DIGITALLY ENABLING THE CONSTRUCTION VIRTUAL ENTERPRISE

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Dedication

For my parents.

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Acknowledgements

Acknowledgement is due to my colleagues from the OSMOS consortium; and to the members of staff and managers at Granlund, OTH/Derbi, and JM, for taking part in the surveys.

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Declaration

The thesis contains some material that the author has used before, and that has been published in the following refereed conference papers:

Wilson, I.E., and Vakola, M., (2002) Open Road: Proposing a Migration Path to the Digital Construction Virtual Enterprise, in *Towards a European Knowledge Economy in the Construction and Related Sectors,* Proceedings of the eSM@RT 2002 conference, University of Salford, UK, 18-21 November, pp.204-215.

Vakola, M., and Wilson, I.E., (2002) The Challenge of Virtual Organisation: Critical Success Factors in dealing with Constant Change, in *Towards a European Knowledge Economy in the Construction and Related Sectors,* Proceedings of the eSM@RT 2002 conference, University of Salford, UK, 18-21 November, pp.264-275.

Wilson. I.E., and Rezgui, Y., (2002) Toward the Digital Construction Virtual Enterprise, in Proceedigns of the 10th European Conference on Information Systems, Gdansk, Poland, 6-8 June, 2002, pp.686 – 695.

It is also based on a central case study, the OSMOS (IST-1999-10941) project, which was a joint research effort. It should be noted that the author's individual contribution to the research in Chapter 5, section 5.3 was limited to some minor interface design and much of the material in Chapter 5 has been previously published in the following refereed journal paper:

Wilson, I. E., Harvey, S., Vankeisbelck, R., and Kazi, A. S., (2001) OSMOS: Enabling the Construction Virtual Enterprise. *Electronic Journal of Information Technology in Construction*, 6 (special issue). Available at http://www.itcon.org

The Researcher was involved in the OSMOS project throughout its complete lifecycle. He led all of the human and organisational aspects of the project including the validation and testing (WP4), took a prominent role in the requirements capture and modelling phases (WP1, WP2), and had a contributory role in all other aspects of the project.

Abbreviations

API	Application Programming Interface
BPR	Business Process Re-engineering
CAD	Computer Aided Design
COM	Component Object Model
CORBA	Common Object Request Broker Architecture
DBMS	Database Management System
EDMS	Electronic Document Management System
FM	Facilities Management
GVEPM	(OSMOS) Generic Virtual Enterprise Process Model
HTML	Hypertext Mark-up Language
HTTP	Hypertext Transfer Protocol
ICT	Information and Communication Technology(ies)
IDEF0	Integrated DEFinition for function modelling
JVM	Java Virtual Machine
KM	Knowledge Management
LAN	Local Area Network
OSMOS	Open System for Inter-enterprise Information Management in Dynamic Virtual EnvirOnmentS
RMI	Remote Method Invocation
RPC	Remote Procedure Call
RTD	Research and Technology Development
SME	Small to Medium Size Enterprise(s)
SOAP	Simple Object Access Protocol
UML	Unified Modelling Language
WAP	Wireless Application Protocol
WIB	Web Information Browser
WSDL	Web Services Description Language
WP	(OSMOS) work package
XML	eXtensible Mark-up Language

Abstract

The construction industry is highly fragmented, consisting of a large number of very small companies that come together as members of non-collocated teams to complete building projects, and who subsequently may never work together again. The industry still faces various challenges in terms of human and organisational issues. The Virtual Enterprise (VE), and other variations of the paradigm, relies on networking organisations as elements forming an alliance or aggregation towards some specific purpose or opportunity. Rather than the VE being a completely new organisational form, the construction industry has adopted many of its characteristics in its *modus operandi* for some considerable time. The construction industry does not operate *effectively* as a VE and in consequence faces many problems. These problems could be addressed by the development of ICT solutions geared towards digitally enabling the VE.

The success of collaborative work, and the successful design and uptake of such ICT tools to support that work relies not merely on the introduction of different technologies, however, but also on critically analysing 'human' aspects of organisation. Using applied research and drawing on a central case study in which a VE solution was developed, tested and evaluated in the context of 'real world' scenarios, the thesis addresses the socio-organisational aspects of technological intervention and seeks to answer four research questions dealing with the above. The main results include recognition that whilst ICT are advanced enough to offer adapted solutions to digitally enabling the construction VE, the technology alone is not sufficient. The construction industry is not yet ready to move to an approach employing latest ICT development, due to the need to manage human and organisational issues central to technological intervention. The thesis finally offers business recommendations highlighting and mapping the critical human and organisational decisions that need to be considered.

Chapter 1
Introduction

Background; Aim and objectives; Methodology; Scope and focus of the research; Background and contribution of the researcher; Structure of the thesis; Conceptual model of the thesis

1.1 Background

Construction is the largest industrial sector in the EU. As such it is also the largest employer, and every job in construction engenders further jobs in other sectors. It is characterised by non-collocated teams of separate firms who come together for a specific project and may then never work together again. Furthermore, there is generally no dominant actor to enforce ICT solutions for the team, information exchange is not normally contractually controlled, and the industry is project oriented with all actors being involved in numerous projects concurrently. Both organisations and individuals participating in construction teams bring their own unique skills, knowledge and resources to the projects, including proprietary and commercial software applications.

Current ICT solutions employed on construction projects tend to be fixed rather than open, and frequently lack support (see Section 2.4.6 below). Recent research (Vakola, 1999; Zarli *et al,* 1998) has shown that the solutions in use present characteristics including that they are often prohibitively expensive particularly for small to medium size enterprises (SME), (of which there are quite literally thousands in the sector – see Section 2.4), and offer only limited growth paths in terms of hardware and software. Moreover, there is often a requirement to organise the enterprise around the adopted technological solution (Rezgui, 2001). Within this context the industry still faces various challenges in terms of working practices including communication, information exchange and management, co-ordination of interactions between actors in dynamic business relationships, and co-operation in planning and scheduling resources in non-collocated teams.

The sector is in need of tools and infrastructures that support co-operation between geographically dispersed teams. Such infrastructure should give construction project participants increased flexibility and effective access to project information regardless of its form, format, and location. Given the above, the construction industry operates in effect as a virtual enterprise (VE), yet it does not do so in an efficient manner. The theme of the thesis therefore is to research the possibility of providing digital support for the industry in the context of a VE.

1.2 Aim and objectives

The thesis seeks to answer one main research question, and three subsequent supporting and scoping questions:

1. Is the construction industry ready to move from a paper-based approach to collaborating and sharing information on projects, to an innovative model-based approach making use of the latest development in ICT?
2. Is the technology advanced enough to offer adapted solutions to the very characteristics of the construction industry?
3. Is the technology on its own able to provide a solution to the needs and aspirations of construction end-users?
4. Given the characteristics of the construction industry, does the industry require a new business model in relation to the purchase of ICT offering an affordable and profitable solution for SME and Clients on projects?

In order to answer these questions, the research methodology employed endeavours to satisfy the following eight objectives of the thesis:

1. Clarify the concept of a Virtual Enterprise.
2. Understand the current practices, limitations and barriers, in organisations and on projects in the construction industry.
3. Provide a high-level process specification supporting ICT-based inter- and intra-company collaboration and communication in the construction industry.

4. Provide a Conceptualisation supporting the high-level process specification of Objective 3.
5. Monitor / Orchestrate and provide useful contribution towards the development of a proof of the concept of Objective 3.
6. Deploy the proof of concept implementations into real end-user scenarios.
7. Test and validate the resulting proof of concept prototype deployment.
8. Analyse the outcome from the evaluation of the prototype and elaborate business recommendations.

1.3 Methodology

The research contained within this thesis is first and foremost applied research. The main research question, in seeking to consider whether or not the industry is 'ready' to move from its current methods of working to an approach that utilises latest ICT developments, implicitly addresses the 'soft', people issues, as it is humans within their organisational context(s) who carry out the work. The research is therefore also socio-organisational, as the primary focus in the main research question concerns the human and organisational aspect of technological development in a 'real world' context. The starting point of the methodology is a literature review that focuses on three main elements: organisational theory, the VE, and the European construction industry.

The methodology is driven by a central case study, which provides the test bed for the ICT solution sought to enable the construction VE. This case study is the recently completed OSMOS (Open System for Inter-enterprise Information Management in Dynamic Virtual Environments) project, funded by the European Commission under the IST programme (IST-1999-10491). This case study is supported by two related IST projects – the ICCI and VOSTER cluster projects – both of which are ongoing at the time of writing. The OSMOS project adopted an action research approach and followed an iterative and incremental development cycle.

A flexible design is used to gather primarily qualitative data, though employing a triangulation approach, and as the focus is applied research the methodology incorporates field trials to test and evaluate the proposed solution in the case study.

1.4 Scope and focus of the research

The scope of the research is encapsulated in the main research question, thus combining human and organisational issues with technical development as explained above. The thesis is focused on primarily the human and organisational (i.e. 'soft') issues, the procedures employed in modelling the organisations prior to development of the technology, and the testing and evaluation of the overall approach taken and the tools and systems developed.

The research for the thesis has been carried out primarily in the OSMOS project and is therefore constrained by the lifespan of that project though the two cluster projects are ongoing and serve to add to and enrich the research results from OSMOS and the literature.

The nature of the proposed solution under investigation is such that it could result in introducing change, not mechanistically, but in terms of people; introducing changes that may directly affect the way people work and potentially changing their world view. Imposed changes are difficult for people to accept and readily adopt, thus, as this research is pragmatic in nature, a participatory methodology was seen as one with a far greater chance of success, and thereby offering the possibility of more meaningful results in terms of a 'real world' context than a machine-minded approach would offer.

1.5 Background and contribution of the researcher

The Researcher was originally trained as a cartographer, and was employed for six years, initially with Ordnance Survey – the UK national mapping agency – and subsequently with BP Petroleum Development Ltd. He then spent ten years in business, primarily in financial services. Since graduating in 1999 with a first class honours degree in Information Technology, he has been employed as a researcher working on the OSMOS, ICCI and VOSTER projects.

The Researcher took a leading role in the OSMOS project, contributing throughout the complete project lifecycle. The main role was leading all of the human and organisational aspects including the validation and testing of the solution, with a prominent role in the requirements capture and modelling phases. In the ICCI cluster the Researcher is involved in all stages of the project throughout its duration, and is leading the human and social issues work. The Researcher is also involved in all stages throughout the project lifecycle of the VOSTER cluster.

1.6 Structure of the thesis

Chapter 2 – Research context and background review: this chapter presents an in-depth, critical, literature review for the study. The literature selection is based on the overall aims of the thesis as outlined above, and reviews the relevant aspects of organisational theory, the VE, and the European construction sector.

Chapter 3 - Research methodology: this chapter includes a review of the principles of research, a description of the derivation of the research questions for the thesis, and the chosen methodology, including the methods and survey instruments developed to collect the necessary data.

Chapter 4 - Business process modelling: this chapter presents the high-level modelling carried out in the requirement capture phase of the thesis case study (the OSMOS project). It presents the method employed to capture and analyse current processes, and presents in detail the resultant VE process model.

Chapter 5 – Proposed VE solution: this chapter presents the proposed construction VE solution realised within the case study. It includes an in depth description of the methodology and outcomes for the specification of the proposed solution, and details the prototype developed from this specification.

Chapter 6 – Results: this chapter presents the results from the various surveys described in Chapter 3. It includes results from the questionnaire survey, interviews and field trials held within the case study project. The field trials test and evaluate the VE prototype described in Chapter 5, and the underlying models and concepts from Chapter 4.

Chapter 7 – Discussion: this chapter draws together all of the elements from the preceding chapters to enable the research questions to be answered. It includes a review of the problem and the VE concept as applicable to the research, discussion and synthesis of the results from Chapter 6, discussion of the potential benefits of adopting the proposed approach, elaboration of business recommendations, and presentation of a 'real world' exploitation of some of the concepts.

Chapter 8 – Conclusion: this chapter concludes the thesis. It includes a section addressing the answers to the research questions, the contribution of the thesis, limitations of the research, and suggestions for possible future research.

There are 5 appendices for reference, which contain copies of the survey instruments developed and used within the research methodology.

1.7 Conceptual model of the thesis

In order to facilitate understanding of the structure of the thesis, and to give the reader an easily accessible, high-level, overview of the methodology employed to satisfy the aims and objectives of the study, Figure 1 below depicts a 'conceptual model' of the thesis in diagrammatic form.

Any meaningful research study involves a circular relationship with the body of extant knowledge in a given domain. This is depicted in Figure 1 by the bold arrows (top and bottom) indicating that the literature review draws from the body of knowledge, and ultimately, in answering the research questions the thesis in turn should contribute to the body of knowledge.

The central case study of the thesis (OSMOS) is depicted as drawing on the literature review itself. In terms of the Researcher's involvement in the case study, and contribution to the body of knowledge via this thesis, the input from the literature review was primarily concerned with grounding the human and organisational aspects needed within the requirements capture, processes, and evaluation and testing elements.

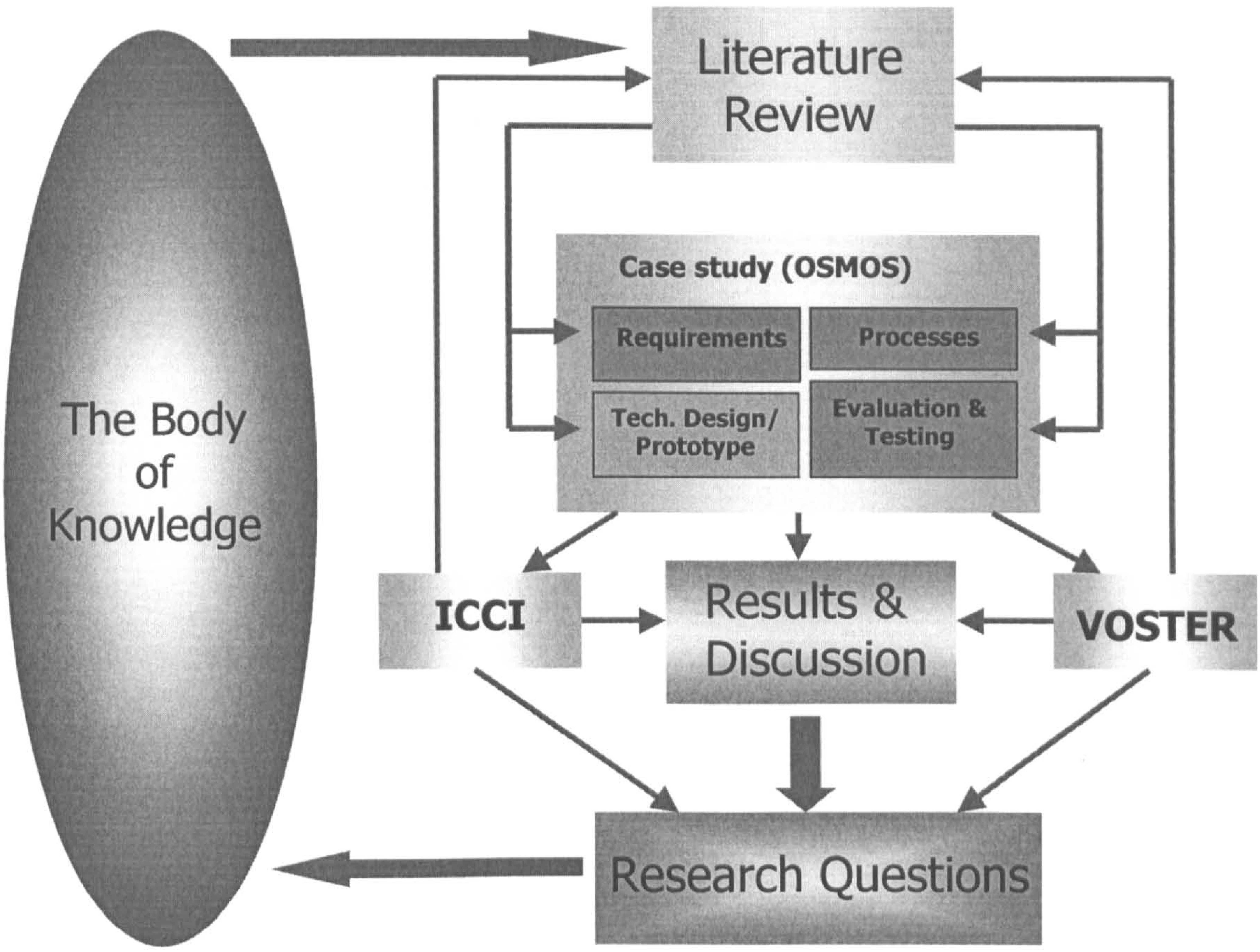


Figure 1: Conceptual model of the thesis

As the OSMOS project is a member project in ICCI and VOSTER, it feeds forward to these supporting case studies, and together, all three contribute to the results and discussion chapters of the thesis. (As ICCI and VOSTER are ongoing at the time of writing, the results from these case studies also contribute to the literature review for the thesis). It is from the results and discussion (with ongoing support from the supporting case studies) that the research questions are answered, and from the answers the thesis in turn contributes to the body of knowledge.

Chapter 2
Research Context and Background Review

> *Review of organisational theory; Review of the Virtual Enterprise; Review of the European construction sector.*

2.1 Introduction

The overall driver of this thesis is the research question querying whether or not the construction industry is ready to adopt latest technological developments in place of current working methods. By its very nature this question demands the study not only (nor indeed *primarily*) of the technology, but also the nature of the industry, the ways in which people and organisations work together, and so on; in short the 'human' aspects involved in technological change. This chapter presents an in-depth, critical, literature review for the study; an essential phase in the research process allowing the researcher to delimit the problem under investigation (Patton, 1990). The literature selection is based on the aim and objectives of the thesis as outlined in Chapter 1. It begins with a review of pertinent aspects of organisational theory: firstly viewing the organisation as a system and highlighting the structure, culture and processes attributes; secondly reviewing business management levels and change management issues, highlighting the human factors relevant to technological intervention; and thirdly reviewing the theory and concepts behind teamwork. The following section reviews the literature regarding the 'Virtual Enterprise' (VE), including clarification of the concept, a view of VE types and the VE lifecycle, and emphasizing the key characteristics of the paradigm. The European construction sector is then examined, initially addressing its definition and context; this is followed by a review of business processes and re-engineering; an examination of the use of ICT in the industry; current ICT best practice; and a short review of available commercial ICT solutions to the construction industry; finally, after summarising the important characteristics of the sector, the construction industry as a VE is addressed.

2.2 Review of organisational theory

The success of collaborative work, and the successful design and uptake of ICT tools to support that work relies not merely on the introduction of different technologies, but also on critically analysing the 'human' aspects of organisation, as it inevitably leads to changes that people either accept or resist (see for example Moniz and Urze, 1999; Grudin, 1991; Cugini *et al,* 1999). Equally, the VE, being a temporary alliance of organisations, requires the beneficial amalgamation of differing organisations, each with its own characteristics. This section therefore draws on the large body of research that has been carried out in relation to organisational theory.

2.2.1 The organisation as a system

It is widely agreed that the approach of viewing an organisation as a system offers insights into its workings (Robbins, 1987). This approach views the organisation as a whole, but also within a larger environment (Burnes, 1996), and as an open system having multiple channels of interaction (Mullins, 1993). Figure 2 depicts the organisation as a system that receives inputs from, and produces outputs to, its environment (Senior, 1997).

Commonly within organisations there are two main sub-systems – the formal and informal sub-systems. (Miller, 1967), however, argues that there are four principal sub-systems: the organisational goals and values sub-system, the technical sub-system, the psychosocial sub-system, and the managerial sub-system. Nonetheless, these sub-systems are subsumed in the bounds of the two depicted in Figure 2). Detailed descriptions of the processes and protocols within the formal sub-system of an organisation are often readily available, and apparently accepted and understood. The informal sub-system, however, is generally less well understood, and yet often has more influence on the organisation than is recognised at face value. It is clear from Figure 2 that the major aspects of each sub-system are *human* in nature. Indeed it is the people, who define any business organisation, whether it is a large multi-national company, or a small/medium size enterprise (SME).

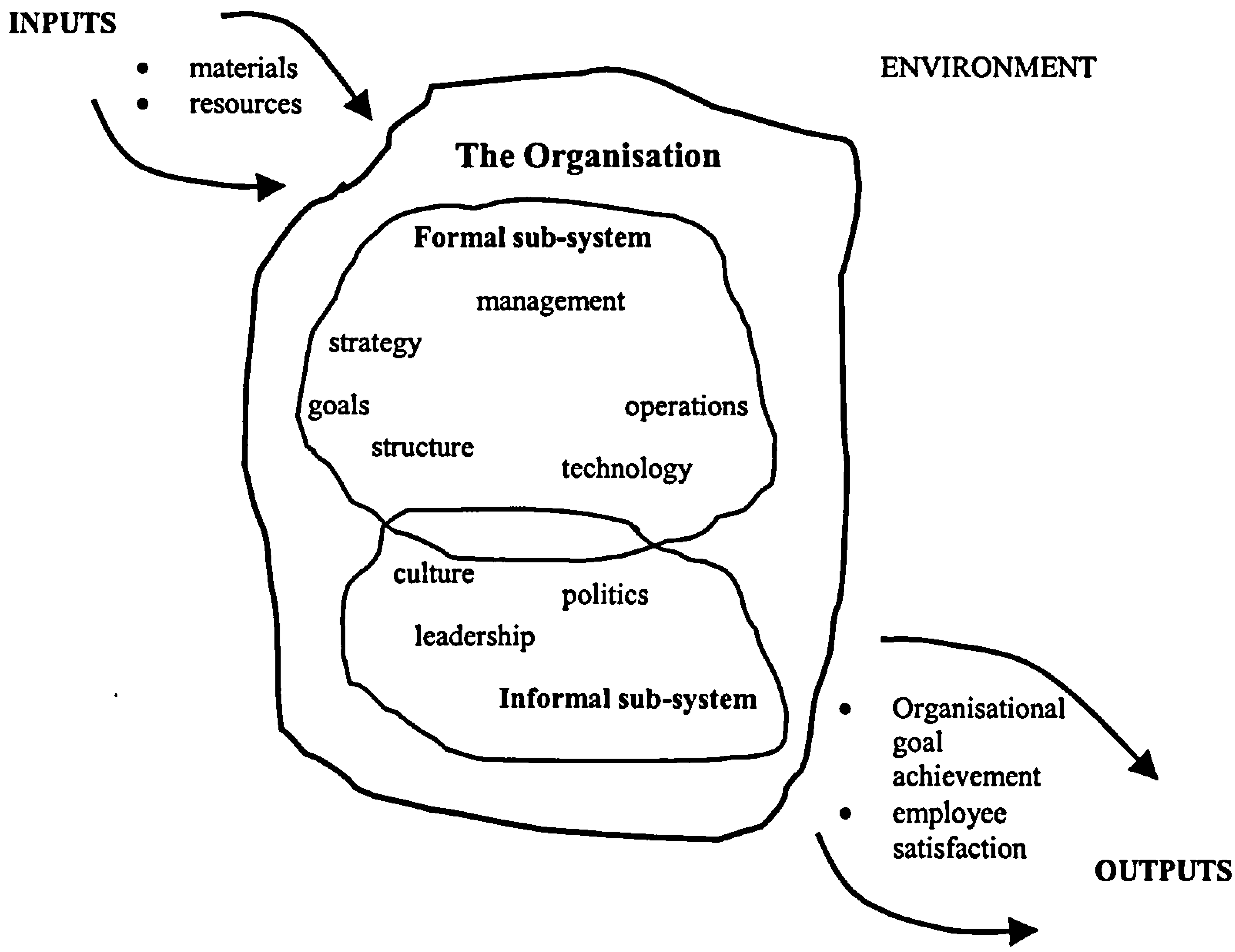


Figure 2: The Organisation as a System (Senior, 1997)

The development of organisational theory has evolved through varying approaches: classical, human relations, and contingency theory (Burnes, 1996). Various approaches have also been made to modelling enterprises, (Nadler, 1980; Harrison, 1994; Rüegg-Stürm 2001) according to different theoretical bases (including computer science, systems theory, production management, organisational management), and to different application areas (information system design, business process reengineering, etc.) (Chen *et al.*, 2002). In the St. Gallen Management Model (Rüegg-Stürm, 2001), which views enterprises from an organisational management perspective, the organisation has been modelled as a *complex* system:

- Manifold and not immediately apparent relationships and interactions exist between the system's elements;
- Due to the 'idiosyncrasies' of, and various feedback effects between the system's elements, these relationships and interactions are in a state of continuous and only marginally predictable development;

- Results 'emerge' from these relationships and interactions (i.e. the systems behaviour): they cannot be traced back to the behaviour of individual elements in any way, but originate in the interaction of the system elements and depend principally on particular patterns of ongoing interaction (Rüegg-Stürm, 2001:4).

