REQUIREMENTS ENGINEERING FOR COMPUTER INTEGRATED ENVIRONMENTS

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PREFACE

A Computer Integrated Environment (CIE) is the type of innovative integrated information system that helps to reduce fragmentation and enables the stakeholders to collaborate together in business. Researchers have observed that the concept of CIE has been the subject of research for many years but the uptake of this technology has been very limited because of the development of the technology and its effective implementation. Although CIE is very much valued by both industrialists and academics, the answers to the question of how to develop and how to implement it are still not clear.

The industrialists and researchers conveyed that networking, collaboration, information sharing and communication will become popular and critical issues in the future, which can be managed through CIE systems. In order for successful development of the technology, successful delivery, and effective implementation of user and industry-oriented CIE systems, requirements engineering seems a key parameter. Therefore, through experiences and lessons learnt in various case studies of CIE systems developments, this book explains the development of a requirements engineering framework specific to the CIE system.

The requirements engineering process that has been developed in the research is targeted at computer integrated environments with a particular interest in the construction industry as the implementation field. The key features of the requirements engineering framework are the following: (1) ready-to-use, (2) simple, (3) domain specific, (4) adaptable and (5) systematic, (6) integrated with the legacy systems. The method has three key constructs:

i) techniques for requirements development, which includes the requirement elicitation, requirements analysis/modelling and requirements validation, ii) requirements documentation and iii) facilitating the requirements management. It focuses on system development methodologies for the human driven ICT solutions that provide communication, collaboration, information sharing and exchange through computer integrated environments for professionals situated in discrete locations but working in a multidisciplinary and interdisciplinary environment. The overview for each chapter of the book is as follows;

Chapter 1 provides an overview by setting the scene and presents the issues involved in requirements engineering and CIE (Computer Integrated Environments). Furthermore, it makes an introduction to the necessity for requirements engineering for CIE system development, experiences and lessons learnt cumulatively from CIE systems developments that the authors have been involved in, and the process of the development of an ideal requirements engineering framework for CIE systems development, based on the experiences and lessons learnt from the multi-case studies.

Chapter 2 aims at building up contextual knowledge to acquire a deeper understanding of the topic area. This includes a detailed definition of the requirements engineering discipline and the importance and principles of requirements engineering and its process. In addition, state of the art techniques and approaches, including contextual design approach, the use case modelling, and the agile requirements engineering processes, are explained to provide contextual knowledge and understanding about requirements engineering to the readers.

After building contextual knowledge and understanding about requirements engineering in chapter 2, chapter 3 attempts to identify a scope and contextual knowledge and understanding about computer integrated environments and Building Information Modelling (BIM). In doing so, previous experiences of the authors about systems developments for computer integrated environments are explained in detail as the CIE/BIM case studies.

In the light of contextual knowledge gained about requirements engineering in chapter 2, in order to realize the critical necessity of requirements engineering to combine technology, process and people issues in the right balance, chapter 4 will critically evaluate the requirements engineering activities of CIE systems developments that are explained in chapter 3. Furthermore, to support the necessity of requirements engineering for human centred CIE systems development, the findings from semi-structured interviews are shown in a concept map that is also explained in this chapter.

In chapter 5, requirements engineering is investigated from different angles to pick up the key issues from discrete research studies and practice such as traceability through process and product modelling, goal-oriented requirements engineering, the essential and incidental complexities in requirements models, the measurability of quality requirements, the fundamentals of requirements engineering, identifying and involving the stakeholders, reconciling software requirements and system architectures and barriers to the industrial uptake of requirements engineering. In addition, a comprehensive research study measuring the success of requirements engineering processes through a set

of evaluation criteria is introduced. Finally, the key issues and the criteria are comparatively analyzed and evaluated in order to match each other and confirm the validity of the criteria for the evaluation and assessment of the requirements engineering implementation in the CIE case study projects in chapter 7 and the key issues will be used in chapter 9 to support the CMM (Capability Maturity Model) for acceptance and wider implications of the requirements engineering framework to be proposed in chapter 8.

