These work models were developed in close collaboration between the user groups of the project team. Afterwards, the storyboarding was conducted. To do so, the user group held a workshop, which resulted in emerging a shared understanding amongst the end users. The user group focused on the further details how the DIVERCITY system should function and how the stakeholders such as client, architect, engineer, and contractor should act to conduct their duties using the relevant functions of the DIVERCITY system. 15 scenes were developed and in each scene the duties of the construction stakeholders and how they should interact to conduct their duties collaboratively were explained. Furthermore, the storyboard enabled the technical team also to understand the requirements clearly and the shared understanding was extended amongst the technical team as well as the end users (Arayici, 2004).

Incremental Prototyping with the User Tests

The most effective way to reduce risk is to start testing early in the development cycle and to test iteratively, with every build. With this approach, defects are removed as the features are implemented (rational white paper, 1999). The user group employed the UML test workflow to conduct the black box tests in a stage wise manner. The testing process played a major role in evolving the requirements and providing a spiral development process.

In DIVERCITY, testing lifecycle incorporates three main testing phases: Alpha, Beta and Final testing. The DIVERCITY tests were also called as black-box tests. This is because, DIVERCITY tests centre on testing the programs against the written specifications and test observes the programs as black-boxes and is totally unconcerned with the internal structure of the programs.

Furthermore, there was a symbiotic relationship between the end users and the developers in the DIVERCITY project. The entire tests in the lifecycle were conducted by the end users not the developers. The developers released the prototypes and the end users, who were distributed across Europe, tested the prototypes continuously in a collaborative manner with respect to the defined types of tests. They continuously provided feedback to the developers throughout the test phases.

CONCLUSION

During the introduction of the paper it was discussed that a key objective of requirement engineering in the construction IT research is to increase the level of technology uptake and reduce the gap between research and practice.

DIVERCITY spent much effort in capturing requirements directly from the end user community, who formed the requirements engineering team. Many methodologies from the requirements engineering community were reviewed and eventually an integrated methodology was adopted and shared among the end users. As such DIVERCITY is viewed as a successful EU research project. Its applications are technically advanced and beneficial to construction practitioners.

However, the construction industry in Europe operates on tight operating margins and is slow in adopting new technologies and working methods. The industry is fragmented, with many business interests and parties operating during each stage of the life cycle. Any innovative application needs to take account of requirements at three different levels (Sarshar & Arayici, 2004), i.e:

- The individual practitioner;
- The project; and
- The organisation and business (for each stakeholder in the construction team).

When these requirements overlap and compliment each other it should be possible to introduce innovative solutions to the industry.

The DIVERCITY requirements engineering approach concentrated on practitioner requirements, and technical project requirements. However, the commercial project requirements, and business needs have been mainly ignored. It is possible that virtual environments such as DIVERCITY could increase project costs, without sufficient benefits, or introduce excessive change in the process and working relationships among stakeholders (Sarshar & Arayici, 2004), (Arayici, 2004).

Tanyer (2003) addresses that in bridging this gap, the research methodologies used in most construction IT research projects are incomplete. Generally the research stops after the production of a working prototype. It is necessary for all construction IT research to continue with testing on live construction projects. This will allow capturing project and business impact and requirements.

The business requirements, and therefore the software requirements, will vary according to the construction sector (e.g. housing, office, etc.). Therefore researchers must explore the business gains for each specific sector before generalising the results for the whole industry.

Within DIVERCITY it was paramount to explore requirements from the business and financial perspective, alongside the technical requirements. It was essential to have a financial vision, in parallel with the technical and process vision. The framework and methodologies from the software sector, which were reviewed, disregarded these dimensions. Construction IT research needs to tailor or develop requirements' engineering methodologies which consider these critical dimensions.

Due to the rigorous capture of end-user requirements, at a practitioner level, some of the DIVERCITY applications have been used in some construction projects. For example, the lighting application has been used in a French museum project, and the collaborative applications have been embedded in software for other industries.

However, to date, most DIVERCITY applications have not found their way into the commercial construction market place.

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