Modelling organisations has allowed better understanding of behaviour through observation, description and analysis, yet the complexity of an organisation (from such a systems perspective) indicates that the ability to predict behaviour is fairly limited, and equally so is the possibility to design or operate the organisation in a purely mechanistic fashion.

Figure 3 depicts the 'core' of the organisation from a strategic and functional perspective.

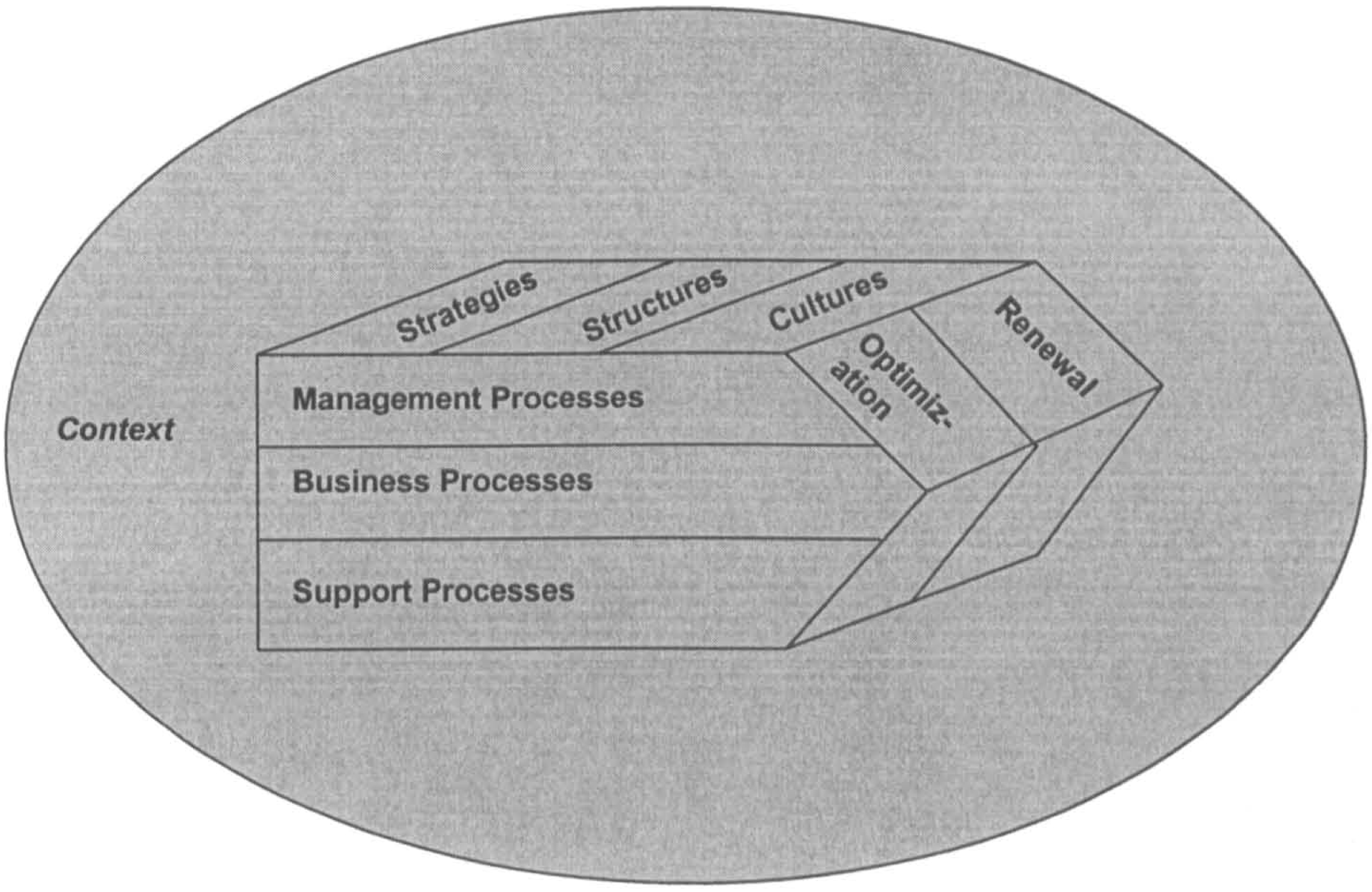


Figure 3: Core of the model of the firm ('model core') (Rüegg-Stürm, 2001)

The model is included here to aid understanding the orientation and workings of the organisation within its context, and not as a normative endeavour. It depicts three principal dimensions within the organisation:

The first views the organisation from a process perspective (*management*: e.g. orientation, strategy development, operations; *business*: e.g. market development, supply chain management, innovation; *support*: e.g. human resources, finance, information and IT, legal, etc.). Processes are an integral part of an organisation's added value, recognised in Porter's (1985) primary and supporting activities within the 'value chain'. The importance of analysing processes has gained increased prominence, however, with the increase in the use of ICT, and the advent of business process re-engineering (BPR) (Hammer and Champy, 1993; Davenport, 1993). A horizontal, process view of the organisation, as opposed to the traditional vertical view – around discrete functions such as purchasing, warehousing, production, personnel, etc. – with planned interventions in the organisation's process, are now seen as key to organisational development (Schnitt, 1993; Beckhard, 1969).

The second dimension views the organisation from the perspective of strategies, structures, and cultures. The strategy of an organisation is the directing function of corporate activity in order to determine success – repeatedly 'doing the right things' (Drucker, 1967). The structure of an organisation then provides the co-ordination across and within processes, to ensure that things are done in the right way. The culture of an organisation embodies the common sense of purpose, which may "find expression in a strong, explicitly stated or implicit vision and a harmonious collective identity" (Rüegg-Stürm, 2001:7). Charles Handy (1999:183-191) observed four main types of organisational culture, which he related to particular organisational structures:

- **Power** culture: frequently found in small entrepreneurial organisations such as occasionally in trade unions, and in some property, trading and finance companies. This culture is associated with a web structure, which depends on a central power source exercising control.
- **Role** culture: is often stereotyped as bureaucracy, and works by logic and rationality. It stresses the importance of procedures and rules, hierarchical position and authority. This culture is associates with an hierarchical (Greek temple) structure, with the role, or job description, often being more important than the individual who fills it.
- **Task** culture: is job or project oriented, 'team' culture, where influence is based more on expert power than on position or personal power. The focus

is on getting the job done rather than strictly prescribing how it is done. Its accompanying structure can be represented as a net, the so-called 'matrix organisation' being a structural form of the task culture.

- **Person** culture: this is unusual and does not pervade many organisations. The individual is the focus of this culture, with a minimal structure that allows groups of individuals to work together if they decide it is in their own interests to do so. Its accompanying structure is a 'cluster', like a galaxy of individual stars.

The culture of an organisation is particularly important in instances of technological intervention, as it is critical to success in organisational change (Section 2.2.2.1). It represents the basic assumptions, values and norms of an organisation's members (Schein, 1990), and as organisations are societies in miniature showing their own cultural characteristics (Silverman, 1970), culture, rather than structure, strategy or politics, is the prime mover in organisations (Deal and Kennedy, 1982).

The third dimension views the organisation from the perspective of development and change, in which evolutionary, incremental phases alternate with more revolutionary phases, i.e. phases of continual optimisation might be followed by a phase of fundamental renewal and transformation (Rüegg-Stürm, 2001).

2.2.2 Business management levels and change management

Conventionally, organisational management, control, and information needs differ in their emphasis according to management levels within an organisation. Three general levels have been defined, which are attributable to Robert N. Anthony (1965), and despite recent trends towards 'de-layering' (for example in large organisations such as public utilities), a similar management hierarchy is common throughout organisations. Figure 4 depicts these levels of business planning. The Strategic level concerns long term planning and decisions made by managers at the top of the organisational hierarchy such as directors. The Tactical level concerns medium term activities at the level of, for example, heads of departments and middle level managers.

Figure 4: Levels of business planning (after Anthony, 1965)

The Operational level is the level at which the organisation's operations occur, and day-to-day planning and decisions are involved. It may therefore generally be taken, *ipso facto,* that those people at the 'strategic' level institute organisational change.

Change in organisations has been studied in depth from an academic perspective (see for example Beckhard and Harris, 1987; Burnes, 1996; Cummings and Worley, 1997; Senior, 1997). Organisations today are facing more changes than ever before, both at a radical, organisational level, and on an ongoing basis (respectively, renewal and optimisation in Figure 3 above). Throughout the 1990s managers have implemented numerous change initiatives to improve competitive advantage, including total quality management, just-in-time, business process re-engineering, team working, reorganising, downsizing, etc., and the implementation of new technology has been both a reactive and proactive measure apropos them. Ostensibly, the causality of such developments lies in the move from vertical, bureaucratic organisational forms, which are suited to conditions of environmental stability with predictable tasks, towards conditions of uncertainty, complexity and instability (e.g. Johnson *et al.*, 2001). Indeed, at a revolutionary level it is believed that in order to increase competitiveness, organisations need to become smaller (Handy, 1989; Peters, 1993), whilst simultaneously globalisation of trade, finance and production, along with rapid technological change, have been exemplified by some as causes of such uncertain conditions (e.g. Waters, 1995).

The literature relating to the management of change in organisations, points out that key guarantors to successful change include commitment, involvement and shared perception (McCalman and Paton, 1992). It is clear that all organisations, and indeed each part of an organisation, has a culture, a structure, and systems that are appropriate to that culture (Handy, 1999). Equally, individuals who work in an organisation differ and have their own cultures. Figure 5 shows how various cultural elements may influence organisational change.

Clearly, elements of organisational culture might support change, or on the other hand put up defences against change. Academics and practitioners have analysed the concept of resistance to change, at both an individual level, where employees often feel uncertainty about their future, are concerned with potential loss of territory and feel fear of failure related to new expectations and tasks, and at a 'team' level. A combination of personality factors such as the need for control, or authoritarianism, and previous bad experiences in change, are related with high levels of resistance to change (Wanberg and Banas, 2000; King and Anderson, 1993). Apart from individual and group factors, organisational factors such as organisational structure, climate, culture and strategy also contribute to levels of resistance (Child, 1984). It can be argued, however, that though resistance to change is considered to be problematic, it can become a tool for change management.

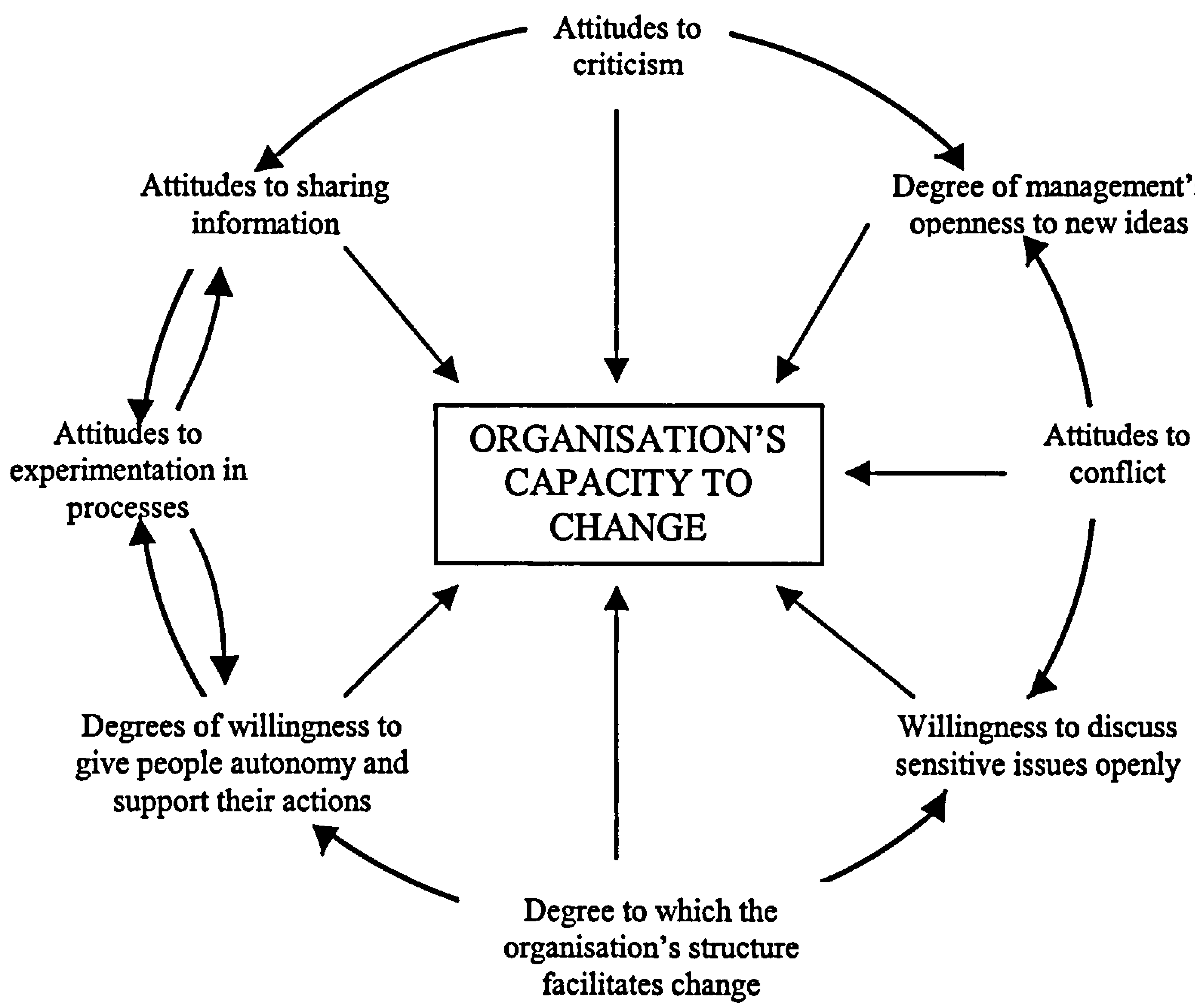


Figure 5: Organisational culture and change (Senior, 1997)

Beckard and Harris (1987) analysed a three-phase model indicating that complex organisational change can be conceptualised as a movement from the present state to a future state, the most important phase being the transition state, in which analysis is made to bridge the gap. As a result, change is a matter of assessing the current situation, developing the right strategy and vision and designing the change process.

2.2.2.1 Human factors in technological intervention

Much of the interest in change management has arisen from the introduction of technologies in organisations, not least due to the early fears inherent in the concept of 'technological determinism' (see Winner, 1977; Dubos, 1968). It is now clear, however, that designing new systems, which *people* will use, without analysing their roles and the organisational culture, is a recipe for failure. It would be unconscionable to contemplate driving a car without ensuring there is sufficient high quality oil in the sump, because the oil is the lifeblood of the engine without which the engine is simply a collection of individual pieces of technology. The lifeblood of an organisation is its people, thus in order to expedite acceptance of new technologies, the human factors should not be ignored. To this end, the process of technology development has, increasingly, to be user-centred. Much work has been documented with regard to human-computer interaction (Shneiderman, 1988; Preece *et al.*, 1994), and benefits from involving usability in design and development (Grudin, 1991; Mayhew, 1999). Despite their importance, acceptance of new technology is not solely reliant on interface design and usability however. Indeed Paulk *et al.*, (1993) take a complete process view for developing and maintaining software in the move toward a culture of software engineering and management excellence.

In the real world the usability of a software product, application or system has to be adaptable to the needs of the user, and reducing the dangers of resistance to change on introduction of the new technology is a 'two-way street'. Involvement of the user from an early stage of the development process aids in both understanding and overcoming resistance from both the managers' and developers' perspectives. Evaluation (as well as testing) of software in development also allows deeper understanding of the real world needs of users. The use of scenarios in field evaluations is recommended especially for development of collaborative technologies (e.g. Cugini *et al.*, 1999). Furthermore, learning issues also need to be addressed. For example, in studying the use of knowledge management (KM) systems, Damodaran and Olphert (2000: 412) note: "KM systems cannot be exploited to any real extent unless there is learning and understanding of the potential they offer."

Despite research results pointing out the benefits of addressing the 'soft issues' (e.g. human, cultural and organisational issues), which can be explicitly addressed through a user-centred approach (Damodaran, 1998), it is interesting to note that managers' choices for technology adoption may still be made, reliant on peer influence (Tingling and Parent, 2002). It is worth considering that such 'mimetic isomorphism' is not a formula for avoiding change management problems.

2.2.3 Team working

Work in organisations is usually performed in groups or teams, and groups play an important and pervasive role in our lives (Buchanan and Huczynski, 1997). Organisations consist of many permanent and temporary groups (Cummings and Worley, 1997) and managers spend an average of 50 per cent of their working day in groups (Handy, 1999). The study of teamwork and its concepts are not new (cf. Mayo's 'Hawthorne' studies in the 1920s: see, for example, Schein, 1980), and it has taken on a more conspicuous role and has been the focus of considerable further research in recent years due to the increase in ICT use in organisations, and the development of multidisciplinary teams. Indeed the structuring of organisations around multidisciplinary teams formed around core processes is seen as a radically new logic (Byrne, 1993; Cummings and Worley, 1997), despite Handy's (1999) discourse on organisational structure and culture (Section 2.2.1 above).

In discussing groups and teamwork, Handy saw, amongst others, the following organisational purposes, which he noted might well be combined or overlap:

- For the distribution of work;
- For the management and control of work;
- For problem solving and decision taking;
- For information processing;
- For information and idea collection;
- For testing and ratifying decisions;
- For co-ordination and liaison;
- For increased commitment and involvement. (Handy, 1999: 151-152)

These may be extended in terms of consideration for inter-disciplinary teams however, the objectives of which Muir and Rance (1995) believe to include:

- breaking down stereotyped attitudes;
- improving the information flow ;
- increasing efficiency and cost effectiveness.

The determinants of the effectiveness of teamwork largely depend on a variety of factors, including leadership style, processes and procedures, motivation, communication, purpose, etc. Being inherently human constructs, the effectiveness necessarily also depends on the individuals who make up the team. Belbin (1981; 1996) considered individuals' personality traits with group behaviour, and linked these to output performance. A result of his research was the identification of nine distinct roles that would be needed to form a fully effective team:

Role and description	Team-role contribution
Plant: creative, imaginative, unorthodox	Solves difficult problems
Resource-Investigator: extravert, enthusiastic, communicative	Explores opportunities, develops contacts
Co-ordinator: mature, confident, a good chairperson	Clarifies goals, promotes decision-making, delegates well
Shaper: challenging, dynamic, thrives on pressure	Has the drive and courage to overcome obstacles
Monitor-Evaluator: sober, strategic and discerning	Sees all options, judges accurately
Teamworker: co-operative, mild, perceptive and diplomatic	Listens, builds, averts friction, calms the waters
Implementer: disciplined, reliable, conservative and efficient	Turns ideas into practical actions
Completer: painstaking, conscientious, anxious	Searches out errors and omissions, delivers on time
Specialist: single-minded, self-starting, dedicated	Provides knowledge and skills in rare supply
Source: Belbin (1996: 122)	

Table 1: Belbin's nine team roles

This mixture of people in a team would provide balance and with the full compliment of roles ensure that all tasks are achieved. In practice however, it is worth noting that Belbin believes the full set of roles to be most necessary where rapid change (in the workforce, technology, market-place or product) is involved, and that more stable groups can often get by without the full set of roles. He also noted that in small teams, one person might have to perform more than one role (Belbin, 1981).

Whilst 'working together' is a potentially vital ingredient for successful teamwork, it remains ambiguous and open to interpretation by individuals. Furthermore, effective teamwork also involves the consideration of issues linked to *how* team members work together (Palmer *et al.*, 1998). The study of teamwork has further important connotations with respect to 'virtuality' and the VE.

2.3 Review of the Virtual Enterprise

The Virtual Enterprise (VE), Virtual Organisation (VO), and other variations of the paradigm, have been the subject of copious research in recent years. The literature concentrates on varying aspects including: overall concepts, management and technologies (Hale and Whitlam, 1997; Camarinha-Matos and Afsarmanesh, 1999; Goransen, 1999), creation and operation (Hoffner *et al.*, 2001; Larson and McInerney, 2002), process (Guss, 1996; Camarinha-Matos, 2001), socio-organisational aspects including teamwork (Cantu, 1997; Moniz and Urze, 1999; Lipnack and Stamps, 2000; Lurey and Raisinghani, 2001), and so on.

This section draws on the literature to provide an overview and clarification of the concept of the VE, potential types of VE and the VE lifecycle, and the key characteristics of the VE.

2.3.1 Overview

The rapid adoption and adaptation of ICT in business supports the notion of Toffler (1980), who describes the third period of economic evolution, as the 'information wave'. Together with the plethora of literature regarding the information superhighway and the Internet (which acts merely as an exemplar for the latter), a body of literature both academic and journalistic, promotes ideas of revolutionary changes and new business paradigms. For example, Gates (1995) suggests that with the fall in price of computers, we stand at the brink of another revolution based around inexpensive global communication; equally, Tapscott (1996) promotes the 'age of networked intelligence' that is producing a digital- and knowledge economy. Much of the literature suggests that information and knowledge are seen as a new economic resource, yet the importance of information is nothing new (Castells, 1996), rather, the way information is accessed is new (Dutton, 1999), and new enterprise models are altering the way information is managed and shared.

The emphasis of new business methods is toward Drucker's 'knowledge worker' replacing capitalists and proletarians, and whose productivity will be the challenge of the post-capitalist society (Drucker, 1993). The effects of convergent ICT are clearly evident through the rapid increase in electronic commerce and the widespread adoption of the term 'virtual' from 'virtual reality' to the 'virtual state'. Davidow and Malone (1992) expound the 'virtual organisation' as a new kind of business that is changing at an electrifying pace, and which promotes a vision of the corporation of the twenty-first century whose importance cannot be overstated. They reaffirm the notion of knowledge as power by illustrating the rapid pace of change in computer technology and stating that "the most important power source of our own generation is information processing" (Davidow and Malone, 1992: 2). With the advent and exponential growth of the Internet, and widespread corporate utilisation of Internet technologies, the globalisation of business has become a reality, concomitant with which is the increased occurrence of virtual organisations and the VE. Hope and Hope (1997) suggest that many of today's successful and accepted management principles and practices are now out of kilter with the new competitive environment of the third wave.