Chapter 6 explains and particularly focuses on how the requirements engineering activities in the case study projects were handled by highlighting strengths and weaknesses. This will also include the experiences and lessons learnt from these system development practices. The findings from these developments will also be utilized to support the justification of the necessity of a requirements engineering framework for the CIE systems developments. In particular, the following are addressed.

- common and shared understanding in requirements engineering efforts,
- continuous improvement,
- outputs of requirement engineering
- reflections and the critical analysis of the requirements engineering approaches in these practices.

The premise of chapter 7 is to evaluate and assess the requirements engineering approaches in the CIE case study developments from multiple viewpoints in order to find out the strengths and the weaknesses in these requirements engineering processes. This evaluation will be mainly based on the set of criteria developed by the researchers and developers in the requirements engineering community in order to measure the success

rate of the requirements engineering techniques after their implementation in the various system development projects. This set of criteria has already been introduced in chapter 5. This critical assessment includes conducting a questionnaire based survey and descriptive statistical analysis.

In chapter 8, the requirements engineering techniques tested in the CIE case study developments are composed and compiled into a requirements engineering process in the light of the strengths and the weaknesses identified in the previous chapter through benchmarking with a Capability Maturity Model (CMM) to ensure that it has the required level of maturity for implementation in the CIE systems developments. As a result of this chapter, a framework for a generic requirements engineering process for CIE systems development will be proposed.

In chapter 9, the authors will discuss the acceptance and the wider implications of the proposed framework of requirements engineering process using the CMM from chapter 8 and the key issues from chapter 5.

Chapter 10 is the concluding chapter and it summarizes the findings and brings the book to a close with recommendations for the implementation of the Proposed RE framework and also prescribes a guideline as a way forward for better implementation of requirements engineering for successful developments of the CIE systems in the future.

LIST OF ABBREVIATIONS

AEC	Architecture, Engineering, Construction
ATLAS	Architecture, Methodology and Tools for Computer-Integrated Large Scale engineering
BIM	Building Information Modelling
CAD	Computer Aided Design
CBSP	Component-Bus-System-Property
CIC	Computer Integrated Construction
CIE	Computer Integrated Environments
CIM	Computer Integrated Manufacturing
CMM	Capability Maturity Model
CORBA	Common Object Request Broker Architecture
COTS	Commercial Off the Shelf
DIVERCITY	Distributed Virtual Workspace for enhancing Communication within the Construction Industry
GenCOM	General Construction Object Model
GQM	Goal\Question\Metric
IAI	International Alliance for Interoperability
ICON	Information/Integration for Construction
IDEF0	Integration Definition for Function Modelling
IFC	Industry Foundation Classes
ICT	Information and Communication Technology
JAD	Joint Application Development

OPIS	Object Model-Based Project Information System
OSCON	Open Systems for Construction
R&D	Research & Development
RD	Requirements Documentation
RE	Requirements Engineering
REAIMS	The Requirements Engineering Adaptation and Improvement for Safety and dependability
ROI	Return-On-Investment
RUP	Rational Unified Process
SME	Small and Medium size Enterprises
SOAP	Simple Object Access Protocol
SPACE	Simultaneous Prototyping for an Integrated Construction Environment
STEP	Standard for the Exchange of Product Model Data
TTM	Time To Market
UCDA	Use Case Driven Analysis
UED	User Environment Design
UML	Unified Modelling Language
VE	Virtual Enterprises
VR	Virtual Reality
VRML	Virtual Reality Modelling Language
WISPER	Web-based IFC Shared Project EnviRonment
XML	Exchange Mark-up Language
XP	Extreme Programming

ACKNOWLEDGMENTS

This book has been prepared from the experience and lessons learnt and research outcomes in various CIE developments in Salford such as nD Modelling and DIVERCITY. In every development, soft issues became more and more important. In other words, there has been a transition from testing and demonstrating the concepts such integrated computer environments, building information modeling towards the need of the stakeholders in construction and practicality and scalability of those CIE developments.