2.3.2 Clarifying the VE concept

Reviewing the literature relating to this area of research reveals that different commentators tend to use the same terminology for differing concepts or purposes. In conceptualising the virtual organisation, Hale and Whitlam (1997) note that 'virtual' became one of the major new buzzwords of the late 1990s, for which a common definition applicable in all of its uses is difficult to find. The word *virtual* is now commonplace, and arguably increasing due to popular embracement of the Internet. Common uses include: virtual enterprise, virtual corporation, virtual organisation, virtual team, and virtual office, in terms of organisation; virtual manufacturing and virtual prototyping relating to processes; through to virtual university, and more prosaic instances such as virtual shopping. From an etymological perspective Lipnack and Stamps (2000) note that *virtual* has the same Latin root as *virtue*, an intimately personal quality of goodness and power. They also offer three contemporary meanings:

> *"Not real" but "appears to exist," something "that appears real to the senses" but is not in fact*
>
> *"Not the same in actual fact" but "in essence," "almost like"*
>
> *Virtual as in "virtual reality," a recent meaning invented for an emerging capability.* (Lipnack and Stamps, 2000: 16).

For the purposes of this thesis, and relating to the conceptualisation of the VE and virtual team working, the second of these three meanings is deemed the most accurate. A VE *is* real, and does exist; yet is not the same as, but acts, 'virtually' or 'almost' like a regular enterprise or organisation.

The literature also offers a wide range of definitions for virtual enterprise, virtual organisation, and virtual corporation, which are often used interchangeably with such terms as extended enterprise, inter-enterprise, smart organisation, network organisation, and so on. Table 2 offers an overview of available definitions:

Tapscott (1996: 50) – virtual corporation (virtual enterprise, extended enterprise, interenterprise): the conjunctional grouping, based on the Net, of companies, individuals, and organizations to create a business.
Dutton (1999: 350) – virtual organization: operation involving many individuals, groups, and firms in different locations using electronic networks to act as if they were a single organization at one site.
Hale and Whitlam (1997: 3) – virtual organization is the name given to any organization which is continually evolving, redefining and reinventing itself for practical business purposes.
DeSanctis and Monge (1998) – a virtual organisation is a collection of geographically distributed functionally and/or culturally diverse entities that are linked by electronic forms of communication and rely on lateral, dynamic relationships for coordination.
Goranson (1999: 66) – a VE is a temporary aggregation of core competencies and associated resources collaborating to address a specific situation, presumed to be a business opportunity.
Camarinha-Matos and Afsarmanesh, (1999a: 4) – a virtual enterprise is a temporary 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.
Severwright and Singh (1998) – the Virtual Enterprise business organisation model is being increasingly seen as offering tremendous competitive advantage for large enterprises, enabling them to reorganise themselves as agglomerations of small distributed working teams, where individuals are drawn from both within the parent enterprise but also from outside.
Lipnack and Stamps (2000: 18) – a virtual team is a group of people who work interdependently with a shared purpose across space, time, and organization boundaries using technology.
Jarvenpaa and Leidner (1998) – we define a global virtual team to be a temporary, culturally diverse, geographically dispersed, electronically communicating work group.

Table 2: overview of VE definitions

It is clear from the above that common characteristics appear within the definitions, and the Researcher does not intend to create a new definition of the VE. The virtual corporation, according to Davidow and Malone (1992) is centred on a new kind of product or services – the 'virtual product' – a business paradigm whose impetus is driven by profitability and speed to market. Virtual manufacturing and virtual prototyping are encompassed in this view of the corporation, with outsourcing, teleworking and strategic partnerships being key initiatives (see e.g. Norton and Smith, 1996). Recent research in the VOSTER project (VOSTER, 2003a) offers further comprehensive definitions and clarification between terms, and suggests that a VE represents a VO and is a particular *case* of virtual organisation: an example of a VO could be a 'virtual municipality', associating via a computer network, all the organisations of a municipality (e.g. city hall, municipal water distribution services, internal revenue services, public leisure facilities, cadastre services, etc.) (VOSTER, 2003a:11).

Goransen (1999), however, draws important differences between the VE and virtual organisations, virtual corporations (and indeed electronic commerce), noting that the term 'corporation' suggests that there is an inherent vision of corporate identity, whereas:

> "Enterprise *conveys the meaning that the shared focus is the project at hand; corporation implies a conventional organization whose control is centralized, which is not what we mean. The VE is unified by its mission and distributed goals, not its control system."* (Goransen, 1999: 66).

'Extended enterprise' is seen to be the closest rival term to VE, and is usually applied to an organisation in which a *dominant* enterprise extends its boundaries to all or some of its suppliers and/or customers. In some cases it is used about manufacturing collaboration, which is continuous (mass production) (VOSTER, 2003a:11). The concept of Smart organisation is seen to bring new perspectives to management decision-making through the organisation, identifying the key practices that enable successful organisations to deliver a stream of winning products and services. Comparing these descriptions of Smart organisations with VO it may be concluded that VO supported by networks enable the realisation of the Smart Organisation concept but do not guarantee it (VOSTER, 2003a:12).

The Researcher finds that the most fitting overall definition of the VE is that provided by Camarinha-Matos and Afsarmanesh, (1999a) (see Table 2), whilst bearing in mind Goransen's note on its unification above. In this sense, it can be argued that from a business perspective the *agreements* made between the relevant actors also define the VE. Such agreements will include both the extent to which information and knowledge are managed and shared and the tools made available to do this, and also the degree of control employed. The research in the thesis therefore, bearing in mind the construction industry context of the study (see Section 2.4), is concerned with the VE rather than virtual corporation, VO, extended enterprise, or smart organisation.

Finally, it should be noted that ICT is generally viewed as a potent defining element to the VE: Camarinha-Matos and Afsarmanesh (1999a) state explicitly that "cooperation is supported by computer networks", furthermore it has been observed that "as an organizational metaphor, the virtual concept is a product of the Information Age generally and the computer industry in particular" Snow *et al.* (1999: 17). The Researcher would contest however that, *pace* these authors, the VE existed as a *modus operandi*, prior to the advent of mass computerisation (see Section 2.4.8).

2.3.3 VE type and lifecycle

The previous section indicates that the VE relies on networking organisations as elements forming an alliance or aggregation towards some specific purpose or opportunity. In analysing these concepts further, the entities that make up the VE could include individual organisations and/or indeed separate divisions within organisations. Goransen (1999) defines four types of VE according to their aggregation mode:

> *Type 1: An aggregation formed in response to an opportunity. In its pure form, this is the prototypical (and most interesting) type where an entity identifies an opportunity (or recognises a change) which takes advantage of a core competency. Then the entity (normally the one that recognises the opportunity) acts as organizer to identify and creatively integrate partners with complementary, required core competencies.*
>
> *Type 2: A relatively permanent aggregation of core competencies that largely pre-exists, and which is seeking an opportunity. Generally, new members must be brought into the partnership in order to address the opportunity.*

> *Type 3: A supplier chain which, while using relatively conventional business relationships, exhibits agility in responding to market needs. Electronic commerce also fits into this group when it employs traditional (albeit automated) business transactions.*
>
> *Type 4: A bidding consortium. Such a group relies on relatively conventional business relationships in its interactions. But it employs agile practices in response to market needs, and it acts as a Virtual Enterprise in representing collective capabilities to a customer.* Goransen (1999: 66-67)

The interesting point from this typology is that in all cases the key to the VE is the *integration* of partners. The integration of partners animates a VE for a purpose, which clearly has a temporal dimension. The VE, therefore, has a lifecycle, which may or may not include the same partners throughout. Camarinha-Matos and Afsarmanesh (1999a) present a minimal lifecycle model as shown in Figure 6.

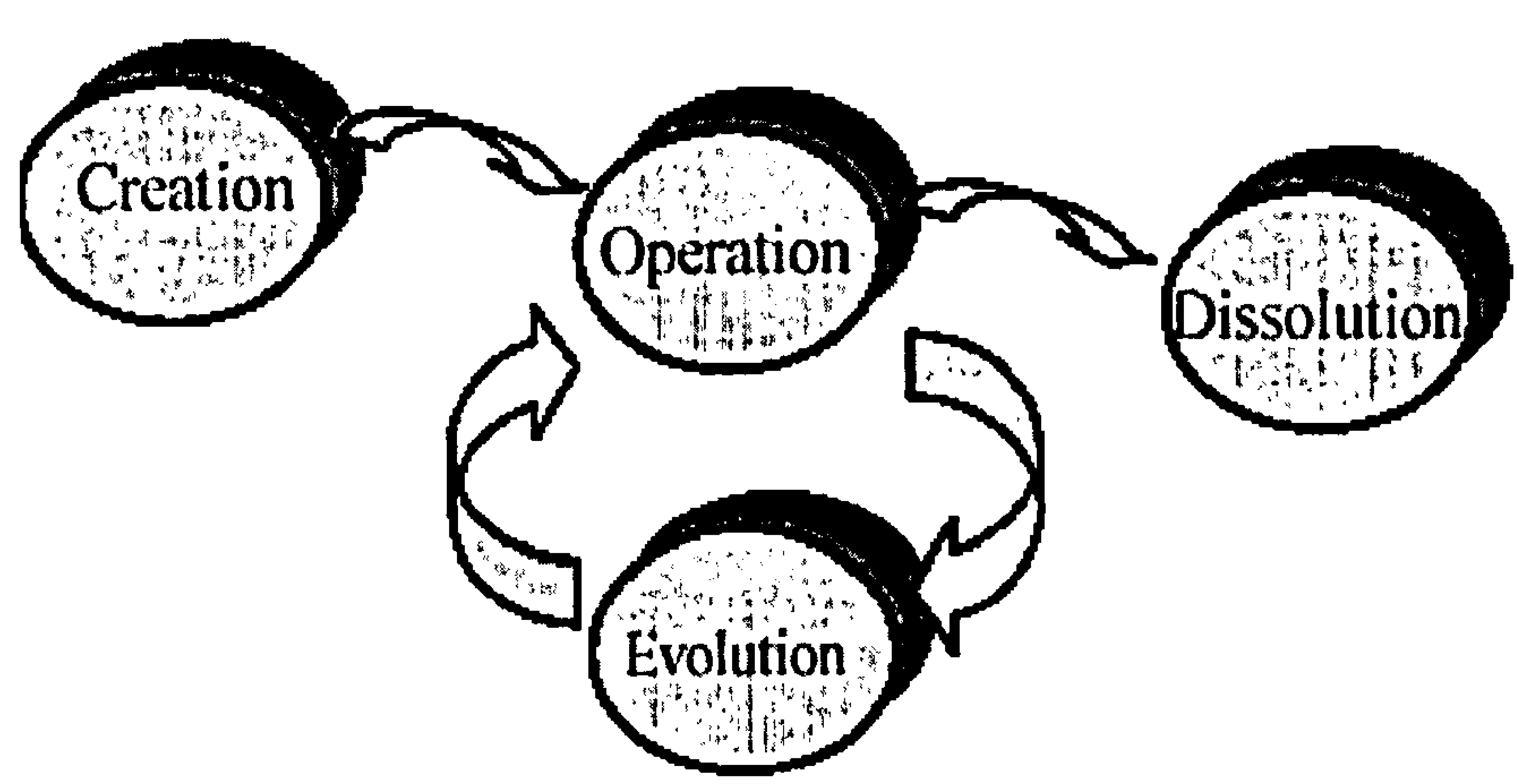


Figure 6: Life cycle of a VE (Camarinha-Matos and Afsarmanesh (1999a: 11)

In providing ICT for the VE, integration becomes of paramount importance in terms of the supporting technical infrastructure(s), as partners will require interoperability to share information in a seamless way. For the technologies to be successful they must be robust, easy to use and integrated with other systems within partner organisations (May and Carter, 2000). From this it then surely follows that the agreed infrastructure needs to be able to accommodate possibly very diverse partners, and varying purposes, according to the different stages of the lifecycle of the VE. In other words the VE will evolve, as depicted in Figure 6.

Furthermore, an organisation or partner may play different roles within a VE during the various stages in the lifecycle. For example, Katzy and Obozinski (1999) recognise roles including: *Broker*, responsible for marketing network competencies; *Competence manager* to bring partners and competencies together; *Project manager*; *Auditor*; *Network coach*, who is in charge of construction and maintenance of the infrastructure, acquisition of partners, and rules for processes; and *Manager in-/outsourcing*, responsible for coordination and communication with the project manager, offering technological know-how, resources and the technology of the company towards the network.

While the integration of ICT is critical to the VE throughout its lifecycle, the rapid integration of the business processes of the participating companies is also viewed as a major issue, as the success of the VE business goals depends on its ability to align the business processes and practices of partner enterprises (Presley and Rogers, 1996).

2.3.4 Key characteristics of the VE

In the context of organisational theory, the VE is still seen as something of a novelty, though it may be argued that in practice many of the 'novel' concepts are extensions to the familiar theory. From the corpus of literature, and in summarising the literature and the preceding sections (*mutatis mutandis*), a number of common factors or key characteristics emerge with respect to the VE, in terms of both technical and 'soft' issues:

- Organisational flexibility
- Transience
- Increased teamwork – cross-functional and cross-organisational
- Horizontal as opposed to hierarchical structure
- Need for greater co-operation between companies
- Exploiting core competencies

- Rapid response to opportunities
- Functional and cultural diversity
- Dynamic processes
- Edgeless, permeable boundaries
- Contractual relationships
- Facilitated by the use of ICT
- Interoperability and integration of systems

As these characteristics differentiate the VE from more traditional forms of organisation, they may be seen as critical success factors for the VE. As such, they need to be taken into account in ICT development to support the VE. Further to these characteristics there are economic and financial factors that should be borne in mind with respect to the VE. For example, O'Brien and Al-Biqami (1998) suggest the nature of ownership, the nature of control and the manner of work allocation within an industrial setting. Reverting to the earlier discussion on change, the integration of an organisation into a VE support infrastructure creates changes to the ways in which the organisation operates (or at least that portion that is integrated). Furthermore, the organisation faces the need to integrate different technologies to automate partial processes (Moniz and Urze, 1999).

As the VE is unconstrained by traditional barriers of space and time the question of trust also proves to be of consequence at different levels: between partners/team members, in the technology, and in terms of the sharing of information.

2.3.4.1 Virtual teams

The concept of virtual teams has gained a good deal of research attention in its own right as well as in the context of the VE. In their influential work on virtual teams, Lipnack and Stamps (2000: 18) offer a definition of a virtual team:

> *"A virtual team is a group of people who work interdependently with a shared purpose across space, time, and organization boundaries using technologies."*

From this definition, and taking a systems theory approach to virtual team working, they have developed a simple four-dimensional model (Figure 7).

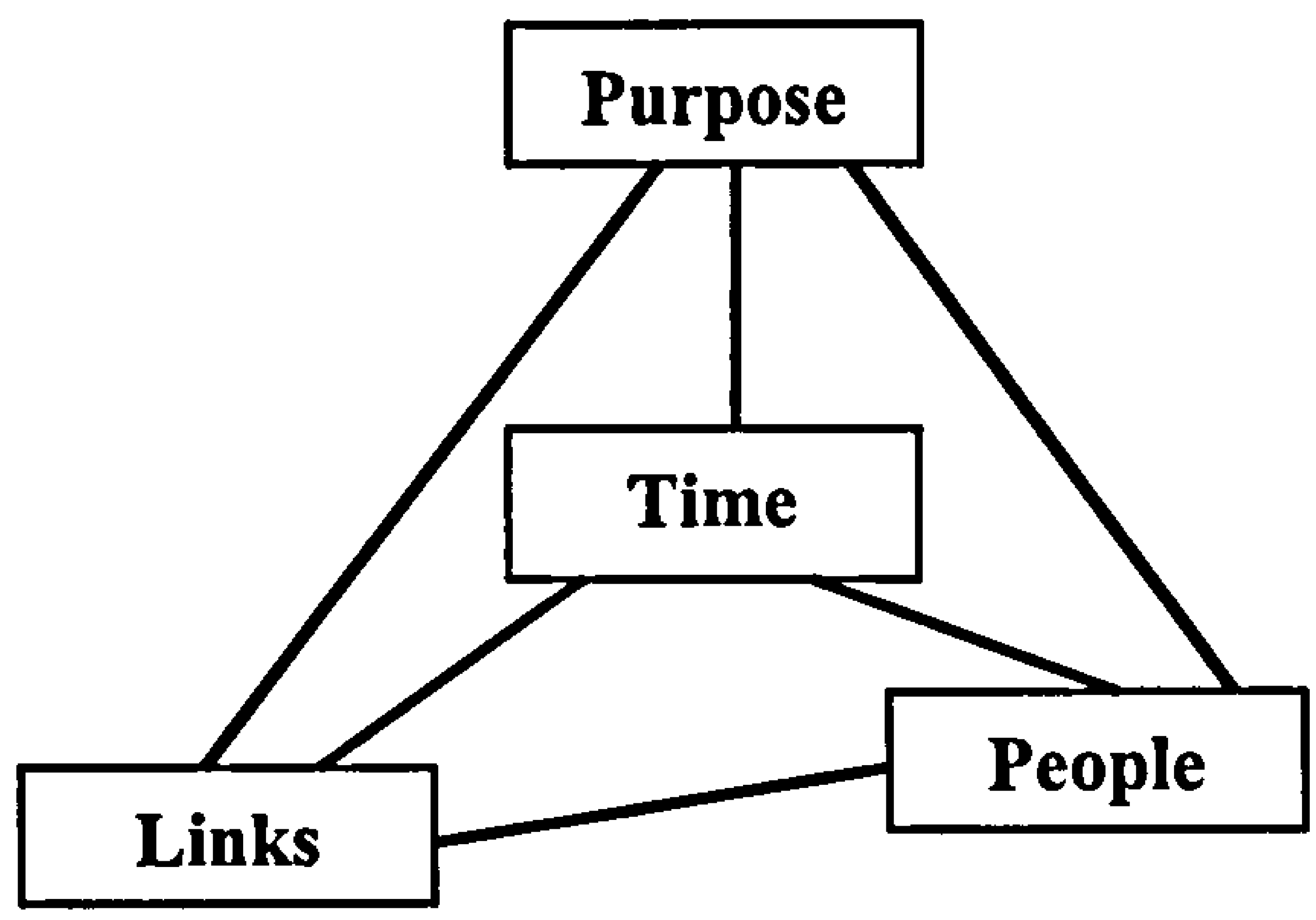


Figure 7: Virtual Team Model (Lipnack and Stamps, 2000: 116)

The Researcher includes this model here as he feels that it describes in microcosm the important aspects to be addressed in the complete VE. While it is a simple model, it is firmly grounded in many of the aspects of organisational theory reviewed above. Lipnack and Stamps (2000) note that virtual work is not haphazard; rather a team structures its information and manipulates it within a context that the team itself creates. The model links the four essential ingredients of a virtual team, as people are linked together with a common (team) purpose to accomplish over time. *People* populate small groups and teams of every kind at every level. *Purpose* holds all groups together, but for teams, the task – the work that expresses the shared goals – is the purpose. *Links* are the channels, interactions, and relationships of a team unfolding over *Time*. The greatest difference between collocated teams and virtual ones lies in the nature and variety of their links.

Interdisciplinary teamwork is an essential factor in the VE, and in terms of team building it is interesting to note that recent work suggests that despite the influence of Belbin (see Section 2.2.3 above), selecting suitable team members based on their interpersonal strengths can be a complicated process (Palmer *et al.*, 1998), and that in a virtual context a demanding performance challenge tends to create a team itself (Katzenbach and Smith, 1993).

2.4 Review of the European construction sector

Worldwide, the construction industry is the largest industrial sector, accounting for approximately 10% of gross productive effort (O'Brien and Al-Biqami, 1998), and it is indeed the largest industrial sector in the EU, representing approximately 11% of Community GDP (CEC, 1997). It is also the largest sector in terms of employment, providing jobs for some 7% of the working population, with every job created in the construction sector generating two further jobs in related sectors (CEC, 1997). Such statistics abound in the literature, and are ever changing. To put these figures into perspective, bearing in mind that the EU comprises 15 member states of varying sizes, in the UK alone the sector employs in excess of 1.4 million people (DETR, 2000), comprises 186,000 SME and includes 165,000 private contracting firms (Foresight, 2001). Clearly, therefore, it is a highly labour intensive industry sector.

The European construction industry does not have a single cohesive identity; rather, each member state operates within varying economic and physical climates, is governed by differing regulations, uses different forms of contract, displays organisational and cultural differences, and so on. It is, however, very important in any developed and dynamic society (Spencer Chapman and Grandjean, 1991):

> "*...[the industry] creates the built environment, the transport, and energy supply networks and telecommunications facilities associated with economic development, the offices, shops and factories in which people work, and the water supply, sewerage disposal and sea defence works needed for health and safety. Its products are large, costly, usually visible, and if they fail widespread damage and disruption can occur.*" (Spencer Chapman and Grandjean, 1991: 29).

2.4.1 Defining the construction industry

Throughout history, one of the key concepts within the construction process is the importance of the relationships between actors, regardless of whether the construction goal is a relatively small housing project, or a major civil engineering effort. Barnes (2000) notes that though a realistic view of what civil engineering is includes the physical artefacts produced, and the processes of design and construction involved in their production, this view misses out the way the actors involved in the process interact with each other. At the time of the Industrial Revolution the predominant interaction in the process was that between engineer and contractor as 'master and servant' (Barnes, 2000). The situation today has moved away from individuals to complex interactions between companies. Furthermore, in the context of the single European market (and with the advent of Internet technologies), construction industry actors have increasing potential to exploit international opportunities.

By its very nature, therefore, it is a complex industrial sector, to which it is difficult to prescribe boundaries. Indeed, 'construction' includes a wide variety of techniques, involving diverse actors across different disciplines. Some of the actors may not even consider their businesses to be any part of the construction industry. For example, a company that manufactures pumps required for water circulation would not necessarily see itself as a key player in construction, yet in terms of information management, other actors in a construction project rely on information about such products, thus the manufacturer (under the umbrella of 'suppliers' to a particular process) constitutes a construction industry actor. Construction industry statistics therefore cannot include data for construction-related activities, as they are seldom available, being included in other manufacturing or service industry surveys (Manseau and Seaden, 2001).

It may indeed be questioned, whether construction is an 'industry' as such, or rather a process. For the purposes of this work, the term 'construction industry' is used broadly to encompass the complete concept from architecture, engineering and construction, to facilities management, and with an acute awareness of the possible related industry actors therein.

2.4.2 The construction industry context

The construction lifecycle covers an unusually long timescale in terms of the manufacture and useful life of an artefact, from the initial idea and requirement for a construction facility, through to its final destruction. Furthermore, each construction project is a prototype as it differs in many respects from every other, and as the product is so durable (and with a high capital value) it is usually repaired or altered rather than being disposed of and replaced. The process of such alteration then constitutes a further 'construction' project within the total lifecycle, requiring another set of actors and operations, needing access to legacy information, and creating new information in turn. The industry is therefore highly 'project oriented', and teamwork is predominant, with actors coming together for a specific project, and possibly never working together again. It is also very common for actors to work on several projects concurrently within teams composed of different partners. Despite the long construction lifecycle, however, there is programme urgency, with ever-growing pressure from clients to deliver high-quality facilities on time and on budget, yet operating within razor-thin margins (Hassan and McCaffer, 2001; Rezgui, 2001; Aberdeen Group, 2000). The sector is also highly regulated (Manseau and Seaden, 2001), which means that the information element also includes a considerable amount of documentation relating to regulations and juridical matters.

The European construction industry is fragmented, consisting of a large number of very small companies and relatively few large companies, and differences remain between member states. In the UK and France, for example, the large companies carry out a greater proportion of the work than in countries such as Germany and Italy, and therefore the large firms play a dominant role (Spencer Chapman and Grandjean, 1991). These disparities affect not only the division of construction contracts between available actors, but also the process of innovation. While new technologies are reshaping the way we live, think, and work, construction is clinging to outdated practices (Broyd, 2000), is conservative, and slow to take up new technologies – indeed is somewhat 'backward' to the extent that in Europe it appears to be trying to change its image but finding it very difficult to do so (CEC, 1997). Although it is recognised that innovation is a key factor in industrial competitiveness (Porter, 1998), Research and Technology Development (RTD) investment in the construction industry is still problematic. Finland, for example, has a pragmatic and entrepreneurial culture with respect to technological innovation, yet the construction sector uses less than 1% of its turnover on RTD-activities (Koivu and Mäntaylä, 2001). Similarly, in France the share of RTD in construction (including building and civil engineering) is about 1 to 2% of the total French RTD effort, compared to an 8-10% share in the national economy (Campagnac and Salagnac, 2001).

In the UK, the Latham (1994) report, and more recently the Egan report (DETR, 1998), identified significant problems in construction, and suggested improvements that could be made. In Europe similar problems are reported (e.g. CEC, 1997), and in many cases similar solutions recommended. However, due in part to the lack of research investment in the sector, but also to the very nature of the industry, the author contends that despite such reports being widely cited in the literature, construction still faces many of the same challenges today.

2.4.3 Business processes and BPR

Due to the nature of the industry (fragmentation, project-based, short-term partnering, slow uptake of technology), key problems still faced revolve around the fact that construction processes remain paper-based in terms of information management, and that construction is a complicated exercise in coordination, collaboration, and communication (Aberdeen, 2000). Research (Tolman, 1999; Bjork, 1999; ECCE, 1998; Alshawi, 2001; *et al*) has emphasised the importance of information to the industry, and the potential for improvement through the use of ICT. However, ICT development and introduction has to be considered within the perspective of the actual process(es) it is intended to improve.

Construction today involves a complex series of processes throughout which many different systems are involved, and which produce an enormous amount of information. Research in recent years (Kagioglou *et al.*, 1998; Aouad *et al.*, 1998) has suggested and sought to equate similarities between the operations of the manufacturing industry with counterparts in construction. Furthermore, it has been noted that many of the issues affecting performance, productivity and competitiveness are predominantly process related, as opposed to being focused on time, cost, or quality elements that are addressed in contemporary 'change' initiatives (Goulding and Alshawi, 2002). Indeed much research has focused on processes within the construction industry, both throughout the building lifecycle (e.g. Kagioglou *et al.*, 1998; Vakola *et al*, 2000), and also in more depth within specific phases (e.g. client requirements: Kamara and Anumba, 2000).

Kagioglou *et al.* (1998) developed a Generic Design and Construction Process Protocol within which were defined four generic stages in the design and construction process with respective phases within them as shown in Table 3 below.

Phase	Description
Pre-project stage	
•	Demonstrating the need
•	Conception of need
•	Outline feasibility
•	Substantive feasibility study and outline financial authority
Pre-construction stage	
•	Outline conceptual design
•	Full conceptual design
•	Co-ordinated design, procurement and full financial authority
Construction stage	
•	Production information
•	Construction
Post completion stage	
•	Operation and maintenance

Table 3: Phases of the GPP (after Kagioglou et al., 1998)

The assertion is that both efficiency gains will be made, and client business needs better met, if all actors within a project can work to an agreed set of processes and procedures. These results have to some extent been successfully embraced and adopted in the (UK) industry. Such an agreement may inevitably require a radical change in working practices, along with inherent change management issues. The problem still remains, however, of the predominance of very small companies that make up the construction sector, and that many companies may not even be aware of the importance of agreeing process protocol.

This type of research can be seen to fall within the paradigm of Business Process Re-engineering (BPR): a fundamental re-thinking and radical re-design of business processes (Hammer and Champy, 1993). BPR involves restructuring (McKay and Radnor, 1998), and has been closely considered from an IT perspective, whilst bearing in mind that the role of IT is not simply to automate an existing process as the economic benefits from this are likely to be minimal (Davenport, 1993).

Within European construction research, Vakola (1999), under the activities of the European funded Condor (ESPRIT-23105) project took a Business Process Re-engineering (BPR) stance, aiming to develop a new strategy and methodology. This research included a critique of BPR methodologies (Vakola and Rezgui, 2000), and the work presented BPR as an ongoing cycle of successive steps including the following eight stages:

- Develop business vision and process objectives
- Understand existing processes
- Identify process for redesign
- Identify change levers
- Implement the new process
- Make new process operational
- Evaluate the new process
- Ongoing continuous improvement

The Researcher feels that the important point from this model is that it is grounded in business terms, as examination and understanding of existing processes is linked directly to strategy ("develop business vision and process objective"). Again, however, the Researcher feels it is not fully clear the extent to which such a model can be of use in the construction industry today, bearing in mind the context described above.

It is clear though, from the literature and the above, that in developing ICT for the construction industry, very close attention needs to be paid to the current business processes. Furthermore, in human and organisational terms, it also indicates the need for assessing the degree to which the actors carrying out the processes are aware of the 'process' nature of their work, and also their openness to change. This introduces the notion and importance of professional culture in ICT development and implementation. For example, different actors, within the multidisciplinary teams necessitated by the construction industry, will focus on different professional priorities. Problems with co-ordination, collaboration, communication, documentation and so on, rely on integrated processes between construction project actors. If integration of processes between actors cannot be agreed upon, ICT will not in itself provide a working solution. As has been noted:

> *"...impaired process integration cannot be solved purely by the implementation of information communications technology and/or management information systems; such applications manage and process data rather than address process discontinuities caused by participant non-interoperability."* Moore and Dainty (2001: 560).

The construction process today, predicated in complex operational and commercial relationships that enable the boundary between design and construction to be placed anywhere within a particular project and varied between different parts of the same project (Barnes, 2000), appears, as is the case with so many other industry sectors, to be ripe for change and realisation of efficiency gains via ICT. The key however, in an industry whose actors are predominantly non-collocated and that is faced with tight margins, lies in effective communication and collaboration. ICT developments in such an arena can serve only to support and enable business processes, but if it is supporting the wrong processes, the result is doing the wrong things more efficiently (Lamont, 2002).

2.4.4 ICT in use in the construction industry

Over the last decade, the construction industry has begun to embrace technology to address the ever-growing pressure from clients to deliver high-quality facilities on time and on budget, resulting in ICT-supported forms of project management and support for business processes (Rezgui, 2001). It is difficult, due to the characteristics of the sector, to achieve research statistics regarding the access to, and use of, ICT throughout the industry. Expanding the statistics of the composition of the industry in the UK alone for example, from a total of 163,426 firms of private contractors in the year 2000, more than 50% comprised one individual (DETR, 2001). Various surveys have been conducted in specific areas across Europe and elsewhere, however (ConstructIT, 1996; Howard *et al.,* 1998; CICA, 2000; BRE, 2001; Ng *et al.*, 2001; Samuelson, 2002), though Howard *et al.* (1998) note that surveys of the use of IT are carried out in many countries in incompatible and misleading ways, and for a variety of purposes. The results are therefore only indicative, allowing a limited number of general conclusions. The following sections draw on such surveys to broadly indicate ICT use in the industry.

2.4.4.1 Access to and use of ICT

In 2000, Samuelson (2002) reported that 88% of all employees in the industry work at workplaces with computers, which is approximately the same level as two years earlier (Howard *et al.,* 1998); most of those who do not, work at small companies with less than nine employees and with a large proportion of skilled workers. The survey points out that 54% of all employees in the industry have their own computer, and 33% have a computer at home that is owned by their company. The figures included both white-collar and skilled workers, with an indication that access to a computer for personal use among white-collar workers had increased to a high level in all categories of companies.

The most common types of software used in the industry are word processors, administration software, e-mail software and spreadsheets. Computers are used for different operations; bookkeeping and invoicing being the common operations that are most frequently performed with computers; tendering operations less so (Samuelson, 2002).

Construction industry actors began to embrace computer technology when they recognised that computer aided design applications (CAD) highlighted the possible returns from software investment (Aberdeen, 2000). CAD is now widely used throughout the construction sector, though drawing by hand has not been entirely replaced. According to Samuelson (2002) the most common software is AutoCAD, which is used 76 % of the design time by engineers and 57 % of the design time by architects. Architects use drawing by hand 23 % of the time while the engineers only use this 11 % of the time. On the other hand architects use model-based programs, such as ArchiCAD and AutoCAD ADT, to a greater extent than the engineers, who do not use them at all.

Much computer software has been developed for scheduling and resource planning processes, though such operations are performed with computers by a surprisingly low share of the industry, with 14% of contractors performing all planning manually and only 10 % using computers all the time (Samuelson, 2002). It is worth noting however that different types of engineers need different kinds of applications. For example architects and engineers use software a little more for planning, with 27% of engineers performing planning with computers all the time.

Software tools are also available and used for costing and budgeting operations. Whilst specially developed costing software with databases for prices and products is available, the solutions used are often in the form of common spreadsheets designed locally. Samuelson (2002) states that property managers were found to make the most use of computers for this purpose, whilst contractors have the lowest use. However, it is remarkable that there are architects, engineers, and contractors, who perform this totally manually.

The ConstructIT (1996) survey distinguished the following six main areas of ICT use in the construction process:

- Management, supervision and administration
- Commercial management
- Legal, health and safety
- Planning, monitoring and control
- Delivery and material handling
- Production on site and off site

The companies surveyed all indicated that ICT use is important in all of the above areas, yet the significant result showed that apart from planning, monitoring and control, ICT use in all of the areas fell into the category of high, *ineffective* use.

2.4.4.2 Communication

Communication takes place at different levels in the construction process: within teams (which may themselves be virtual), between teams and departments, and with external partners. Increasing use and reliance on technology for communications is somewhat tempered though when considering the fact that most end-users in the construction industry are not computer-literate (Rezgui, 2001). The processes of design and construction involve a substantial tacit knowledge, which complicates communication between different professionals (Bower *et al.,* 2001). Most information used during the design-and-build process of a construction project is conveyed using documents, which are most of the time exchanged, for contractual and legal reasons, on a paper-based medium, even when produced using computers (Rezgui, 2001). However, use of the Internet and web-based services are increasing. Company websites are also common, but electronic trade is not widespread in the industry, with 64% of all employees working at workplaces that do not use electronic trade at all (Samuelson, 2002).

Minutes of meetings are the document type most commonly sent digitally; with descriptions, and orders, invoices and tender enquiries showing much lower levels of computer transfer. The minimal use of digital communication in these cases might depend on security problems and/or lack of standards for digital signatures.

Despite electronic communication between processes being supported, communication is still conducted orally and with paper-based mediums, using telephones and fax machines, and although companies exchange data electronically (predominantly using email or removable disks) there is generally no significant use of direct electronic data exchange throughout a project.

2.4.5 Current ICT best practice

Many of the current ICT best practices lay in the field of information and knowledge management, which despite interest and effort put in by many leading companies, is a discipline still in its infancy (Rezgui, 2001). Many practitioners and researchers have acknowledged the limitations of current approaches to managing the information and knowledge relating to and arising from a project (Choi and Ibbs, 1995). Some of the key reasons for these limitations are:

- Much construction knowledge resides in the minds of individuals.
- The intent behind decisions is often not recorded or documented.
- People responsible for collecting and archiving project data may not understand the specific needs of those who will use it.
- Data are usually captured and archived after people with the project knowledge may have left for another project.
- Lessons learned are not well organised and are buried in details.
- Since people move from one company to another it is difficult to reach original report authors who understand the hidden meaning of historical project data.
- New approaches to the management of knowledge within and between firms imply major changes in individual roles and organisational processes. While potential gains are desired, the necessary changes are resisted. (Rezgui, 2001).

Key developments in the application of ICT in the construction sector in recent years, that are viewed as current best practice in the domain include: document management systems, product data technology, groupware systems, decision support systems, data warehouse solutions, mobile services, and eCommerce and eBusiness solutions. Table 4 gives an indication of the potential benefits of each of these technologies.

Technology	Benefits
• Document management systems	Reuse of knowledge and lessons stored within documents: opening the 'black box' of documents
• Product data technology	Cross-disciplinary information integration through product modelling and model-based applications
• Groupware systems	Management and tracking of the project lifecycle, information exchange and synchronisation, workflow
• Decision support systems	Knowledge elicitation, human-like problem solving mechanisms through case based reasoning
• Data warehouse solutions	Centralised, filtered and value added data, with multidimensional user view of the information base
• Mobile services	Mobile connection to the (virtual) enterprise information systems, facilitating site activities requiring high mobility
• eCommerce and eBusiness solutions	Allowing services to be provided via corporate portals, providing means for electronic transactions

Table 4:ICT developments as current best practice in the construction domain.

The literature provides quite clear evidence that ICT use is widespread within the construction industry, yet integration of tools remains problematic, and training in ICT is still widely required. Furthermore, many companies are still using the same basic tools they have been using for a decade, and attempts to leverage the benefits of ICT merely automate the traditional paper-based methods, with many of the resultant tools being adapted to specific needs of designers, consultants and contractors. Equally, many of the more advanced solutions employed are 'in-house' developments. As construction project consortia are often formed on an *ad hoc* basis, there is often no dominant actor to enforce ICT solutions, and as information exchange within a project does not generally include the client, there is little or no contractual control over the systems used. Consequently communications, and exchange and sharing of electronic information between partners within a project team, are hindered due to the use of computer systems from differing software vendors with varying file formats.

2.4.6 Commercial solutions for the construction industry

The automation of tasks within companies may have some benefits in itself – notwithstanding any issues of change management that need to be overcome on its introduction – but the tools that emerge do not address the underlying problems faced by the industry. With the increased use of Internet technologies and e-commerce, commercial tools and solutions are being developed, some of which are targeted to construction industry actors.

Commenting on the move towards e-solutions, King (2001) cites Jay Walker, chairman of Priceline.com (http://www.priceline.com – an e-commerce solution for the travel industry) as saying: "if they're to succeed, new Internet businesses must solve a real-world problem, rather than simply automate an old process." This view is however surely as true for designing electronic tools for established businesses and industries. In the construction domain the problem is not simply with ICT tools, rather with the accessing, sharing, communication capabilities and relevance of tools, and the process of information management generally. Moves to address some of the problems associated with virtual teamwork have been founded in the domain of extranets and peer-to-peer solutions. Solutions such as 'Groove' (http://www.groove.net) and 'Ikimbo Omniprise' (http://ikimbo.com) have appeared in the marketplace. Groove – developed by Ray Ozzie, the inventor of Lotus Notes (http://www.lotus.com) – offers a peer-to-peer collaboration platform allowing direct interaction among users, including calendar and discussion tools, shared workspaces, and resources for the setting up of work groups or teams. Omniprise also offers the ability to set up groups, share and exchange files, and enable real-time communications. Such tools, however, though they can be implemented quickly, still address only a subset of the challenges above.

Various commercial web-based electronic document management (EDM) systems are also available, offering document and workflow management services across the Internet, some of which are tailored specifically to the construction industry. These solutions aim to address more comprehensively the problems mentioned above throughout the building lifecycle. Table 5 gives an overview of some of the key offerings available:

Company	Summary of offering
Bricsnet www.bricsnet.com	ASP-integrated technology, services and information. Building & Operations management technology for corporate real estate executives to manage the information they need to rapidly deploy buildings and efficiently manage operations from one central location. Project specific collaboration solutions, and architectural modelling and CAD tools. Database of worldwide building product information, plus procurement facilities.
Buzzsaw www.buzzsaw.com	Project management services capable of hosting multiple projects, adding project members and designating permission levels to project drawings and documents stored in a central location. Provision of Autodesk design tools. Project hosting and online meetings facilities.
BuildOnline www.build-online.com	Business-to-business e-commerce services. Platform independent project collaboration facility, allowing sharing and communication of information. Secure repository for hosting tender documentation on-line, linked to the collaboration tool. Tendering and procurement tools. Interactive information exchange between buyers and suppliers.
Citadon www.citadon.com	Collaborative project management including document management and business process management systems. Online marketplace for purchasing and support for the bidding process. Print services for project related plans, drawings and specifications. Financial services geared towards the real estate lending process.
Primavera www.primavera.com	Comprehensive project management software including scheduling and resource planning tools, some of which are available in foreign language versions. Contract management and project administration solutions with document management. Tools to enable purchasing of materials, services and equipment.
Groupe Le Moniteur www.lemoniteur-expert.com	Prosys Online – a project management internet server. Services include project directory listing companies, members, groups, roles, and rights. Electronic exchange and management of any type of documents. Viewing, redlining and downloading files of any format. Relating and linking of documents. Workflow processes. Structured or full text search, query and reporting. Alerts, reminders, acknowledgement of receipt. Construction specific modules. Simplified or advanced administration. Online help, documentation, training and support.
OTH/Derbi www.sgti.com.fr	The SGTi EDM system provides a set of functionality for storing, archiving and exchanging documents, including drawings and written documents, in a structured manner. The system also offers a number of advanced services, including a function to co-ordinate the approval process of documents; a change request management service; an advanced construction specific financial tool; and a subsystem (GPP) that is dedicated to the production and management of drawings in a multi-actor environment.
Reference: the information was sourced from the addresses listed	

Table 5: Overview of Internet building solutions

The first five of the companies selected and displayed in Table 5 are offering international products, which are not largely diffused and used in some countries (especially, for example, in France). Indeed, Buzzsaw, Citadon and Primavera are

American organisations. Bricsnet is a Belgian organisation and BuildOnline claims to be the first business-to-business e-commerce solution specifically for the European construction industry. Each of the solutions mentioned above has enjoyed some success since their introduction, and boasts many large corporations as customers. The product offerings from Groupe Le Moniteur and Derbi are both of French origin.

It is noticeable that the services offered by these companies are based currently on their own, already available, software applications. This is not unsurprising, as they are commercial ventures; for example Buzzsaw emerged as a spin-off from the design-software company Autodesk, and thus offers Autodesk software solutions. The Researcher feels, however, that due to the tight margins by which construction actors are constrained, achieving integration by investment in such 'closed' offerings is not a suitable solution. Indeed in the dynamic situation of construction project consortia, information sharing and exchange based on a solution that effectively ties the companies to one supplier may prove to be no better than in-house, *ad hoc* solutions when new companies become involved. ICT infrastructures offering open solutions, based on open standards are required.

Furthermore, the use of ICT to enable business in the construction industry is not simply a technical question, but also a cultural issue. The commercial services offered cater well for architects, for example, who often have high exposure to the technology, whilst many of the smaller enterprises involved in the building lifecycle may have little or no ICT experience. Solutions need, therefore, to be user friendly and intuitive.

2.4.7 Summary of the characteristics of the construction industry

The preceding sections indicate that the construction industry exhibits characteristics that differentiate it from other industrial sectors. In summary these include:

- The sector is heterogeneous and highly fragmented, depending on a large number of very different professions and firms, predominantly small/medium size enterprises (SME).
- It is one of the most geographically dispersed sectors.
- Construction is highly project oriented, and any ICT used within a project must be deployable and profitable within one project to all/several partners.
- Teamwork is predominant in the industry, requiring all actors involved to work effectively together in cooperation.
- Each construction project is a prototype. The final products are very durable, non-transportable, and when obsolete are most often repaired, modernised or transformed rather than disposed of and replaced with new.
- The sector is highly regulated; rigorous regulations and standards involve several levels of governments (local, provincial, national).
- The entry-level for new contractors is relatively low.
- The sector is very labour intensive, with high mobility of the workforce and growing skills needs as construction technology becomes more sophisticated.
- Business relationships are temporary and often short-term, bringing together partners who may never work together again.
- Within a project VE there is often no dominant actor to enforce ICT solutions.
- Information exchange within any construction project is mainly between others than the client and is not, therefore, contractually controlled.
- All actors are involved in numerous projects at the same time.

These characteristics play a large part in shaping the research efforts for the industry, as they also implicitly point to problematic issues. The introduction and use of ICT in construction, due in some respects to both the characteristics of the sector and also to *ad hoc* development, has not only proved to be a blessing, but also to some extent to add to the problems (Dado, 2002). There is a *de facto* recognition of the now familiar phenomenon of 'islands of automation' (Hannus, 1998) in construction, which is one reason for the application of (particularly state-of-the-art) ICT still not paying dividends in the industry. There is still a need for integration of differing technologies and effective communications.

2.4.8 The construction industry VE

Comparing the characteristics of the industry above, to the review of the VE (Section 2.3.4), indicates that the construction industry has in fact adopted the *modus operandi* of the VE for decades. What it hasn't achieved however, due in part to its conservative and somewhat technophobic nature, is *effectively* operating as a VE. In order to work effectively and to overcome many of its problems, the construction VE requires technology that will digitally enable it. The Researcher believes that in order to develop pragmatic business solutions, the above characteristics have to be closely addressed in developing such enabling technology for the sector. Many of the characteristics are pointedly human and organisational in nature, which means that social and, ultimately, economical considerations have to be made rather than concentrating the development process on the technology alone. From a technological standpoint the Internet has become the international standard for electronic communications. Adoption and adaptation of technology may be key to the future of the sector, but the fact that construction is such a labour intensive industry points clearly to the need for a focus on human issues: its people bring the industry to life, not merely its technology.

2.5 Conclusion

This chapter presented a critical review of the literature for the thesis, the literature selection being based on the themes and overall objectives of the study. A review of relevant aspects from organisational theory was followed with reviews of the literature regarding the VE, and finally that examining the European construction sector.

It is clear from this chapter that rather than the VE being a completely new organisational form, the construction industry has adopted many of its characteristics in its *modus operandi* for some considerable time. It is also clear, however, that the sector faces many problems, which could be addressed by the development of ICT solutions geared towards digitally enabling the construction VE (and thereby realising the commonly held view of the 'VE paradigm').

The characteristics of the sector suggest that in researching, developing, and evaluating and testing such potential solutions, the human and organisational aspects require particularly close attention.

Although much research work has already been carried out in the construction arena, there is still an ongoing need for further research, to which this thesis adds. The literature review gave the Researcher a 'conceptual framework' upon which to base the specific research tools to be used in the rest of the study.

The following chapter presents the research methodology for the study.

Chapter 3
Research Methodology

Principles of research; Derivation of the research questions; Methodology chosen for the thesis.

3.1 Introduction

Following the literature review in the previous chapter, this chapter presents the methodology used for the thesis. The first part of the chapter draws on the literature and offers a discourse on the principles of research methodology, the importance of purpose, research design, and research approaches. The second part then details the research questions being addressed through the thesis and how they came to be asked, and summarises the research objectives. The third part of the chapter then describes the methodology chosen for the thesis, and the rationale based on the literature review and research questions.

3.2 Principles of research

A substantial literary corpus exists concerning the principles of research, including definitions, methods, design, tools, approaches, strategy, and so on. In the midst of the literature there also exist many contradictions in the use of terminology relating to these abundant elements, and ongoing (often heated) debates concerning different practitioners' employment of research 'methodologies' or 'paradigms'. Indeed, 'research' itself provides a dynamic, somewhat recursive research topic, from which copious (and, at times, contradictorily confusing) advice is offered. A very brief observation of definitions of 'research' shows that as an art it incorporates elements of inquiry, experimental design, data collection, measurement and analysis, interpretation and presentation of results (e.g. Greenfield, 1996); a process aiming to better understand the complexities of human experience, and in some genres to take action based on that understanding (e.g. Marshall and Rossman, 1999). From this, the Researcher believes that the driving element in research is *purpose*.

3.2.1 The importance of purpose in research

It is from the central position of purpose that informed decisions should be made regarding the methods and tools to use in a study. Indeed, the Researcher considers differing purpose to be the progenitor of available research paradigms. The aim of this chapter is not to add to the debate over research methodology; rather it is to clarify some of the elements prior to elaborating the methodology selected for the current study, notwithstanding which, however, some comment on the debate is fitting at this point. The Researcher contends that some of the debate about research methodologies could in fact be mitigated through perusal of much earlier work regarding scientific paradigms such as Thomas Kuhn's seminal work on scientific revolutions first published in 1962. In Kuhn's work 'paradigm' has two main interrelated but distinguishable meanings. Firstly 'it stands for the entire constellation of beliefs, values, techniques, and so on shared by the members of a given community' (Kuhn, 1996: 175). Secondly it denotes one sort of element in that constellation, an exemplar, or concrete puzzle-solution, which becomes the basis for future work. Kuhn explicitly stated that it is this second sense that is philosophically the deeper, yet discussions of (particularly more sociological as opposed to purely scientific) research methodologies appear to focus on the first. Kuhn noted:

> *"A paradigm is what the members of a scientific community share,* and, *conversely, a scientific community consists of men who share a paradigm. Not all circularities are vicious, but this one is a source of real difficulties. Scientific communities can and should be isolated without prior recourse to paradigms; the latter can then be discovered by scrutinizing the behaviour of a given community's members.* (Kuhn 1996: 176)

Given this, different research *purposes* in different settings will clearly require the particular methods most fitting to the attainment of a viable research solution. The research methodology chosen for a particular study is certainly important, but care is surely prudent in order to avoid the risk of what some commentators refer to as 'methodolatry' – the privileging of methodological concerns over other considerations (Chamberlain, 2000).