As a result, this book is produced from the PhD study by Dr Yusuf Arayici under the supervision of Prof. Ghassan Aouad by looking into requirements engineering practices and experiences in a number of the CIE developments such OSCON, GALLICON, DIVERCITY and nD Modelling to specifically identify a requirements engineering process for the integrated, collaborated, distributed virtual reality (VR) based system and BIM implementations so that this study can contribute for the future CIE systems developments and BIM implementations projects to ensure successful deployments. Therefore, I would like to express our special thanks to the OSCON, GALLICON, DIVERCITY and nD Modelling consortia.

As an academic effort, this book is developed at the School of Built Environment at the University of Salford. We also would like to thank Lynn Williamson who constantly helped us edit the book

FOREWORD

Collaborative working using innovative integrated ICT systems in construction has become a reality as many activities are performed in a distributed manner with the construction stakeholders situated in discrete geographical locations. Computer Integrated Environments (CIE) or contemporarily so-called BIM (Building Information Modelling) is the type of innovative integrated information system that helps to reduce the fragmentation and enables the construction stakeholders to collaborate together in the construction projects. Researchers have raised that the concept of CIE/BIM has been the subject of research for many years but the uptake of this technology has been very limited because of the development of the technology and its effective implementation. Furthermore, the industrialist and researchers conveyed that the networking, collaboration, information sharing and communication will be crucial issues in the future, which can be managed through CIE systems. In order for successful development of the technology, successful delivery and effective implementation of the user and industry-oriented CIE and BIM systems, the requirements engineering is a key parameter.

Requirements Engineering is a branch of systems engineering and it is related to the issues of the development of the CIE technology and its effective implementation. That is to say, it helps what to develop, how to develop and when to implement. Requirements Engineering is concerned with the goals, desired properties and constraints of complex systems such as the CIE systems that involve software systems, organisations, people and process. Furthermore, it covers all activities related to the acquisition, specification and maintenance of requirements throughout the lifecycle. It also covers how requirements

relate to business processes, work redesign, system and software architecture and testing and validation. Therefore, this book is about the development of a requirements engineering process for CIE system development and BIM implementation through case study projects, which presents the mechanism to smoothly and collaboratively conduct the construction projects from early briefing stage to the detailed design stage and even further by the end of the construction phase in construction project lifecycle over an integrated environment.

The Requirements Engineering framework that has been proposed in this book is targeted at the Computer Integrated Environments (CIE) systems. The key features of the requirements engineering framework are the following: (1) ready-to-use, (2) simple, (3) domain specific, (4) adaptable and (5) systematic, (6) integrated with the legacy systems. The method has three key constructs: i) techniques for requirements development, which includes the requirement elicitation, requirements analysis/modelling and ii) requirements validation, iii) requirements documentation and facilitating the requirements management.

In short, this book focuses on the user driven CIE system development methodologies and successful BIM implementation and adoption in the construction industry. Thus, I would like to conclude this foreword suggesting this book as an added value for user led CIE/BIM development and implementation.

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CHAPTER 1: INTRODUCTION

1.1. DEFINITIONS

1.1.1. Computer Integrated Environments

A Computer Integrated Environment is to establish an alliance of enterprises that come together to share skills or core competencies and resources in order to better respond to business opportunities, and whose cooperation is supported by computer networks. It is a manifestation of Collaborative Networks and a particular case of Virtual Organization or Virtual Enterprise.

Collaborative working using innovative Computer Integrated Environment (CIE) systems has become a reality as many activities in multi-disciplinary work environments are performed with the stakeholders situated in discrete geographical locations. Such an ICT (Information and Communication Technologies) system helps to reduce fragmentation and enables the scattered professionals to communicate and collaborate virtually together in synchronous or asynchronous manner.