Patton (1990:150) sees purpose as the controlling force in research, and offers the following typology of alternative purposes:

(1) *basic research* to contribute to fundamental knowledge and theory;

(2) *applied research* to illuminate a societal concern;

(3) *summative evaluation* to determine program effectiveness;

(4) *formative evaluation* to improve a program; and

(5) *action research* to solve a specific problem.

Patton (1990:158) continues, stating: "there are not hard-and-fast lines of demarcation between these five different types of research." They in fact form a continuum from knowledge and theory development for its own sake, to action orientation aiming at solving immediate problems. Along this continuum, researchers engaged at different points feel very strongly about researchers at other points. (This is manifest to the extent that some basic and applied researchers do not view formative evaluation and action research as 'research' at all). As a final observation on the above debate, it is worth noting for example, that where Patton (1990) includes action research as a 'purpose', it may also be viewed as a 'method' (Baskerville and Wood-Harper, 1996), or indeed used as a 'research strategy' or a 'theory of social science' (Peters and Robinson, 1984).

The purpose of research may range for example from the purely scientific, researching cause and effect, in which case traditional laboratory experiments may be the best method, to the socio-organisational, for which more 'applied' or 'action' oriented research demanding quite different methods may be better. The purpose being addressed through the research questions in this thesis is aligned more to the latter, therefore the rest of the chapter draws more on the literature regarding 'social' research rather than that pertaining to 'scientific' inquiry *per se*.

3.2.2 Research design

From clarity of purpose an appropriate research design can be chosen. It is worth noting that research design is different from data collection methods (which is another source of confusion in the literature). Research design gives logical structure to a research inquiry, thus data for any design can be collected with any data collection method; how the data are collected is irrelevant to the *logic* of the design (de Vaus, 2001). Research design "deals with a logical problem and not a *logistical* problem," (Yin, 1994: 29), it is also, therefore, distinct from a work plan, which details what has to be done but itself is a result of the research design. In defining research design, de Vaus (2001: 9) postulates:

> *"The function of a research design is to ensure that the evidence obtained enables us to answer the initial question as unambiguously as possible."*

The aim therefore is to ensure that the relevant evidence is collected to answer the research question(s), to test theory(ies), to prove hypotheses, etc., in a convincing way. In order to do this, decisions have to be made regarding what types of data need to be collected and analysed, and the methods employed. The research design will generally describe the number and nature of the methods to be employed within the research (Sarantakos, 1998). (In order to avoid the dangers of the aforementioned semantic problems in describing research methodology, in the following the term 'research approach' is used to encompass what others have called methods, tools, instruments, etc., to examine the elements that may be used once the research design is decided).

3.2.3 Research approaches

The research approach employed will depend to some extent on the research perspective adopted. Three perspectives have been defined that are "the most dominant and provide a theoretical basis for the methodologies employed in the social sciences." (Sarantakos, 1998: 35). These perspectives are detailed in Table 6.

Criterion	Positivism	Interpretivism	Critical perspective
Reality is:	Objective Perceived through the senses Perceived uniformly by all Governed by universal laws Based on integration	Subjective Created Interpreted differently by people	Both objective and subjective Complex Created by people, not nature Full of contradiction Based on oppression and exploitation
Human beings are:	Rational individuals Obeying external laws Without free will	Creators of their world Making sense of their world Not restricted by external laws Creating systems of meanings	Creators of their destiny Oppressed, exploited Brainwashed, misled Hindered from realising their potential
Science is:	Based on strict rules & procedures Deductive Relying on sense impressions Value free	Based on common sense Inductive Relying on interpretations Not value free	Conditions shape life but can be changed Emancipating, empowering Relying on values
Purpose of research:	To explain social life To predict course of events To discover the laws of social life	To interpret social life To understand social life To discover people's meanings	To explain, interpret and elucidate To disclose myths and illusions To emancipate, and empower

Table 6: Theoretical perspectives in the social sciences (after Sarantakos, 1998: 35)

Disagreements abound in the literature regarding the use of 'quantitative' methods compared to 'qualitative' methods, and indeed their respective value. From the perspectives detailed above, it is clear that quantitative and/or qualitative data may be useful depending on the criterion (or criteria) being researched and the perspective taken. In virtually all areas of social research (including applied fields such as education, business management, etc.), research designs based largely or exclusively on the collection of qualitative rather than quantitative data are now considered to be respectable and acceptable (Robson, 2002). However, research designs are often still equated with the employment of either one or the other. For example, social surveys are typically classed as quantitative research, evaluated against statistical, quantitative research methods and analysis; case studies are seen to typically to fall into the category of qualitative research, adopting an interpretive approach to data studying things in context and considering peoples' subjective meanings (deVaus, 2001). A third camp, advocating a combination of quantitative and qualitative research further complicates this situation.

3.2.3.1 Surveys

It is possible to distinguish two broad types of survey: descriptive and analytical (Oppenheim, 1992). The descriptive survey is designed for fact-finding and to count, and is therefore enumerative. Census surveys are a good example, and in cases where it is not possible or feasible to count everyone, a sample is used from which inferences are made about the population as a whole. Descriptive surveys do not 'explain' things or indicate causal relationships. Analytic surveys on the other hand are used for analysing causality – answering the 'why' questions that an enumerative survey cannot (Oppenheim, 1992). Such surveys allow examination of relationships between variables.

Quantitative data

Quantitative data are the predominant data collected in scientific experiments, descriptive surveys, and indeed any type of research that allows categorisation of the object(s) being studied into ways that facilitate counting. They are generally collected through standardised observation instruments, questionnaires, highly structured interviews, etc. Through the collection and analysis of quantitative data the complexities of the world can be decomposed and assigned numerical values (Kerlinger, 1986). Being numerical, very large amounts of quantitative data can be readily analysed using computerised statistical analysis tools and programs, thus allowing surveys to draw on large population samples. Clearly they are ideal for descriptive survey, but they also allow analysis of causality through the distinction between 'independent' and 'dependent' variables. An independent variable is one that has an impact upon a dependent variable, whilst a dependent variable is an effect of an independent variable. There are basically three types of quantitative data analysis:

univariate, bivariate, and multivariate (Bryman and Cramer, 1990), which are the analysis of a single, two, and more than two variables respectively, and the variables themselves can be classified into types:

- Nominal (sometimes categorical) – classification in terms of a concept (discrete categories);
- Ordinal – classification in terms of categories, but the categories can be ordered or ranked (e.g. 'more' or 'less');
- Interval/ratio – classification is also in terms of categories with the differences between categories being identical. These are variables that are, strictly speaking, ordinal, but which have a large number of categories (e.g. multiple item questionnaire measures);
- Dichotomous – classification into only two categories (e.g. male or female). They are usually classed as nominal, but can sometimes be ordinal (e.g. pass or fail).

There are some obvious benefits associated with quantitative data such as: numbers make comparison of data easy, the data are easily standardised (Miller, 1994), and they are less susceptible to subjective interpretation, which allows straightforward assessment of validity. On the other hand, quantitative data collection does rely on the use of a standardised approach, thus people's experiences are limited to certain predetermined response categories (Patton, 1990).

Qualitative data

In contrast to quantitative data, qualitative data are "a source of well-grounded, rich descriptions and explanations of processes in identifiable local contexts," Miles and Huberman (1994: 1). The purpose of qualitative inquiry is to produce findings (Patton, 1990: 371), and the culminating activities of qualitative inquiry are analysis, interpretation, and presentation of findings. Qualitative data consists mostly of words, and analysis of the data is done through assembling, and clustering the words into semiotic segments, allowing the researcher to contrast, compare, analyse, and bestow patterns upon them (Miles and Huberman, 1994). In large studies, unlike the case with quantitative data, which are amenable to the use of digital analysis programs, in order to make sense of massive amounts of qualitative data they first have to undergo reduction in volume, which then allows the identification of such significant patterns. This data reduction occurs continuously and even before the data are actually collected anticipatory data reduction is occurring as the researcher decides which cases, which research questions, and which data collection processes to choose (Miles and Huberman, 1994).

Qualitative data are collected through three principal sources: in-depth, open-ended interviews, direct observation, and written documents. The data from interviews consist of direct quotations from people about their experiences, opinions, feelings, and knowledge in response to open-ended questions (Patton, 1990). Open-ended questions enable the researcher to understand and capture the points of view of other people without predetermining them in prior selection of questionnaire categories (though it should be noted that questionnaires can also contain questions that allow open-ended responses). Further sources include administrative and archival records (Yin, 1994). Qualitative data are used to develop concepts as opposed to applying already established ones, and to understand and explain phenomena, and qualitative research is essentially an investigative process.

Samples for qualitative data tend to be more purposive than random (which is the case for quantitative data collection). This is due partly to the initial definition of the universe being more limited, but also because social processes have a logic and coherence that is unmanageable in random sampling (Miles and Huberman, 1994). There are no formulas for determining significance with qualitative data, and no straightforward tests for reliability and validity, which means that the researcher must ensure diligence in fair representation of the results gained from the data

In many ways the contrast between quantitative methods and qualitative methods is a trade-off between breadth and depth. Qualitative methods permit the evaluation researcher to study selected issues in depth and detail because the data collection is not constrained by predetermined categories of analysis (Patton, 1990).

Triangulation

Research generally employs one basic methodology and one basic method, taken from one methodological context – the qualitative or the quantitative (Sarantakos, 1998). Over the years, many authors have argued forcefully that qualitative methods should replace the dominant quantitative methods, a view that has been strongly opposed by the advocates of quantitative methods. It has also been argued however, that this classification has created an artificial line and given rise to unnecessary conflicts among scientists (Gummeson, 1991). As mentioned above, there is a third camp that advocates the use of a combination of quantitative and qualitative methods. Combining different methods of data collection, for example surveys and experiments, experiments and observation, or observation and documentary methods when studying the same social issue is called triangulation, and is equally employed by quantitative and qualitative researchers (Sarantakos 1998).

Triangulation is thought to enhance the rigour of research and allow the researcher:

- to obtain a variety of information on the same issue;
- to use the strengths of each method to overcome the deficiencies of the other;
- to achieve a higher degree of validity and reliability;
- to overcome the deficiencies of single-method studies;
- to enhance interpretability (Blaikie, 1991; Sarantakos 1998; Robson, 2002).

For example, in a primarily quantitative study, the interpretation of statistical analyses may be enhanced by a qualitative narrative account (Robson, 2002). Denzin (1989) distinguished four types of triangulation:

- *data triangulation*: the use of more than one method of data collection (e.g. observation, interviews, documents);
- *observer triangulation*: using more than one observer in the study;
- *methodological triangulation*: combining quantitative and qualitative approaches;
- *theory triangulation*: using multiple theories or perspectives.

There are researchers who disagree with the concept of triangulation however, and many writers have discussed the problems (e.g. Blaikie, 1991; Denzin, 1989; Silverman, 1985). The arguments include: that generalisations of this kind are unfounded, that expanding the spectrum of methods employed to collect the data does not necessarily guarantee better results (Sarantakos 1998), and that triangulation opens up possibilities of discrepancies and disagreements among the different sources, for example interviews and documents may be contradictory (Robson, 2002).

The Researcher, however, contends that triangulation has great value, especially on the consideration that:

> *"If the aim is to change the world rather than study it, the sole view can be confidently stated. But triangulation is an acknowledgement that social research is rarely decisive and that confidence is often best established by collecting and presenting a number of viewpoints."* (Shipman, 1997: 106).

Questionnaires

It is a fact that surveys are often carried out on the basis of insufficient design and planning (if any at all), and that whilst 'fact-gathering' can be an exciting and tempting activity, the questions for a questionnaire should not be produced by the researcher simply trying to think of some interesting things to ask (Oppenheim, 1992; Robson, 2002). With poorly conceptualised designs, there is a very real danger that the weaknesses in the design are frequently not recognised until the results have to be interpreted, at which point it is too late to repair.

Questionnaire construction is a very demanding task, requiring important consideration being given to format, what types of questions to ask, and the length of the questionnaire, and it should be presented so that it is clear, easy to read and attractive to the respondent, and most importantly, that it achieves its purpose (Sarantakos, 1998). The questions should be designed such that they directly help achieve the goals of the research. Thus, a good questionnaire not only addressses the research questions, but also gets the co-operation of the respondents, and elicits accurate information (Robson, 2002). Furthermore, a questionnaire will not emerge fully-fledged; it has to be created, adapted, developed and piloted to ensure that it works as intended (Oppenheim, 1992). The questionnaire respondents have to be able to understand the questions in the way that the researcher intends, have access to the information needed to answer them, and be willing to, and actually answer them in the form called for by the question. It may therefore be necessary to alter the language of the question so that it is both understandable and unambiguous to respondents (Robson, 2002).

Questionnaires have both advantages and disadvantages. Table 7 illustrates the main advantages and limitations.

Advantages	Limitations
Less expensive than other methods	Do not allow probing or clarification
Produce fast results	Motivating respondents to participate
Can be completed at the respondent's convenience	Researcher does not know whether the intended person answered the questions
Anonymity	Impossible to check question order followed
Less opportunity for bias	No opportunity to collect further information via observation
Stable, consistent, uniform measure	
Objectivity	No supervision therefore partial response possible
Wide coverage	

Table 7: Advantages and limitations of questionnaires

Interviews

Conducting good interviews is an art that requires considerable interpersonal skills on the part of the interviewer. He or she must be able to put the interviewee at ease, pose questions in an interested manner, be able to strike rapport with the respondent in a short space of time, be aware of non-verbal cues (body language), and at the same time note down responses without interrupting the interview flow, and give support and prompting without introducing bias.

Interviews in qualitative research can be classified into three types based on the degree of structure or standardisation (Sarantakos, 1998; Robson, 2002):

- *Fully structured interview:* predetermined questions with fixed wording, usually in a pre-set order. A structured interview is in reality a questionnaire read by the interviewer as prescribed by the researcher.
- *Semi-structured interview:* predetermined questions, but the order can be modified based on the interviewer's perception. While some are closer to structured interviews, others are closer to unstructured interviews. Question wording can be changed and explanations given.

- *Unstructured interviews:* have no strict procedures to follow and can be completely informal. The interviewer lets the conversation develop on the basis of certain research points, formulating questions as and when required and employing neutral probing.

The degree to which interviews are structured depends on the research topic and purpose, resources, methodological standards and preferences, and the type of information sought, which of course is determined by the research objective (Sarantakos, 1998).

Interviews generally rely solely on open-ended questions, yet the interviewee must ensure bias is not introduced by asking 'leading questions'. In fact, if an interview is going well there should hardly be any need for questions as such, the interviewer may merely suggest a topic with a word, or a trailing sentence, and the interviewee will 'take it away' (Oppenheim, 1992).

The main disadvantages in interviewing are leading questions, interviewer bias, cost of conducting interviews, and consistency in both question presentation and data analysis. It is almost essential for interviews to be recorded on tape. This allows detailed analysis afterwards, for there is much that will escape the interviewer during the actual interview (Oppenheim, 1992).

3.2.3.2 Case study

Until recently, the authors of 'methodology' texts considered case study to be of dubious value by itself, and as a methodological 'soft option', whose real value was as an exploratory precursor, or as a complement, to an experiment or survey (Robson, 2002). It is worth noting, however, that:

> *"Case study research is remarkably hard, even though case studies have traditionally been considered to be "soft" research. Paradoxically, the "softer" a research strategy, the harder it is to do."* (Yin, 1994:16)

Today, case studies are considered to be a valid form of inquiry, not as a second-rank research stepping-stone to quantitative studies, but as a research enterprise of their own (Sarantakos, 1998; Robson, 2002). They are particularly valid when the research context is too complex for survey studies or experimental strategies, and when the researcher is interested in the structure, process and outcomes of a single unit (Sarantakos, 1998).

As a form of research, case study is not a methodological choice but a choice of what is to be studied, and is defined by interest in individual cases, not by the methods of inquiry used (Stake, 2000). The *case* therefore, is the situation, individual, group, organisation or whatever it is in which the research is interested (Robson, 2002). As a scientific inquiry, the aim is to study social action, openly and flexibly, within its real-life context, especially when the boundaries between phenomenon and context are not clearly evident (Sarantakos, 1998; Yin, 1994). In studying the phenomenon in its natural setting, the research is conducted via interaction and communication with, and as interpreted by, the respondents; this highlights the important criteria of openness, communicativity, naturalism and interpretativity (Sarantakos, 1998).

As phenomenon and context are not always distinguishable in real-life situations, a set of technical characteristics, including data collection and data analysis strategies, are defining elements to case study. The case study inquiry:

- copes with the technically distinctive situation in which there will be many more variables of interest than data points, and as one result
- relies on multiple sources of evidence, with data needing to converge in a triangulating fashion, and as another result
- benefits from the prior development of theoretical propositions to guide data collection and analysis. (Yin, 1994: 13)

Case study as a research strategy therefore comprises an all-encompassing method using multiple sources of evidence, in which the logic of design incorporates specific approaches to, and employs a number of methods of, data collection and data analysis (Yin, 1981; Yin, 1994; Sarantakos, 1998). The use of triangulation (Section 3.2.3.1) in case study research far exceeds that in other research strategies. It allows an investigator to address a broader range of historical, attitudinal, and behavioural issues, but the most important advantage presented by using multiple sources of evidence is the development of converging lines of inquiry, thus any finding or conclusion in a case study is likely to be much more convincing and accurate if it is based on several different sources of information (Yin, 1994).

Case studies can include both single- and multiple-cases. In some fields, multiple-case studies have been considered a different "methodology" than single-case studies however, Yin (1994) views the choice between single- and multiple-case designs within the same methodological framework, the important point being that every case should serve a specific purpose within the overall scope of inquiry.

In summary, the important points of case study research are that it is:

- A *strategy*, i.e. a stance or approach, rather than a method, such as observation or interview;
- Concerned with *research*, taken in a broad sense and including, for example, evaluation;
- *Empirical* in the sense of relying on the collection of evidence about what is going on;
- About the *particular*: a study of that specific case;
- Focused on a *phenomenon in context*, typically in situations where the boundary between the phenomenon and its context is not clear; and
- Undertaken using *multiple methods* of evidence or data collection. (Robson, 2002: 179)

From the above it can be seen that case study research is highly appropriate for research in information systems, and ICT in organisations. In such research there is a need to study not only the technology, but also to consider managerial and organisational questions, and indeed how innovation interacts with its proposed context. Benbasat *et al.* (1987: 370) believe there are three reasons why case study research is viable for information systems research:

- the researcher can study information systems in a natural setting, learn about the state of the art, and generate theories from practice.
- the case method allows the researcher to answer "how" and "why" questions, that is, to understand the nature and complexity of the processes taking place.
- a case approach is an appropriate way to research an area in which few previous studies have been carried out.

3.2.3.3 Action research

Action research has been used in the field of social science since the 1940s as a research strategy that integrates theory and practice through change and reflection (Lewin, 1947; Argyris, *et al.*, 1985; Reason, 1993), but it still has yet to draw a large following in the main stream of social science (Baskerville and Wood-Harper, 1996). It aims to pursue action and research outcomes concurrently, using components that resemble both consulting and field research. The process of action research is generally thought to involve a spiral of self-reflective cycles of:

- planning a change
- acting and observing the process and consequences of the change
- reflecting on these processes and consequences, and then
- re-planning and so forth (Kemmis and Wilkinson, (1998: 21).

The social basis of action research is involvement, its operation demands changes, and the *action* required is of both the system under consideration, and of the people involved in that system (McNiff, 1988).

Robson (2002) aligns action research with a 'real world' research emphasis, suggesting applied rather than pure basic research, policy rather than theoretical research (cf. Patton's purpose continuum, section 3.2.1 above). In questioning how different (if at all) action research is to other types of research, Sarantakos (1998) concludes that it uses the same type of research model as other research types, with some modifications regarding the role of the respondent and the manner in which data collection is conducted. McNiff (1988) sees action research as attempting to make sense of situations from a completely different standpoint to that of the 'traditional' view of research involving an experimental group and tests to measure their progress. She claims that action research "is research *with* rather than research *on*" (McNiff, 1988: 3).

In terms of information systems research, Susman (1983) detailed a five phase, cyclical, action research process as depicted in Figure 8. At the heart of the cycle is the system or environment under research.

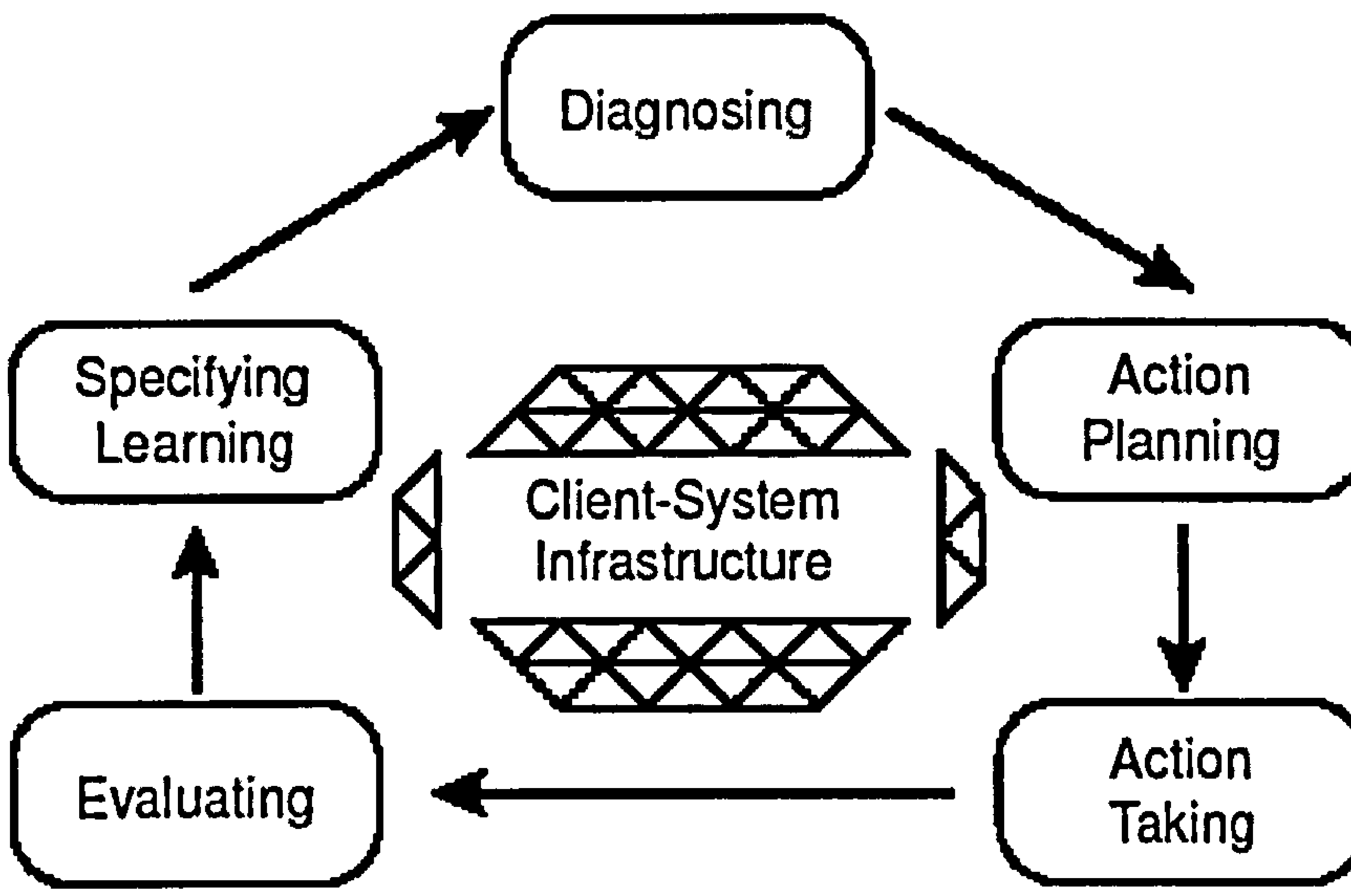


Figure 8: The action research cycle (Susman, 1983)

The five phases of Diagnosing, Action Planning, Action Taking, Evaluating and Specifying Learning are then carried out iteratively throughout the duration of the research process, and from this standpoint action research is regarded by many as the ideal research method for information systems research (Baskerville and Wood-Harper, 1996).

The elements that characterise action research, according to (Sarantakos, 1998: 113) are the personal involvement of the researcher, the emancipatory nature of the research, the active involvement of the researched, and its opposition to certain established policies and practices (which sets action research within the parameters of the critical perspective cf. Table 6 above).

Some authors see lack of impartiality of the researcher as a disadvantage with action research. As Benbasat *et al.* (1987) note, the action researcher is not an independent observer, but becomes a participant. Furthermore, Robson (2002: 216) points out: "if notions of collaboration and participation are taken seriously, then some power of decision about aspects of the design and data collection are lost by the researcher." A further disadvantage is that action research is context bound, thus not easily allowing for generalisations to be made to the wider world.

3.3 Derivation of the research questions

In reviewing the principles of research above (Section 3.2), it was stated that the Researcher believes that the driving element in research is the purpose. It could be said that without a genuine purpose research suffers the danger of becoming a mere passing interest in a particular subject or branch of learning. The purpose in this study is to work towards finding a viable solution to a real world problem. This problem is located in the domain of the European construction sector.

From the literature review (Chapter 2) it becomes clear that the construction industry in general could be viewed as having operated as a Virtual Enterprise (VE) for some considerable time. It is also clear, however, that it does not *effectively* operate as a VE; and this at a time in history when many other industrial sectors *are* employing advanced ICT to alter their own *modus operandi* in favour of the VE paradigm as defined in the literature.

The underlying problem being addressed therefore, is that whilst the construction industry operates like a VE, its ICT support for communication and information exchange still needs improving; interactions between actors are still not well co-ordinated; and ICT support for Information and document management varies from one company to another, but overall is still done in a traditional and *ad hoc* way.

In short, a solution needs to be found that will digitally enable the construction industry, which leads to the main research question of the thesis:

> *1. "Is the construction industry ready to move from a paper-based approach to collaborating and sharing information on projects, to an innovative model-based approach making use of the latest development in ICT?"*

It is inevitable with any considered research effort that the act of asking a pertinent and searching question of a particular branch of learning, will lead to yet more questions. That indeed proved to be the case with this main research question. Furthermore, in asking this overarching question, the Researcher recognised the need to realise a scope to ensure that the question could be answered within the constraints of a doctoral thesis. The thesis therefore aims to address three further, related and delimiting, research questions.

The literature relating to the VE indicates that one of the key characteristics is the integration of partners. As the 'links' between the people in the virtual teams that constitute the VE are supported by ICT solutions, it follows that a high degree of integration and interoperability is required with and between the different technology elements as well. Reviewing the fragmented nature of the construction industry, together with the fact that SME actors dominate it, and bearing in mind the disparate technologies already in use, led to the second research question:

> 2. *"Is the technology advanced enough to offer adapted solutions to the very characteristics of the construction industry?"*

Reviewing the literature regarding organisational theory emphasised the inherent 'human' nature of organisations, the influence and importance of the informal elements of the organisational system, and the change implications intrinsic to technological intervention. The lessons contained therein suggest that in attending to the need to digitally enable the construction industry a balance is required between on the one hand, integrated information infrastructures, tools and systems, and, on the other, the organisational peculiarities and complexities intrinsic to this sector. This then, begs the third research question:

> 3. *"Is the technology on its own able to provide a solution to the needs and aspirations of construction end-users?"*

As the characteristics of the construction industry indicate, it is a sector that survives on razor thin financial margins, is dominated by a few very large and influential companies, and is highly labour intensive with growing skills needs. These facts, combined with the preceding questions gave rise to the final research question:

> 4. *"Given the characteristics of the construction industry, does the industry require a new business model in relation to the purchase of ICT*

offering an affordable and profitable solution for SME and Clients on projects?"

3.3.1 Summary of research objectives

The main aim of the thesis is to find balanced answers to the above research questions, which address the underlying problem. In order to fully address the problem this aim can be converted into a number of objectives:

1. Clarify the concept of the virtual enterprise.
2. Understand the current practices, limitations and barriers, in organisations and on projects in the construction industry.
3. Provide a high-level process specification supporting ICT-based inter- and intra-company collaboration and communication in the construction industry.
4. Provide a conceptualisation supporting the above high-level process specification.
5. Monitor/orchestrate and provide useful contribution towards the development of a proof of the concept of the above specification.
6. Deploy the proof of concept implementations into real end-user scenarios.
7. Test and validate the resulting proof of concept prototype deployment.
8. Analyse the outcomes from the evaluation of the prototype and elaborate business recommendations.

3.4 Methodology chosen for the thesis

It is clear from the literature review and the above discussion of the research questions that the problem being addressed is posited in the arena of advanced ICT use in an organisational setting. The Researcher's background, experience and research interests are in the socio-organisational aspects of such problems as opposed to the highly technical issues. The research contained within this thesis is *applied* research, investigating pragmatic solutions to a 'real world' problem, rather than purely theoretical research. The Researcher concurs with the view of Hakim (1987), who sees the difference between what she terms as 'policy' research and theoretical research in terms of emphasis. For her, the main features that distinguish policy research from theoretical research are:

> *"an emphasis on the substantive or practical importance of research results rather than on merely 'statistically significant' findings, and second, a multi-disciplinary approach which in turn leads to the eclectic and catholic use of any and all research designs which might prove helpful in answering the questions posed."* (Hakim, 1987).

The research design in this thesis incorporates a central, driving, case study: the OSMOS project (section 3.4.2), which is centred on action research principles. This is added to, and enriched by research and results from two further (ongoing) studies: the VOSTER project (section 3.4.3), and the ICCI project (section 3.4.4).

3.4.1 Literature review

As already stated in the introduction to Chapter 2 (section 2.1), literature review is an essential phase in the research process allowing the researcher to delimit the problem under investigation. The reviewing process of suitable literature is generally the starting point in any research study, which was of course the case with this thesis. However, with the 'body of knowledge' being continuously added to (at an ever increasing rate it appears), it is prudent to be iterative in one's approach to literature review. The Researcher has, therefore, approached the literature reviewing process as a dynamic element in the methodology, especially in the awareness of the fact that the field of learning continues to be added to in the interval between obtaining the results of one's research, and completing the writing up.

3.4.2 Introduction to the OSMOS project

As aforementioned, the OSMOS project is the driving case study for the thesis. It is via this project that the objective of testing and validating a potential solution to digitally enabling the construction VE was realised. In effect it was used as the main 'test bed' for the thesis research. OSMOS (Open System for Inter-enterprise

Information Management in Dynamic Virtual EnvirOnmentS) was a European funded project (IST-1999-10491), carried out over a 27-month period between January 2000, and March 2002.

The overall aim of OSMOS was: "to enhance the capabilities of construction enterprises, including SME, to act and collaborate effectively on projects by specifying, setting up and promoting model-driven, value-added, Internet-based flexible services that support team work in the dynamic networks of the European construction industry."

3.4.2.1 The OSMOS consortium

The OSMOS project was driven by the needs of end-users and the market, through the expertise of European leading construction businesses, including construction IT service providers, and European leading research centres. A consortium comprising the following six organisations undertook the work:

Derbi – Derbi is a subsidiary of the French consulting engineering firm **Groupe OTH** (OTH). Founded in 1970, the company is engaged in three main fields of activity: Research, software and application design and development; implementation of solutions for computerised data exchange; and network management consultancy.

CSTB – The "Centre Scientifique et Technique du Bâtiment" (CSTB) is the French national public research establishment in the construction field. CSTB's activities cover four major fields: research, technical consultancy, quality assessment and knowledge dissemination.

Granlund – Granlund is the largest engineering company in building services consulting in Finland. Founded in 1960, it employs 280 people, and is privately owned (mainly by the employees). The company's main activities are building services design, facilities management consulting, and development of design and facilities management software.

JM – JM AB (publ) is Sweden's largest housing developer, with an increasing focus on project development of both residential and commercial properties. Founded in 1945, it employs approximately 2500 people, and is a public company. Restricting most of its activities to the particular niche of housing construction, JM undertakes the complete building project from land acquisition to the development of detailed development plans.

ISI-USAL – The Information Systems Institute (ISI) was founded as a partnership between the University of Salford and leading businesses in the UK. The ISI research centre involved in the OSMOS project, one of the most successful in the UK and internationally recognised, is focused around information and management systems applied to the built and human environment.

VTT – Technical Research Centre of Finland, is the largest research establishment in the Nordic countries and one of the largest in Europe. The research group of VTT involved in the OSMOS project focuses on four main activities: design methodology, project management, information networking and product data technology.

3.4.2.2 The OSMOS project methodology and work plan

The OSMOS project adopted an action research approach (pursuing action and research outcomes at the same time – see section 3.2.3.3 above). By adhering to the principles of action research, the consortium adopted an incremental and iterative approach to address the objectives of the project. The project duration was 27 months, with the work being carried out across three iterations (of nine months each). Each iteration allowed the consortium to assess and validate the OSMOS infrastructure, and address the potential risks in relation to the implementation of the proposed solutions. Figure 9 graphically represents this approach.

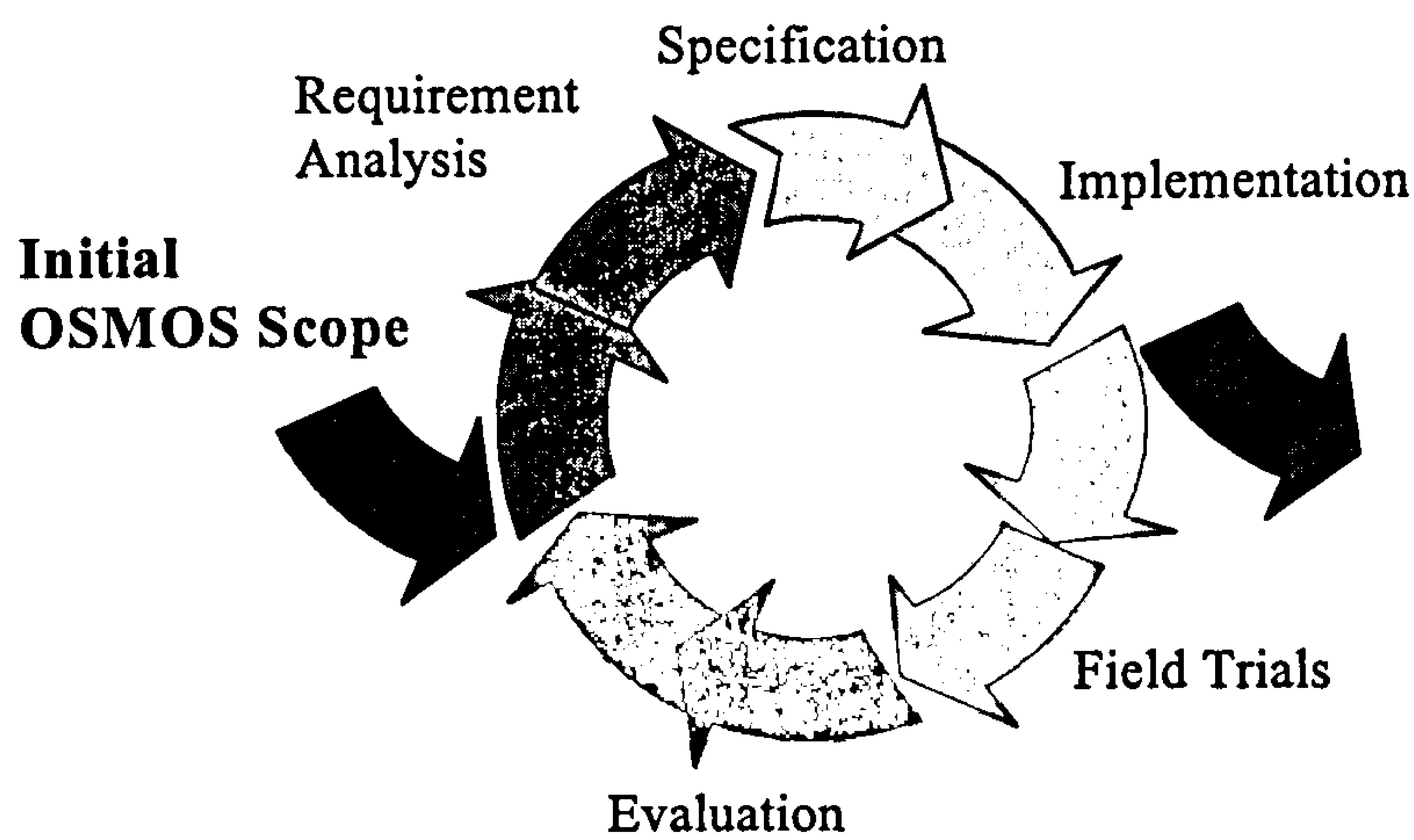


Figure 9: OSMOS Iterative and Incremental Approach

A single iteration of the project was carried out across six work packages (WP) (including ongoing project management and dissemination), which were interdependent, providing feedback in a cyclical manner. The four technical work packages were:

1. WP1: State of the art and requirements capture.
2. WP2: Architecture definition and specification.
3. WP3: OSMOS infrastructure implementation.
4. WP4: Evaluation and organisational recommendations.

The Researcher was involved in the project throughout its complete lifecycle. He led all of the human and organisational aspects of the project including the validation and testing (WP4), took a prominent role in the requirements capture and modelling phases (WP1, WP2), and had a contributory role in all other aspects of the project.

3.4.3 Introduction to the VOSTER project

VOSTER (Virtual Organisation Cluster) is a European funded project (IST-2001-32031), being carried out over a 30-month period from December 2001 until May 2004. It is a cluster project initially clustering 29 EU projects (one of which is OSMOS) and accompanying measures that are researching the VO and Smart Organisations, covering elements of the complete lifecycle of a typical VO. The VOSTER consortium comprises thirteen European organisations (including the ISI, University of Salford) representing eight different countries.

The aim of the project is to collect, analyse and synthesize the results from a number of leading European research projects on Virtual Organisation (VO). The main objectives of VOSTER are to consolidate VO related concepts and their relationships, VO types, characteristics and indicators into a reference model; identify and recommend useful approaches for VO modelling; identify and promote best practices for VO formation and operation (particular focus on SME); identify relevant technologies and standards and assess their potential for VO infrastructures and interoperability; define functions of VO infrastructures and suggest ways to implement them; and promote VO approaches in European industries.

The Researcher is involved in all stages of the project throughout its duration. Research results from VOSTER form a part of the methodology in this thesis, to enhance the VE research of the main case study, and also to aid in generalising the results.

3.4.4 Introduction to the ICCI project

ICCI (Innovation co-ordination, transfer and deployment through networked Co-operation in the Construction Industry) is also a European funded cluster project (IST-2001-33022). It is being carried out over a 28-month period from September 2001 until 31st December 2003. The project initially clusters six EU projects (one of which is OSMOS). The ICCI consortium comprises nine European organisations (including the ISI, University of Salford) representing six different countries.

The project is addressing a wide spectrum of construction industry related issues dedicated to ICT: Virtual Enterprises and eWork, concurrent engineering, virtual collaborative workspaces; e-Business and e-Commerce applications in construction, organisational and social issues, and legal and contractual conditions for ICT use and deployment in construction organisations and projects. It is trying to establish a critical mass of European involvement to meaningfully start the process of change that is now required in the construction sector.

The Researcher is involved in all stages of the project throughout its duration, and is leading the work addressing organisational and social issues. Methodologically, the results from ICCI, particularly those regarding organisational and social issues, enrich and advance the results from the main case study, and form an important part of the discussion in Chapter 7.

3.4.5 Methods and instruments

The Researcher has employed a number of methods and developed various research instruments to produce the results he required for this thesis, which are described below. The main instruments developed include a questionnaire dealing with IT and the construction VE, which was used in the first iteration of OSMOS; an interview guide employed in a series of interviews during the second iteration of OSMOS; and field trial evaluation forms used in field trials during all three iterations of the project. Whilst all of these instruments were used for the specific purposes of the OSMOS project, the Researcher designed them primarily for the purposes of this thesis.

The questionnaire and interviews were used to glean information from people employed at different levels within the industrial organisations in France, Finland and Sweden (Derbi, Granlund and JM respectively). The questionnaires were aimed at the operational/tactical levels, whilst the interviews were aimed at the strategic/tactical level. This is depicted in Figure 10, which is based on the concepts of Figure 4 in Chapter 2.

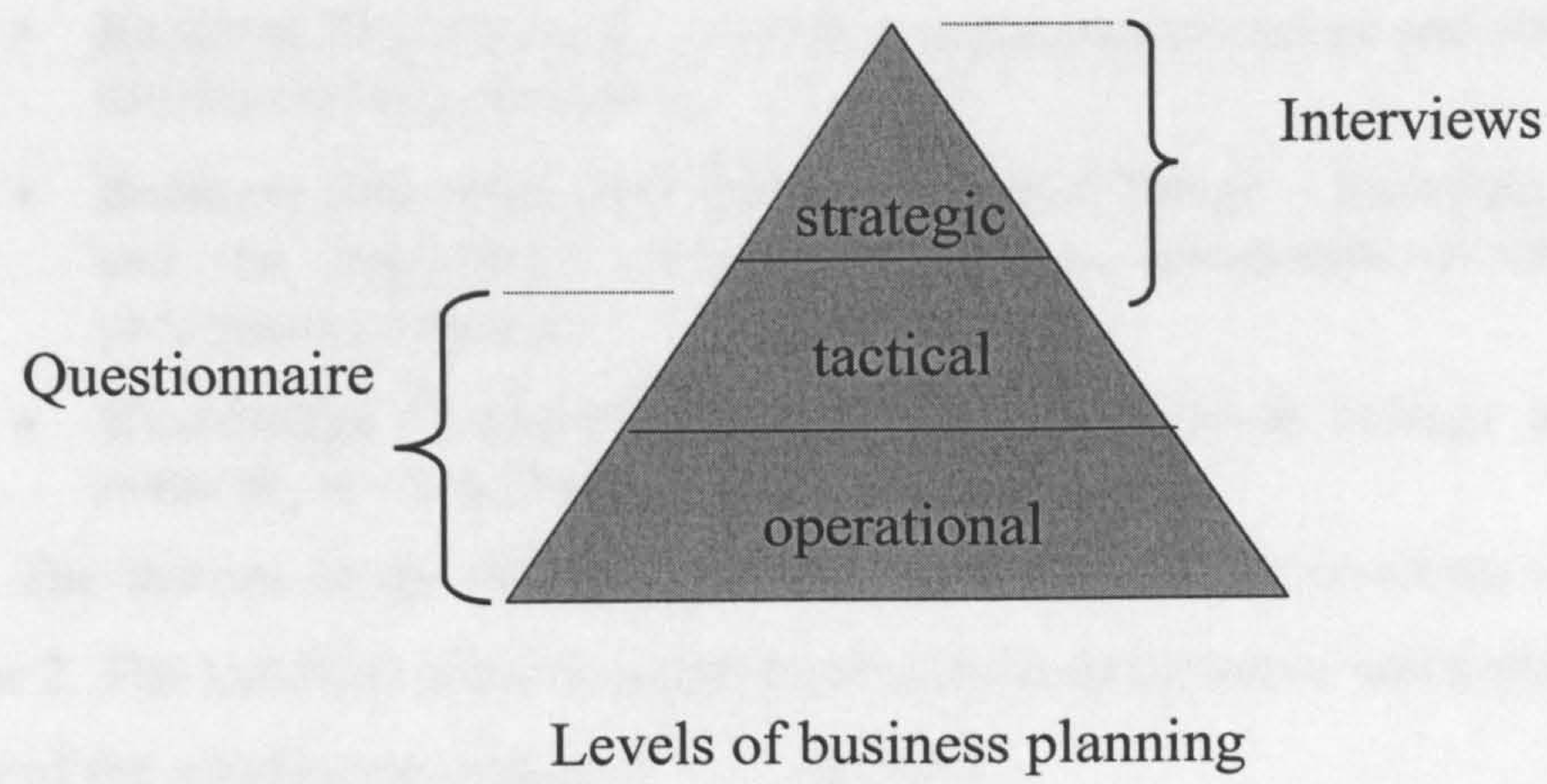


Figure 10: Levels of targeted personnel

It is worth noting here, that especially in terms of the questionnaire and interviews, the Researcher's intentions met with some strong initial resistance from the industrial partners in the consortium.

3.4.5.1 Questionnaire

As already mentioned, within the OSMOS project, the Researcher led the work package devoted to evaluation and organisational recommendations. It was within this work package that the IT and construction VE questionnaire was developed. However, the results had some bearing on the other work packages in the project, as the questionnaire also validated the requirements capture and provided feedback to the modelling efforts in the second iteration.

The questionnaire was designed to research factors that are often neglected in systems analysis and requirements capture within technical projects, and also to study how the organisations actually work, taking into account the informal as well as the formal sub-systems. It was divided into six sections:

- **General Information** – including personal information such as organisation, department name, tenure, and company specific information.
- **Information Technology** – including use of computers, skills and training needs.

- **Teamwork** – including composition and effectiveness of teams, communications methods, and information sharing.
- **Business Environment** – including organisation culture and structure, and decision making processes.
- **Business Processes and Organisational Change** – including awareness and the importance of business process, awareness of change, and perception of change.
- **Knowledge Management** – including information storage and sharing methods, and legal aspects.

The themes of the different sections are based on the concepts reviewed in Chapter 2. The questions were designed to elicit both quantitative and qualitative data. A copy of the questionnaire appears in Appendix 1.

In developing the questionnaire, the Researcher took advice from other people knowledgeable in the VE and organisation development fields. Using this feedback the questionnaire was further reviewed to eliminate any ambiguity before a final version was issued for pilot testing.

A pilot test of the questionnaire was made among the OSMOS partners, which revealed a possible language problem with the intended respondents in France and Finland. The Swedish partner commented that the English language would not be problematic. French and Finnish language versions were then produced. An initial reluctance to the questionnaire was voiced, due to its length, the number of responses required and also due to concerns regarding the validity of the questions in the context of a technical project.

In terms of sampling and analysis, the initial intention was to distribute the questionnaires electronically to 40 people chosen at random in each of the end-user organisations. This would ensure a representative sample and expedite the completion process. It was stated in all cases however, that a sample of 40 people in each organisation would be impossible to provide, and that lists of staff e-mail addresses could not be released for the purposes of random sampling. The questionnaire was finally distributed to 25 people at Derbi, 25 people at Granlund and 27 people at JM. On distribution of the questionnaire, a covering letter was attached explaining the purposes of the survey, and emphasising anonymity. The principal aim of the questionnaire was to create a profile of the industrial organisations in terms of all of the areas that would be impacted by the introduction of a digital VE solution. Due to the relatively small numbers of questionnaires, although the Researcher did employ an electronic analysis tool (SPSS – Statistical Package for Social Science) during the quantitative data analysis, there was little need for deep statistical analysis.