The concept of CIE has been the subject of research for many years but the uptake of this technology has been very limited because of the development of the technology and its effective implementation. However, professionals and researchers have confirmed that networking, collaboration, information sharing and communication will be significantly more crucial and in demand in the future as conducting business in multi-disciplinary and interdisciplinary environments will be a must for success and sustaining competitiveness. Subsequently, in order for successful development of the technology, successful delivery

and effective implementation of user oriented systems, which require a correct balance between technology, process, organization and people aspects, the requirements engineering has become critically important. The specific features of computer integrated environments or virtual enterprises can be summarized as follows:

- boundary crossing
- complementary core competencies
- geographical dispersion
- complementary nature of the partners
- participant equality
- extensive use of information and communications technology

Over the last couple of decades, there has been a major shift from an industrial economy to that of an information economy. This has led to an enormous increase in competitiveness among companies, and new technology is needed to help capitalize on the information economy. Computer Integrated Environments CIE for Virtual Enterprises (VE) or Virtual Organizations (VO) is a new and major trend in the cooperative business. CIE allows businesses to specialize and be flexible within their environments. In the past, this business model has been applied to outsourcing and supply chains, as well as temporary consortia. Due to the fact that the formation of these virtual enterprises is an intricate process, a new form of technological support has been developed. The most ambitious of the support systems actually intends to automate part of the creation process, as well as the operation of these enterprises (Cardoso & Oliveira, 2005).

As with all types of enterprises, virtual enterprises present both benefits and challenges. Organizations can benefit from virtual enterprises through more economical connections with suppliers, greater opportunities to create revenue, more efficient operations, and a reduction in administrative costs. The challenges facing virtual enterprises are: inexperienced users, security, expense control, and the level of incorporation required to create a successful virtual enterprise (Sun Microsystems, Inc., 2004).

VE challenges the conventional rule for operating an organization. They do so by accomplishing tasks traditionally meant for an organization much bigger, better resourced, and financially stable. A company having the technical capability, one with the right human skill set, the other with the solution, may come together to create a VE. For example, the current situation within the construction industry is that many projects are one-of-a-kind and involve the coordination of practitioners such as designers, engineers and suppliers. A typical construction project consists of a number of organizations and teams that are brought together for the duration of that particular project to form a so-called "virtual enterprise". This enterprise often contains units that are in different physical locations and use different computer platforms and have a need to work collaboratively and to share the same project data (Faraj et al, 2000). Some of the key benefits include but are not limited to:

- Emphasis on collaborative work for the construction stakeholders. The industry currently suffers from a considerable degree of fragmentation.
- Proposed new data exchange standards, such as IFC, for information exchange between the stakeholders.

- Proposed new construction processes, which eliminate non-value adding activities.
- CIEs commonly provide shared access to project information via integration over a central database or a communication layer. This prevents information duplication among stakeholders.
- Claims to provide savings in lifecycle project costs and time.
- Not extensively used in industry and there is little experience on their use.
- They provide VR (Virtual Reality) functions and 4D simulations for decision making processes in order for optimised solutions.

There have been extensive studies in the area of CIE in the last decade such as ATLAS (Greening and Edwards 1995), COMBINE (Augenbroe 1995), RATAS (Björk, 1994), ICON (Aouad et al 1994), COMBI (Scherer 1995), OSCON (Aouad et al 1997), OPIS (Froese and Paulson 1994), SPACE (Alshawi et al, 1996), ToCEE (Amor et al 1997) WISPER (Faraj et al, 2000), GALLICON (Sun et al, 2000), BIDSAVER (http://www.ceconsulting.it/ve/bidsaver.html), ALIVE (Chris et al, 2001), LEGAL-IST (www.legal-ist.org), ECOLEAD (Lavrac et al, 2005)

1.1.2. Requirements Engineering

Requirements engineering is a branch of systems engineering and it is related to the development of the technology and its effective implementation. That is to say, it helps to define what to develop, how to develop and when to implement. Requirements engineering is concerned with the goals, desired properties and constraints of complex systems such as the CIE systems that involve software systems, organizations and people.