The results from the questionnaire survey appear in Chapter 6.

3.4.5.2 Interviews

The Researcher carried out semi-structured interviews in the three industrial partner organisations of OSMOS. The aim of the interviews was to analyse the strategic positioning of each organisation and its technological and organisational capabilities and competencies. The choice of interviewees was based on seniority and years of experience in the same company, and the resultant participants in the interviews were senior people such as managers, senior managers and owners of the company.

The Researcher has many years' experience in interview situations, and so was able to conduct all of the interviews himself. As an aid during the interviews, and in order to ensure consistency between the various interviews, an Interview Guide was developed (a copy can be found in Appendix 2). The guide clusters questions under four themes: Business environment; IT in construction; VE integration services; and Change. The guide was quite literally an *aide-mémoire* for the Researcher, and the order and wording of questions was not of consequence. All of the interviews were recorded on audiotape and the Researcher received no objections when asking the interviewees if this was acceptable.

Four interviews within OTH/Derbi, six interviews within Granlund and four interviews within JM were conducted. The interviews lasted from 25 minutes to one hour each and took place in the offices of each interviewee in the cases of OTH/Derbi and Granlund, and by telephone between Sweden and the UK in the case of JM. The language used throughout was English. There were no problems or difficulties reported because of the use of a foreign language, which can perhaps be explained by the seniority of the participants.

The results from the interviews also appear in Chapter 6.

3.4.5.3 OSMOS Field trial evaluation forms

Towards the end of each of the three iterations of the OSMOS project, field trials were held to test and evaluate the OSMOS approach in an iterative and incremental manner. The Researcher developed evaluation forms to be completed by the people taking part in the field trials in each of the industrial partner organisations. These survey instruments, in line with the technology, were also improved and developed iteratively. In the first iteration the forms were focused mainly on usability issues, and each participant in the field trials completed the same form. By the third iteration, the VE tools had developed to the extent that fully realistic end-user scenarios could be introduced, with different participants taking on different roles in the VE and therefore evaluating different aspects of the approach. The different 'roles' were arrived at according to the field trials scenarios in each country (see Chapter 6), and were based on perceived VE roles as discovered in the requirements capture research (see Chapter 4).

For the final field trials the Researcher designed three evaluation instruments. Firstly, the 'VE Server Administrator and Third Party Service Provider' evaluation form (a copy of which is presented in Appendix 3). This evaluation tool was developed as a basic questionnaire requiring only tick-box responses. The majority of the questions are grouped into two categories: Integration, and Training. Following these categories a generalised question eliciting ranked responses regarding the perceived importance of potential business benefits that may be gained through the introduction of the OSMOS approach was also included, designed to evaluate the overall approach in a generic fashion. A space was also provided for any other additional comments the respondent's might wish to make.

Secondly, the 'VE Project Administrator and User' evaluation form (a copy of which is presented in Appendix 4). This evaluation tool was also developed as a basic questionnaire requiring only tick-box responses and includes the same final generalised question described above and space for further comments as required. The majority of questions are grouped into four categories: Usability, Training, Job effectiveness, and Organisational effectiveness.

Both the VE Server Administrator and Third Party Service Provider evaluation form and the VE Project Administrator and User evaluation form are in the format of basic 'tick-box' questionnaires. Four boxes are provided for the recording of answers in the form of a Likert scale with scores from 1 to 4. A score of 1 denotes 'not at all'; a score of 4 denotes 'very much'. For the field trial in France the questions were translated into French. The language was not felt to be problematic for the testers in Finland and Sweden, however, so the questions remained in English. (It should be noted here that a VE Server Administrator and Third Party Service Provider form was not used in the Swedish field trial as this trial was focused solely on users).

Thirdly, the 'Observer' evaluation form (a copy of which is presented in Appendix 5). In order to ensure that the people testing the system could concentrate fully on the task at hand in the scenario, rather than having to break off to hand write 'qualitative' answers, it was decided to have at least one independent observer present at each field trial in the second and third iterations. The observers' role was to gain further information from the participants completing the other evaluation forms. This triangulation measure was used to add validity to the research results. It was recognised that different perspectives would be taken between the different people involved in the field trials according to their roles within the scenarios, thus for example, a participant ticking an answer of '1' (Not at all) would have a varying reason from that of another participant, and so the observer was asked to gain further 'qualitative' information for answers at the extremes of the scale. Further to the questions presented on the evaluation form, the observers were also asked to glean any other comments and observations that the participants felt necessary to make.

The evaluation form presents the observer with open questions in two sections: five questions directed to those people acting as the VE Service Providers; and twelve questions to those acting as VE Project Administrators/Users. The first two questions in both sections are the same, asking if the respondent feels that the software could be improved, and whether or not errors were found. The remaining three questions in section one (VE Service Provider) request comments regarding potential efficiency gains compared to current methods, the possibility of issues arising regarding the handling of contractual information, and any other comments. The remaining questions in section two (VE Project Administrators/Users) were designed to implicitly test the added value of the OSMOS approach. The questions are posed in an understandable and direct way to evaluate aspects including management, change, acceptance, and business benefits through the provision of third party services.

The results of the final (i.e. third iteration) field trials are detailed in Chapter 6.

3.4.5.4 Modelling

It is clear from the literature review that many of the business processes in the construction industry are still fully reliant on paper-based methods. In order to develop a pragmatic ICT solution to digitally enable the construction VE, current processes have to be analysed to ascertain the processes required in the digital VE. In the OSMOS project the Researcher was deeply involved in this process, where both intra-company information processes and inter-company interaction processes were analysed. From the analysis of these processes, a generic process model was developed (and refined in an iterative manner throughout the project) to specify the high level processes required in the VE. The method used for modelling these processes was IDEF0. The results of the modelling exercise are described in Chapter 5. From the high-level process model for the VE, the lower level processes (i.e. the technical functionality of the solution) could then be modelled, and the initial proposed system specified. In order to achieve this an object oriented modelling approach using the Unified Modelling Language (UML) was employed. The details of this are presented in Chapter 5.

This modelling methodology (a combination of IDEF0 and UML) enabled a deep comprehension of the industrial end-user organisations' business processes, from the level of the overall creation of a VE, through to the specifics of the required technical functionality, in a consistent manner.

3.5 Conclusion

For any research study, the importance of choosing the methodology best suited to the aims of the research should not be underestimated. However, it is also important to ensure that considerations of the methodological 'purity' of the study do not overshadow the aims. Having described the principles of research and pointed out the importance of logical design based on explicit purpose, this chapter then explained the provenance of the research questions that are to be answered. The methodology employed for this thesis includes an extensive literature review, which has already been presented in the main, in the previous chapter, and is driven by a central case study that is based on the principles of action research. This case study is supplemented by research from two other studies in which the Researcher is still involved. A variety of tools have been used, employing both quantitative and qualitative data collection and analysis. The chosen methodology is rationalised by the pragmatic, 'real world' nature of the purpose of the research.

The following chapter presents the business process modelling that was carried out within the requirement capture phase of the OSMOS project.

Chapter 4
Business Process Modelling

Methodology; The OSMOS Generic Virtual Enterprise Process Model.

4.1 Introduction

As already shown in Chapter 2 (section 2.2.1), central to the core of the organisation are the business, management and support processes. In defining the VE (section 2.3.2), it was shown that interdisciplinary teamwork is an essential factor in the VE, and one of the key elements in such teamwork is the purpose for which the virtual team is established. In order to move towards answering the main research question of the thesis, it is necessary to model the processes (which, if they are well researched, will directly achieve the purpose) that are required to digitally enable the construction VE.

This chapter presents the high-level modelling carried out in the requirement capture phase of the thesis case study (the OSMOS project). It first details the methodology used in the requirement capture phase, including some initial problems that were faced, defines perceived VE roles discovered in this analysis, and identifies inefficiencies and contractual, IPR and legal issues that deserve consideration. The following section then presents the high-level business process specification.

4.2 Methodology

The business process modelling presented in this chapter constitutes the first stage in the development and delivery of a digitally enabled construction VE platform, i.e. it aims to fulfil the third objective outlined in Section 1.2 above: to provide a high-level process specification supporting ICT-based inter- and intra-company collaboration and communication in the construction industry. Once the high-level processes to enable the construction VE were uncovered, they could be further decomposed at a system functionality level, ready for the development of suitable tools to be tested in the context of digitally enabling the construction VE. (The low level modelling, and development of tools that could be tested and validated, is presented in Chapter 5).

The process modelling was carried out in the context of the requirement capture phase of the central case study of the thesis. In order to arrive at a high-level specification for the business processes (i.e. the human and organisational actions and steps taken to achieve the purposes) of the VE, the requirement capture phase consisted of three elements: intra-company processes and information practices; inter-company processes and information practices; and ICT used in supporting the intra- and inter-company processes and information practices. The first of these elements provided a consistent view across the three end-user organisations taking part in the study (OTH/Derbi, Granlund and JM, in France, Finland and Sweden respectively), of how the organisations interacted and managed information on construction projects conducted within their organisations, according to the phases of the construction lifecycle that they most commonly operate. Analysis of the data obtained from this element revealed limitations in the working methods (see Section 4.2.4), and also provided input, regarding the types of ICT used, to the third element. The second element provided a consistent view across the three end-user organisations of how they interacted and managed information on construction projects conducted with external partners. As shown in Chapter 2 (Section 2.4.8), the *modus operandi* of the construction industry has in fact been that of a VE (though not efficiently supported by ICT). This second element therefore posed the question of how the construction organisations currently managed their processes in a virtual context. Analysis of the data from this element provided the primary input to the modelling of the generic processes required in the digitally enabled VE (Section 4.3). Furthermore, as with the first element it also revealed limitations in the working methods (Section 4.2.4), and provided input to the third element. The third element analysed the organisations' currently used software applications, in order to establish which types of applications might require integration within the VE. (As the focus of the thesis is the human and organisational aspects of enabling the digital construction VE, the remaining sections concentrate on the second of these three elements).

The processes studied were elicited from the construction organisations in the form of IDEF0 diagrams (described in the following section). On receipt of the completed IDEF0 models, the Researcher analysed the processes (especially the inter-company processes in the context of this thesis) by comparing the models from the three organisations, and extracting the common processes that enabled inter-company (i.e. 'VE') operation and information management. It should be noted again here, that this procedure was carried out in an iterative and incremental fashion across the lifecycle of the main case study of the thesis. The first iteration results were analysed with a view to developing a digital VE platform that could be tested initially via field trials conducted within separate organisations. It was not until the third iteration that the complete high-level VE processes (in the form of the OSMOS Generic Virtual Enterprise Process Model (GVEPM) – see Section 4.3 below) could be fully tested and validated. In analysing the IDEF0 models, processes were also extracted that showed where an individual organisation had activities that others might not have been explicitly addressing at that time. For example, Derbi were already using their own proprietary Electronic Document Management System (EDMS) as a basis for setting up a 'VE' via configuring roles and access rights between different companies taking part in an inter-organisational construction project. They were aware of the need for different VE 'roles', but the process showed inefficiencies (see Section 4.2.4) due to the organisation not having explicitly formulated those roles.

4.2.1 Intra-company processes

In the first iteration of the procedure for eliciting and analysing the construction organisations' business processes, an internal template was provided and distributed to the organisations for them to detail their business process and information practices as well as the ICT supporting their core business processes. The use of this template proved somewhat to be a failure. It consisted of a 'questionnaire' format providing the organisations with boxed areas in which to present textual descriptions of: their processes in terms of 'Use Cases'; their current software and hardware infrastructures; interfaces implemented between the various software applications used; and current IT skills in terms of business process and information management practices, interactions between teams on projects, and common construction applications. It was found that the templates provided caused some confusion between the end-users, however, resulting in information being supplied in varying formats that were difficult to analyse. For the second iteration an example format (initially elaborated by Granlund) was suggested, using IDEF0 functional modelling (NIST, 1993). Figure 11 below shows an annotated example of the format used for the analysis.

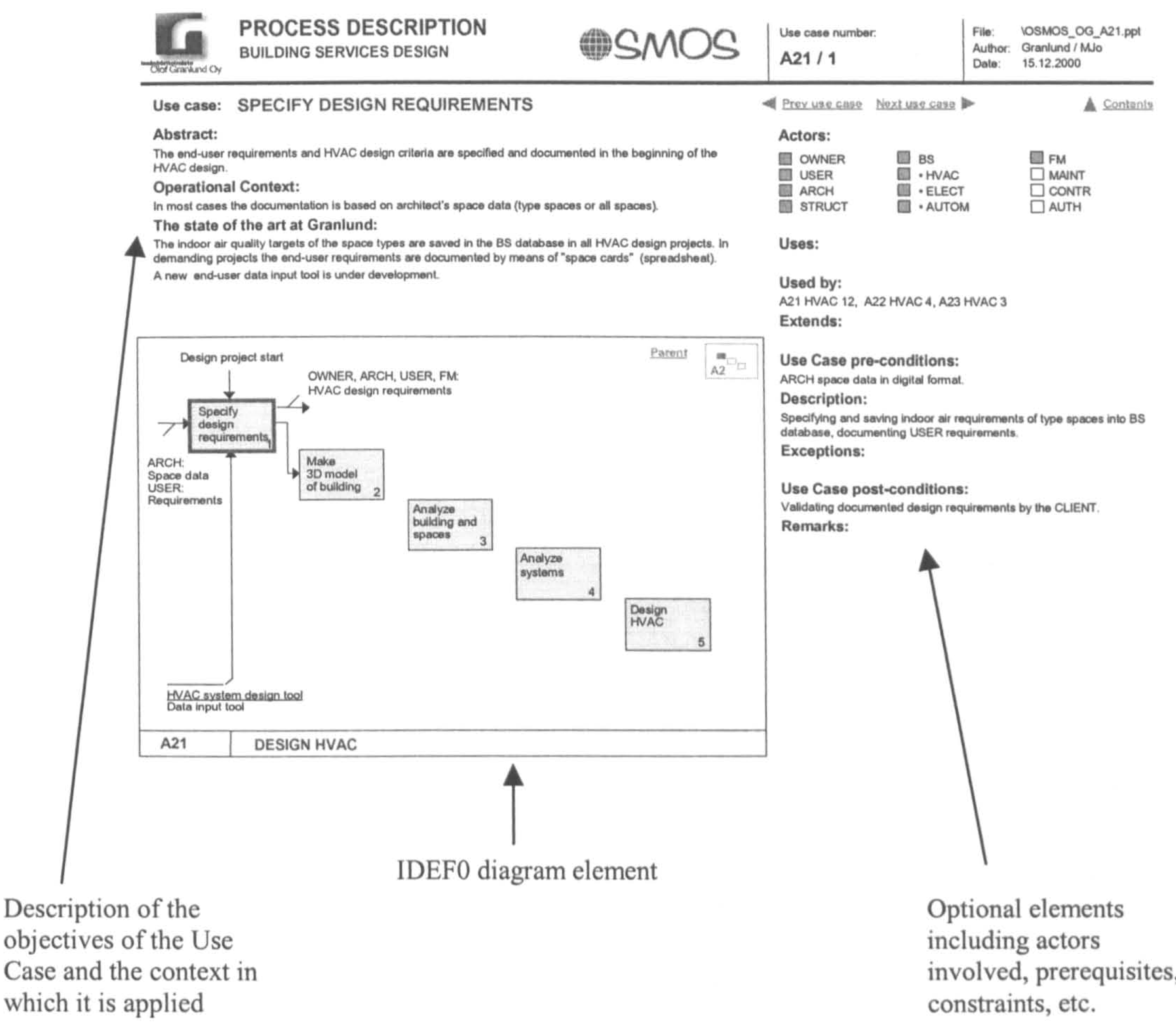


Figure 11: Suggested Format for Process Analysis

This format allowed the end-users to present their current processes as IDEF0 diagrams, and to include additional information to describe the activity being modelled and the operational context in which it is applied, plus the actors involved in the activity, any existing pre-conditions and/or post-conditions, exceptions, and other remarks pertinent to the activity. (It is worth mentioning that the Researcher is aware of the limitations of IDEF0 alone for process description, and it is argued that this standardised format enhanced the procedure).

The resultant models, which are presented in full in appendixes to Wilson, (2001a) provided a comprehensive view of the intra-company business activities and the methods of information handling between actors. This was the first step towards the specification of a high-level business process model for the construction VE. (These models are not presented here as they were primarily focused on intra-company, rather than 'VE' processes per se).

It is worth noting that from the failure of the initial template, the Researcher chose to focus on the particularly 'soft' issues, for example IT skills, in the separate questionnaire survey (see Chapter 6, Section 6.2), rather than confusing the issue of eliciting the business processes at this stage.

4.2.2 Inter-company processes

The next phase of the requirement capture was an analysis focused on the current management of teams and other actors in the context of a VE. This analysis (which also employed the above template) provided a comprehensive view of the inter-company interactions of the actors commonly involved in a construction project. The results of the analysis indicated the many variables to be taken into account during the life of a VE, including the requirement for processes at each stage of the VE lifecycle (creation, operation, evolution, dissolution – see Figure 6 above). As noted above, the procedure for modelling the high-level processes was iterative and incremental, and at each stage the nascent GVEPM was discussed in detail with representatives from each of the construction partner organisations involved, resulting in constant refinement and strengthening of the evolving concepts.

As noted in Chapter 2 (Section 2.4), the construction industry is characterised by (amongst other things) project work. In the first part of this section, it was stated that the processes were viewed according to the phases of the construction lifecycle in which each of the organisations involved most commonly operate. The organisations involved do in fact tend to focus their operations on differing phases of the construction lifecycle, and in different disciplines to some extent. Derbi/OTH, for example is involved in the complete lifecycle; Granlund focuses on building design and, predominantly, maintenance (i.e. facilities management (FM) towards the end of the building lifecycle); and JM covers the period from the acquisition of land until the planning of the construction phase in housing projects. It became clear during the analysis from these differing perspectives that a VE in the construction industry ought to be contemporaneous with the lifecycle of any specific building project, or indeed any particular phase of the building lifecycle where enterprises come together for a project in that particular phase. Depending on the actors involved therefore, a single VE may for example exist for the complete lifecycle of a building, whilst others may exist only during the design phase or FM phase. Each of these examples would require different infrastructures, available services, information management practices, and so on. (The complete models produced are presented in full in Wilson, (2001b), and are not presented here due to space considerations).

The analysis of the models highlighted interactions and processes that were common to all of the end-user companies, and also those that were specific to each, according to their individual perspectives in terms of the building lifecycle. Furthermore it became clear that actors would be required to take on specific VE "roles" according to their requirements for provision, operation, maintenance, and use of a digitally enabled construction VE. (Three potential "roles" within the VE were revealed, which are presented in the following section).

The combined results of the methodology described for requirement capture, provided the basis for the specification of a high-level business process model for the entire construction VE. This model is intended to illustrate the *generic* processes required in the VE, i.e. those processes that would need to be considered in each separate instance of a construction VE. The requirement capture models indicated that whilst each VE – contemporaneous with a construction 'project' – would require tools and services, the tools and services may not remain static throughout the VE lifecycle; indeed due to the rapid development of new ICT tools the generic process model would have to incorporate activities for provision, maintenance and removal of services as required.

Early versions of the GVEPM were predicated on a highest-level activity that focused on providing and maintaining a VE service. This activity then decomposed to three activities: *Provide and manage VE integration services, Provide VE service,* and *Maintain VE service.* From the above discussion it emerges that the highest-level activity required would be to manage and use the VE 'platform' (i.e. the digital solution provided to enable the construction VE), which would decompose to two quite separate activities: *Provide and maintain VE services,* and *Provide and maintain VE project.* In this solution (described further in Section 4.3 below), two distinct roles can be accommodated, one for a company or entity that may wish to act as an overall VE Service Provider (see below) and one for a company or entity that may wish to act as a provider of services to be made available to users via the 'platform' provided by the former. Furthermore the process model also allows for multiple projects to be run concurrently, with different configurations according to the specific VE requirements.

4.2.3 Perceived roles in the digital construction VE

As noted in the previous section, through detailed consultation with the industrial end-user organisations during the iterative requirements capture phase, three potential roles within the OSMOS VE model emerged. The three roles are:

A. *VE Service Provider*: a company wishing to provide the complete OSMOS VE system and services will take on this role.

B. *Third Party Service Providers*: companies taking this role will provide services that will plug in to the OSMOS system.

C. *VE Client*: this role includes any company that will sign up to the OSMOS VE Service to run a project.

These roles and their relationships in the context of the OSMOS solution are depicted diagrammatically in Figure 12 below.

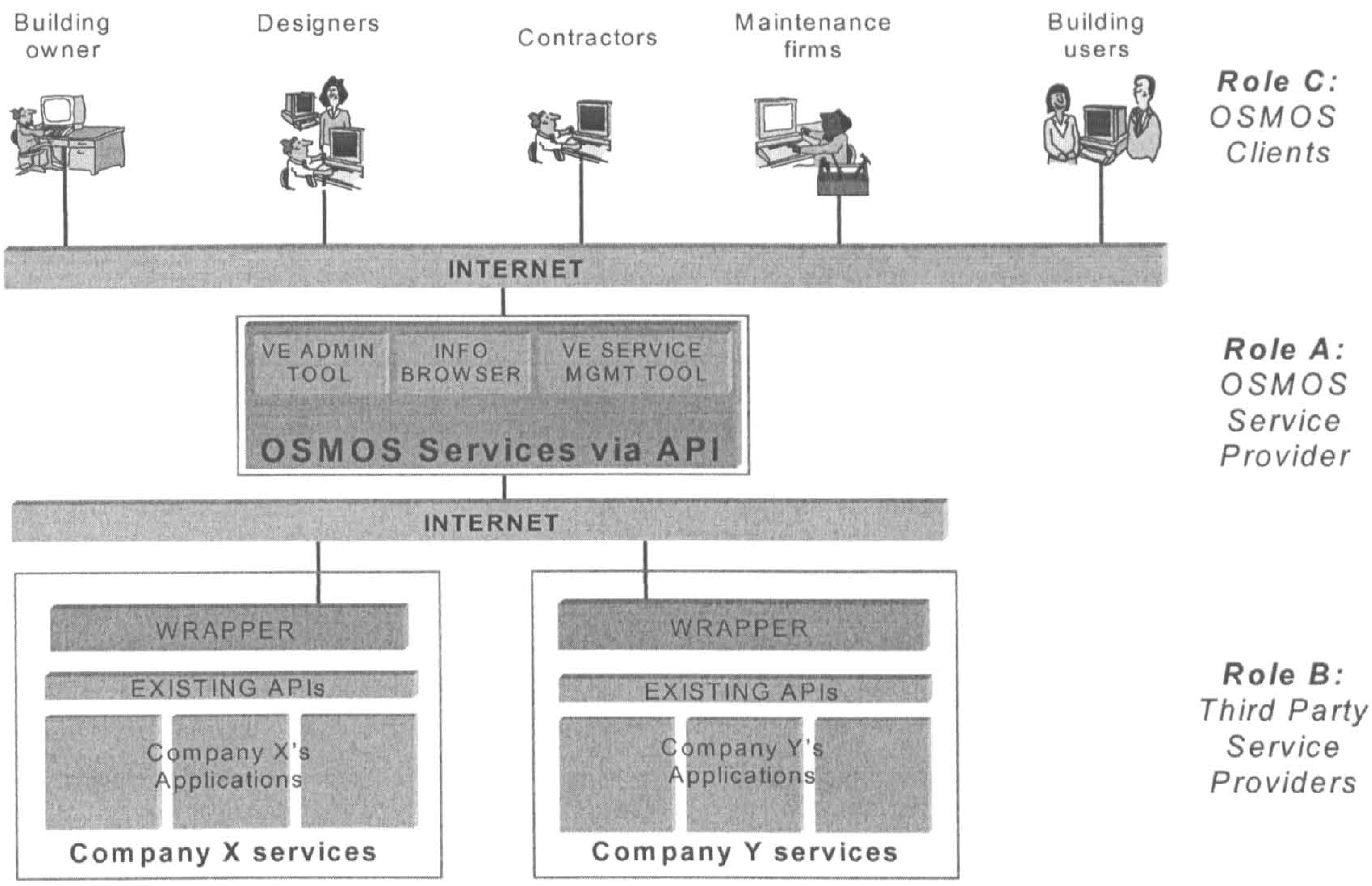


Figure 12: OSMOS Model and Proposed Roles (source: Wilson, 2001a)

In essence, the concept of the digitally enabled construction VE is to federate services and/or tools, and make them available to the people working in virtual teams in order for them to employ the tools to their purposes. With the tools and services being made available through links that are provided by Internet technologies, the people can avail themselves of such instruments in their own time. There are effectively two types of tools/services – firstly, those that will be used to create, operate, manage, and ultimately dissolve the VE (according to the VE lifecycle, see Figure 6), and secondly services provided by third parties (i.e. other than the VE service provider and the client). Thus, a VE Service Provider offers its web-based VE service to clients (individuals and/or organisations) via the Internet. Third Party Service Providers offer their own applications and services to clients through the API of the platform provided by the VE Service Provider. This allows the clients to receive a complete VE management service that is customised to their specific project requirements. (It is interesting to note that in terms of real world potential, the Researcher found that similar roles were also recognised (though with differing nomenclature) within the ISTforCE (IST-1999-11508) project – another project in the ICCI cluster – which aimed to establish an open concurrent engineering platform with access to tools and services. See for example Katranuschkov *et al.*, 2001).