Furthermore, it covers all activities related to the acquisition, specification and maintenance of requirements throughout the lifecycle of the software development projects. It also covers how requirements relate to business processes, work redesign, system and software architecture and testing and validation. This process is regarded as one of the most important aspects of building an information system as it is during this process that it is decided what is to be built.

Requirements engineering is also known as systematic requirements analysis (Weigers, 2003). It is sometimes referred to loosely by names such as *requirements gathering*, *requirements capture*, or *requirements specification*. Requirements engineering is critical to the success of a development project (March, 2005). Requirements must be actionable, measurable, testable, related to identified business needs or opportunities, and defined to a level of detail sufficient for system design.

Car (2000) defined the requirements as properties, attributes, services, function, and behaviours, which are needed in a product to accomplish the goals and purposes of the system to be developed. Requirements engineering is an iterative process by which the needs and requirements of individuals and groups significant to the product development are researched and identified. Requirements engineering defines (Cooper et al, 1998):

- Customer, user and market requirements
- Design requirements
- Technical requirements

Maguire (1996) emphasised that adopting a user centred design process leads to more usable systems and products. It reduces the risk that the resulting system will under-deliver or fail. User centred design implies the following:

- Early focus on users, tasks and environment
- The active involvement of users
- An appropriate allocation of function between user and system
- The incorporation of user-derived feedback into system design
- Iterative design whereby a prototype is designed, tested and modified

Numerous surveys have been conducted which conclude that project failures are caused by a lack of proper attention to requirements processes. A survey, which was undertaken by The Standish and Gartner groups, reports that only 26% of software projects are considered successful and 74% are unsuccessful.

When detailing the causes of success or failure, the most frequent area is the subject of user requirements (Eberlein, and Leite, 2002). The CHAOS development report published in 1995 and 2000 by the Standish group showed that almost half of the projects failed or were cancelled due to the lack of requirements engineering effort. The main reason for project success for a similar percentage of projects was ascribed to good requirements engineering (Eberlein and Leite, 2002).

Another survey by McPhee (2002) showed that senior software developers and project managers believe that the requirements activities should account for 25% of the total development effort. This was the outcome of the survey although the survey focused on

the projects that had a critical time for delivery to the end users. As a result, this survey clearly proves that requirements engineering is crucial in systems development. Understanding the users' real requirements is absolutely critical to the development of successful information systems.

To achieve a user-oriented and a high level quality of system, it is important that the user requirements must be captured and modelled in the right way. If done correctly, the system to be developed will meet the user needs and lead to better user satisfaction and implementation. On the other hand, if the user requirements activities are done poorly, the software is less likely to meet the user requirements, even if the software conforms to the requirements specifications developed.

1.2. WHY REQUIREMENTS ENGINEERING IS NEEDED FOR THE CIE DEVELOPMENT

CIE is an important solution for the integration of the processes through the supply chain. Research has emphasized some of the benefits of integration such as reducing the project lifecycle and cost, removing the non-value added activities for achieving lean processes and production, encouraging collaboration and increasing client satisfaction (Sun & Aouad, 2000). For example, the construction industry is of a multi-disciplinary, traditional and fragmented nature, which results in many different issues and bottlenecks such as lead time, lack of buildability, increased cost, unsatisfied clients, inefficient documentation and many more. These challenges can be overcome by implementing CIE systems. However, people in the industry have little awareness of how to use such

systems effectively in their work environment because of unfamiliarity with such systems; this results in a gap between the developers of CIEs and industrialists.

One route to developing more user-centred systems is the use of appropriate systems development methodologies, which are appropriate to the CIE systems. However, there is currently little debate within the research community as to what the characteristics of a CIE systems development methodology should be.

To date, CIE researchers especially within the construction industry have had little focus on the requirements engineering in systems development, which is actually necessary to develop the user-oriented and more practical CIE systems. Despite the increasing interest by both academia and practitioners in CIE, there is little research to identify the best practices in requirements engineering. On the other hand, according to the Vision reports published by Sarshar (2000 and 2002) and Aouad (et al, 1998), communication, networking, integration and information sharing will be major issues over the next ten years in the construction industry. The increasing trend towards the implementation of BIM (Building Information Modelling), which enables information sharing, collaboration and interoperability, will make the uptake of the CIE systems inevitable for the construction industry.

Some countries such as Finland and Denmark have brought up new legislations for BIM implementation. This has already led to the compulsory use of BIM based computer integrated environments in construction projects in those countries. It is believed that

these legal requirements will soon be in place in other countries including the UK for the implementation of BIM based computer integrated environments as a result of moving towards a knowledge economy. Consequently, requirements engineering will be vital for the successful development of the CIE technologies for virtual enterprising such as BIM based computer integrated environments for the construction industry. Employing appropriate requirements techniques will provide the following benefits:

- More practical CIE systems
- Increased usability and ease of use
- Configurable systems
- Flexible and scalable systems
- Contribution towards closing the gap between the practitioners and the researchers
- Contribution towards increasing the uptake of CIEs by the industrialists
- Support for the business processes modelling and the product modelling

Requirements engineering techniques and methods can vary according to the nature, structure and size of the system development project. In other words, while a requirements engineering technique works well for a kind of software system development, the same method may not work well for another type of system. Therefore, it is necessary to define a RE (Requirements Engineering) method that is targeted at software systems for computer integrated environments. The method should provide a standard template of the requirements engineering process that is applicable to all different CIE systems developments. Therefore, requirements engineering will be addressed in this book with a particular focus on the following issues

- Ascertain the level of awareness about requirements engineering in the CIE community and justify the need for the identification of a requirements engineering framework.
- Gain a deeper understanding of the requirements engineering concept in system development.
- Evaluation of the requirements engineering approaches explored
- Elaboration of the requirements engineering approaches in the case study developments
- Analysis and evaluation of experimented requirements engineering approaches in the case study projects.
- Mastering a requirement engineering approach for future CIE system development based on the analysis and evaluations
- Validity and implication of the mastered RE framework for future studies and CIE developments.

1.3. HOW THE REQUIREMENTS ENGINEERING APPROACH IS FORMULISED

Once contextual knowledge about requirements engineering and computer integrated environments is built in the book, it is then followed with the identification of the assessment criteria for the requirements engineering approaches. In order to extract the key issues of requirements engineering, discrete research studies that approach requirements engineering from different angles are investigated. In order to set up associations between the key issues and the characteristics of a RE process in a CIE development. , the relevance and suitability of these key issues for CIE systems development are also considered and discussed.

In order to measure the success rate of the RE processes under evaluation the book then explains an instrument to evaluate or assess the requirements engineering processes. This

leads to analysis of the key issues and criteria through a benchmarking process between the key issues and the criteria. Such analysis enables confirmation of the validation of both the key issues and the criteria by establishing categories, sub-groups, relationships, and possible dependencies (Hammersley and Atkinson, 1983). Figure 1.1 shows the coherent relationships between the groups.

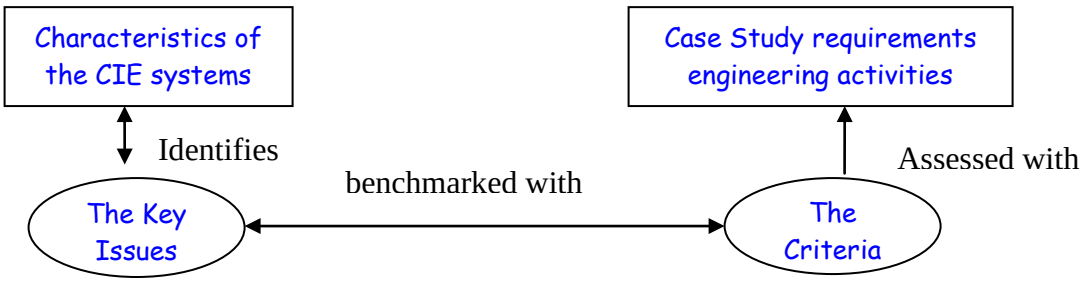

Figure 1.1: Criteria development to assess the requirements engineering experiences

The criteria specified in the book are designed to measure the success of the requirements engineering processes after the implementation of the RE processes in system developments. Therefore, using the criteria for the assessment of the requirements engineering activities in the case studies is more appropriate than the key issues. However, the key issues will be used as part of the validation process of the Proposed RE Process at the end.

After the criteria are benchmarked with the key issues, the requirements engineering carried out in the case study projects is analysed to explore the strengths and the weaknesses according to these criteria. From the analysis of the case studies, strengths and weaknesses, and any problems in the requirements engineering approaches adopted in the case study, projects are clearly identified. The process is then enhanced to cure the weaknesses and provide a ready-to-use, simple, adaptable, systemic, domain specific

requirements engineering process for the future CIE developments. The enhanced requirements engineering framework is validated before proposing it to the CIE community. Because the empirical validation is not possible currently, only theoretical validation is conducted comprehensively. For the empirical validation, the framework should be implemented in a CIE development project. It is done in two steps; internal validation and external validation.

Internal validation is done against the key issues to be explained earlier in chapter5 of the book. The use of the key issues are more appropriate than the criteria for the internal validation because the criteria are designed to measure the success of the requirements engineering process after the implementation while the key issues are actually designed to improve the requirements engineering process before the implementation of the RE process. Lastly, making use of the key issues for internal validation will allow the setting up of a coherent relationship and a good balance between the stages of the research methodology. This is depicted in figure 1.2 below.

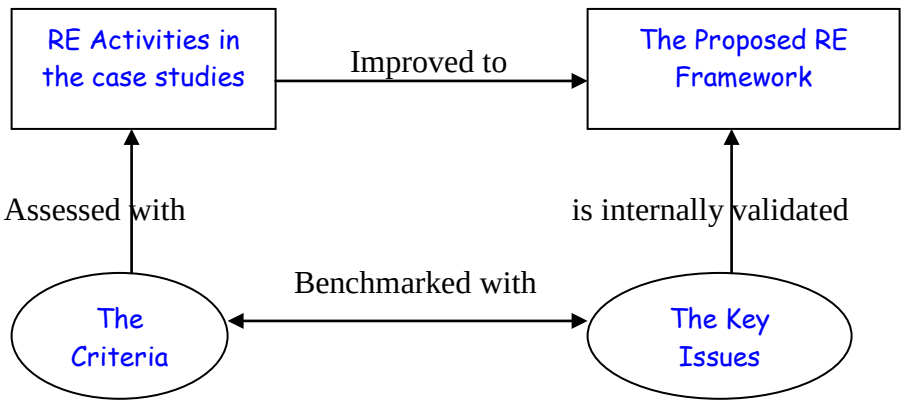

Figure 1.2: interrelations between requirements engineering aspects in the development of the ideal RE framework for CIE systems development

The figure denotes the evolution of the development of the proposed RE framework: The association between the key issues and the criteria are established through benchmarking analysis. After the critical analysis and elaboration of the requirements engineering activities in the case studies, the association between the criteria and the case study requirements engineering activities is established in order to evaluate, analyse and measure the success of the requirements engineering processes in the case studies. Based on this evaluation and analysis, a further association is established between the requirements engineering activities in the case studies and the Proposed RE Framework. A final association is established between the key issues and the Proposed RE Framework to enable internal validation.

External validation is conducted through benchmarks against the external assessment models. Two different models are used for the external validation. The REAIMS assessment model (Sommerville and Sawyer, 1997), which is a capability maturity model, and project risk factors determined by Keil (et al 1998), Carr (2000) and CHAOS survey (Standish group, 1995 and 2001).

Lastly, the validated requirements engineering process is recommended to apply to the CIE development projects or applied to the framework of the previous CIE systems to realise what has been underperformed in these developments in regard to requirements engineering.

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