4.2.4 Identified Information and Process Inefficiencies

During the analysis of the processes and practices of the industrial end-user organisations in the OSMOS consortium described above, a number of process inefficiencies that were present at that time were identified.

4.2.4.1 Process Limitations in OTH/Derbi

Three different kinds of process inefficiencies were identified within OTH/Derbi for which it was hoped a digitally enabled construction VE would help: the set-up complexity of an adapted team-work solution, the risk of non-added value services, and the limited capacities in terms of services.

The complexity of the set-up process was more a reaction of the users than a technical problem remaining unsolved. Setting up a VE with their existing Electronic Document Management System (EDMS) SGTi, required a methodology led by an EDMS consultant and meetings with the construction project management (the owner, the architect and the engineering design teams). There was no default configuration to immediately address the needs of the actors. Once the methodology was achieved, a certain level of autonomy was given to the VE administrator who generally belonged to the construction project management. But transferring the VE management from the provider to the administrator could not work without teaching the administrator how to manage the system. The actors themselves also had to be taught how to carry out their own tasks on the system. A solution to these inefficiencies was seen to be a 'light' version of SGTi (i.e. one made available rapidly and at low cost via a web browser, and not necessarily including all of the available functionality of the full EDMS), integrating more and more services through the proposed VE solution.

From this the second inefficiency emerged: it was necessary to provide actors with a large number of services adapted to their process needs and requirements. In their existing practices, Derbi had tried to imagine links between SGTi and Internet sites, but this would not give the dynamic effect expected by users. A more openly available and larger view was required.

The third recognised inefficiency, the risk of non-added value services, can be divided into two classes: non-added value service due to the functionality itself, or non added-value service due to the way users manipulate the system and diverge from the original aim of the functionality. To ensure that functionality is added value services, it is important that they are based on information and documents standards used. Some functionality is at the level of documents (creating files with different documents), others are closer to the production tools, and each time production tools are involved, a standard must be used. Non-value added services might also result in incorrect use of the system. For instance, architects often complain about EDMS because they have the impression that it tends to produce an artificial number of document indexes, while the number of different versions is less important in the case of paper document production (especially for drawings). This means that services promoted and integrated to the digital VE must diffuse an acceptable quantity of information to the user. This is also an important issue regarding any potential reengineering and help required for users adopting the proposed tools.

4.2.4.2 Process Limitations in Granlund

The existing Facility Management (FM) systems delivered by Granlund were based on client server architecture and thus problematic in large, geographically decentralised environments. Large installations can contain several thousand buildings at many different locations that are maintained by a centrally located maintenance organisation supported by local service personnel. At that time such cases could only be handled by dividing the building database into several smaller sub-databases that were subsequently merged back to the main database at regular intervals. Such a practice is error prone and leads to substantial additional effort.

It is often the case, especially in smaller renovation projects where facility data has to be updated, that building owners need to allow limited access to the FM-system to external consultants for short periods. At that time such arrangements were problematic and led to temporary, usually inefficient solutions. Large installations were also problematic from a maintenance point of view. Software updates had to be installed on all workstations connected to the system, a process that is expensive, time-consuming, and heavily burdens the IT-support personnel.

The existing FM systems were also primarily aimed at professional FM-users. They had a rich set of features, which led to a rather steep learning curve. Thus they were not well suited for more occasional use by, for example, ordinary building users. This led to problems in implementing services such as help desks.

4.2.4.3 Process Limitations in JM

Several systems for information storage co-existed at JM at this time, and frequently the same document was saved multiple times in different locations. This often led to problems, not only in terms of storage capacity, but also in terms of versioning control of the entire information repository system. In some cases external third-party databases were used offering a document management service to end-users on projects. However, these solutions revealed to be rather inefficient and often time consuming for users. Additionally, there was no direct link between external third-party databases and the internal information systems at JM.

There was a clear lack of effective IT support during the design stage. If, for example, the design manager did not have access to a CAD facility, he was effectively out of the communication chain, and could only rely on paper-based drawings. It was possible to use simple CAD-viewers (on free download) for drawing management, but in most cases these do not provide enough functionality and do not support some important drawing standards and formats such as .plt and .dwg. The most common tool for exchanging information was the email system, which was easy to use and required no formal training. Email systems do not, however, offer satisfactory solutions in terms of addressing more general actor needs and requirements.

JM felt it needed a system where all project information could be stored and made accessible for all participants in a project, regardless of whether the information was created internally or externally, and for the user to be able to view the information regardless of the software in which it was created.

4.2.5 Contractual, IPR and legal considerations on projects

During the process analyses within the requirement capture phase described above, various potential sources of litigation, due to contractual, legal and intellectual property rights (IPR) issues between partners on projects, were also identified. These were found to fall into broad categories including:

- Database and project knowledge ownership on projects.
- Validity of electronic signatures.
- Security and integrity of information in both static form and in transmission.
- Risk of perceived non value-added properties of electronic information (e.g. extensive and inappropriate use of indexes).
- Problems in relation to the dematerialization of information contained in paper project documents.

In the light of these issues, it was clear that in designing the high-level process specification for the VE the need for the controlling influences of contractual agreements, agreement of management protocols and procedures, and the legal environment in which a project is carried out should be included. Furthermore, much of the output from any construction VE operation will be in the form of information, whether it is product (or service), operational, process, or archive information. At the lower, functional specification, level therefore, logging activities, storage and transmission of information and data, and rights of access to and reuse of information demand consideration.

4.3 The OSMOS Generic Virtual Enterprise Process Model

The analyses described above, to describe current business processes and information practices and interactions between virtual teams, helped to understand current and perceived practices in terms of managing a VE. By abstracting from these analyses, it was possible to begin specifying the high-level processes for the digital construction VE. This specification was also achieved using IDEF0 modelling, and the resultant process model is presented here. The model is termed the 'Generic VE Process Model' (GVEPM), as by its very nature, the model is intended to be generic, allowing the VE solution to be implemented throughout the construction industry (and perhaps ultimately to other industrial sectors).

As aforementioned, in the first iteration of the project, an initial proposed GVEPM was developed based on the earlier analyses achieved at that time. That model was used as the basis for the system specification and development of the first prototype VE tools, which were also field-tested. The field trials results, and further analysis of the end-users' processes for supporting the VE, highlighted shortcomings in the early model, and these were taken into account in the second iteration (allowing for the perceived VE roles, and concurrent multiple projects). At the beginning of the second iteration therefore, the original model was redesigned, and an initial revised GVEPM was produced and delivered to the end-users for approval. After much consultation a second revision was designed, which was detailed to a very deep level in order to substantiate the concepts and discover the points at which the processes modelled actually become system functionality. This tentative interim model showed the direct mapping between the end-users' current practices, the proposed generic solution design and the actual system design. Finally, the GVEPM as presented below was defined after identifying and removing the lower level functionality aspects that were more correctly at the 'Use Case' level. These Use Cases were then defined in the specification of the OSMOS VE solution (see Chapter 5).

The model is presented as a set of IDEF0 diagrams with supporting text showing the basic processes required in the operation of the proposed solution.

Figure 13 shows the top-level (A-0) activity of the model and its interface to the process environment. The activity represents all the actions required to manage the VE platform, and to use the platform to run a complete VE Project (each project, as stated being a VE) from initial client requirements to the end of the contract.

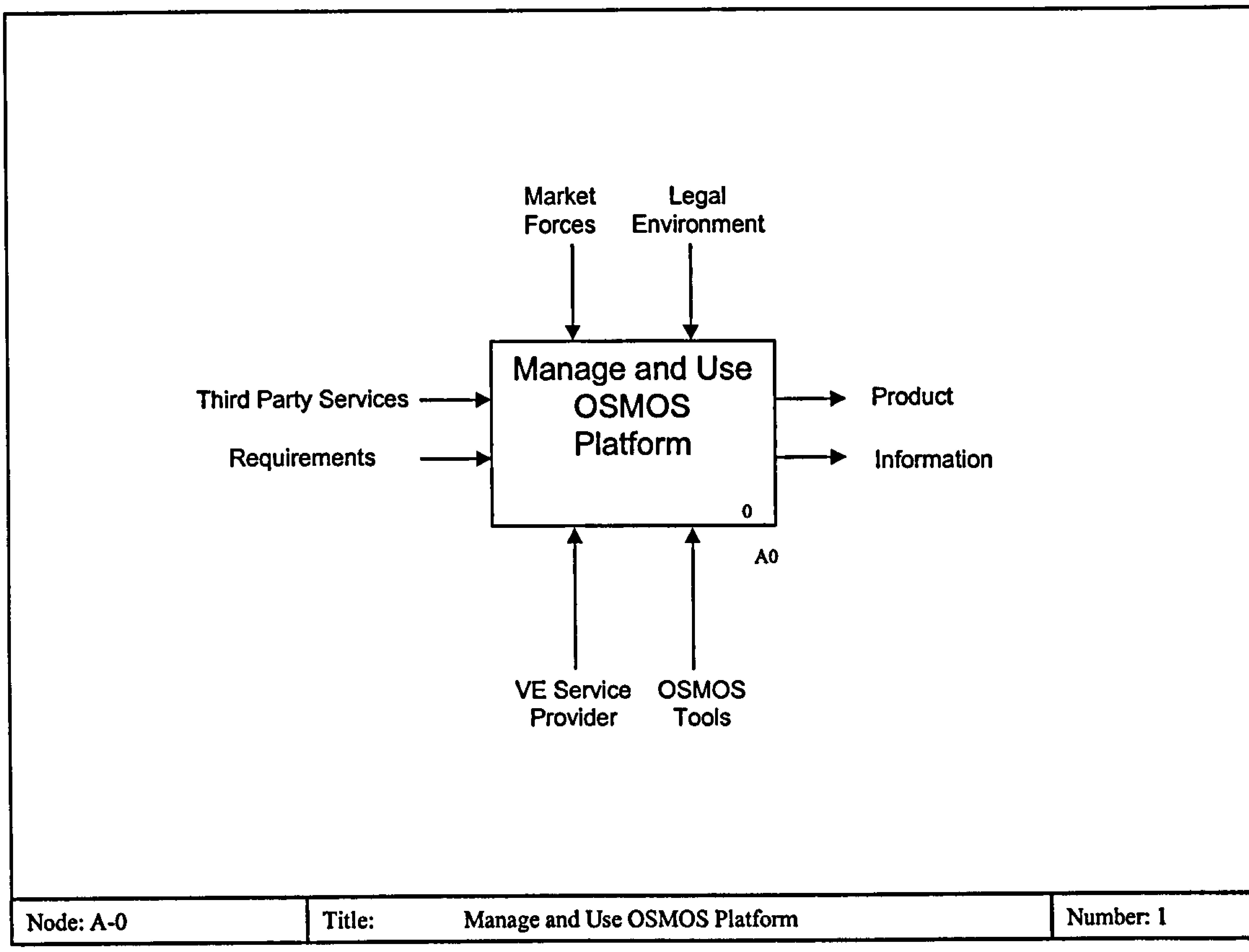


Figure 13: Node A-0 of the OSMOS Generic Virtual Enterprise Process Model

The overall inputs are Requirements and Third Party Services. Requirements include Project Requirements, Client Requirements, Legal Requirements and Industry Requirements as appropriate. Third Party Services are provided through or are made available via the OSMOS Platform. The legal environment operating at the time and current market forces control the activity. A product (or service) and accompanying information in varying formats form the outputs. The VE Service Provider using the OSMOS Tools performs the activity (the tools developed are described in Chapter 5).

This activity decomposes to *Provide and Maintain VE Services* and *Provide and Maintain VE Project* represented in node A0 (Figure 14).

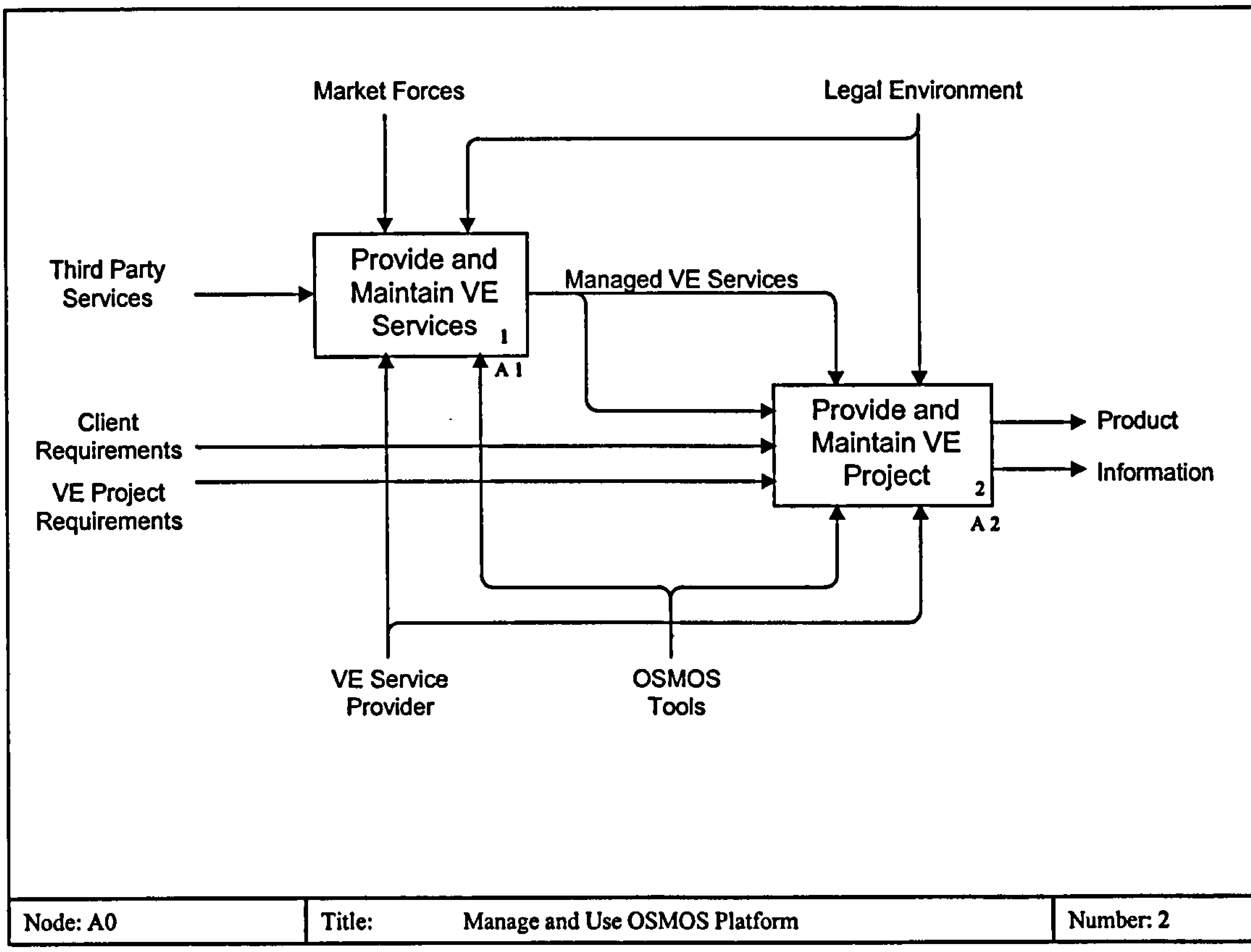
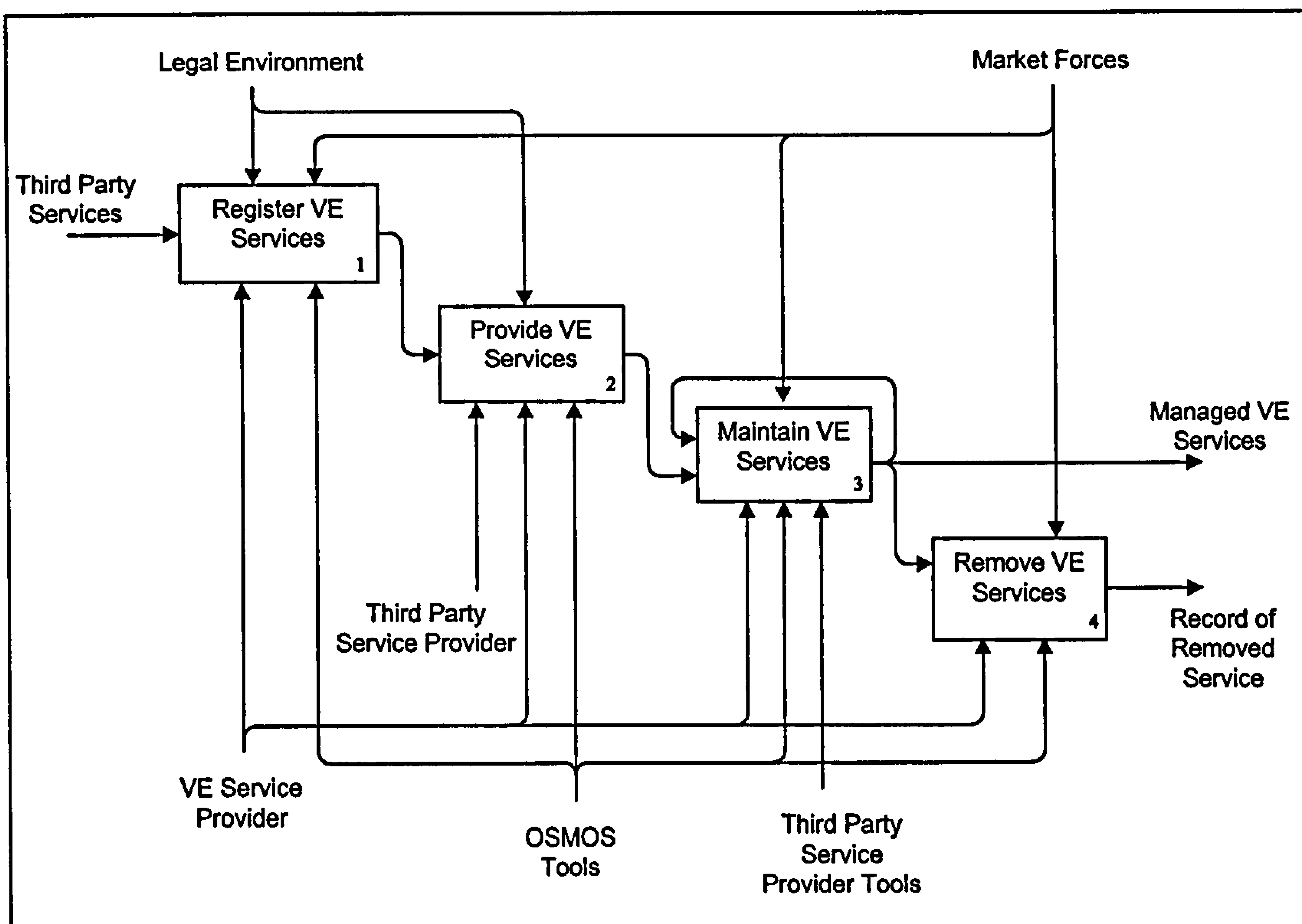


Figure 14: Node A0 – Manage and Use OSMOS Platform

Provide and Maintain VE Services – this activity involves the provision and management of the services available through the VE platform. Input to the activity is the Third Party Services. The legal environment operating at the time and current market forces, which will dictate the types of services currently available, controls the activity. The output is a set of managed and maintained VE Services, which form both input to and control over the *Provide and Maintain VE Project* activity. The VE Service Provider using the OSMOS Tools performs the activity. This activity decomposes to node A1 (Figure 15).

Provide and Maintain VE Project involves the provision and management of a VE Project. The inputs include the managed VE Services, the Client Requirements, and the VE Project Requirements. Client Requirements may change as available services, software applications, etc., are developed and included via the maintenance of the VE Services. The current legal environment and the managed VE Services control the activity. Outputs include the product (or service) produced by the VE Project, plus information from the project (including records of events throughout the project as well as the project archives). The VE Service Provider using the OSMOS Tools performs the activity. The activity decomposes to node A2 (Figure 16).



Node: A1	Title: Provide and Maintain VE Services	Number: 3

Figure 15: Node A1 – Provide and Maintain VE Services

Node A1 consists of four activities that are carried out to ensure the provision and maintenance of VE Services.

Register VE Services – this activity involves the actions required to register those services made available to the VE Service Provider by Third-Party Service Provider companies. Input to the activity is the available Third Party Services. The legal environment operating at the time and current market forces control this activity. The activity's output is VE Services that can be offered through the VE platform (and thus forms input to *Provide VE Services*). The VE Service Provider using the OSMOS Tools performs the activity.

Provide VE Services – this activity allows the VE Service Provider to offer Third Party Services to Clients via the VE platform. Input to the activity is those Third Party Services registered to the VE Service Provider from the Third-Party Service Provider companies. The legal environment operating at the time and current market forces control this activity. The activity's output is VE Services provided via the VE platform (and thus forms input to Maintain VE Services). The VE Service Provider using the OSMOS Tools performs the activity. It must be noted here, however, that the Researcher contends that some Third Party Services may be offered directly to Clients by Third-Party Service Provider companies rather than directly through the VE platform. Such cases would occur on an individual project basis, and the involvement of the VE platform would simply be to act as a gateway to the services. In these instances the Third Party Service Provider would perform that portion of the activity.

Maintain VE Services - this activity involves the ability to add, upgrade, and/or remove services as required, and as available. Such services are controlled according to the current market forces. Inputs to the activity include provided VE Services and also the managed VE Services that are the output of the activity. (Clearly, if a service is upgraded, for example, this may affect the required maintenance of the service). The VE Service Provider using the OSMOS Tools (and any necessary Third Party Service Provider Tools) performs the activity.

Remove VE Services – this activity allows the VE Service Provider to remove services from the VE platform. The input to the activity is managed VE Services, and it is controlled by the current market forces. When a service is removed from the platform a record of the action must be made (for contractual reasons). The VE Service Provider using the OSMOS Tools performs the activity.

Node A2 (Figure 16) consists of six activities that are carried out to ensure the provision and maintenance of a VE Project.

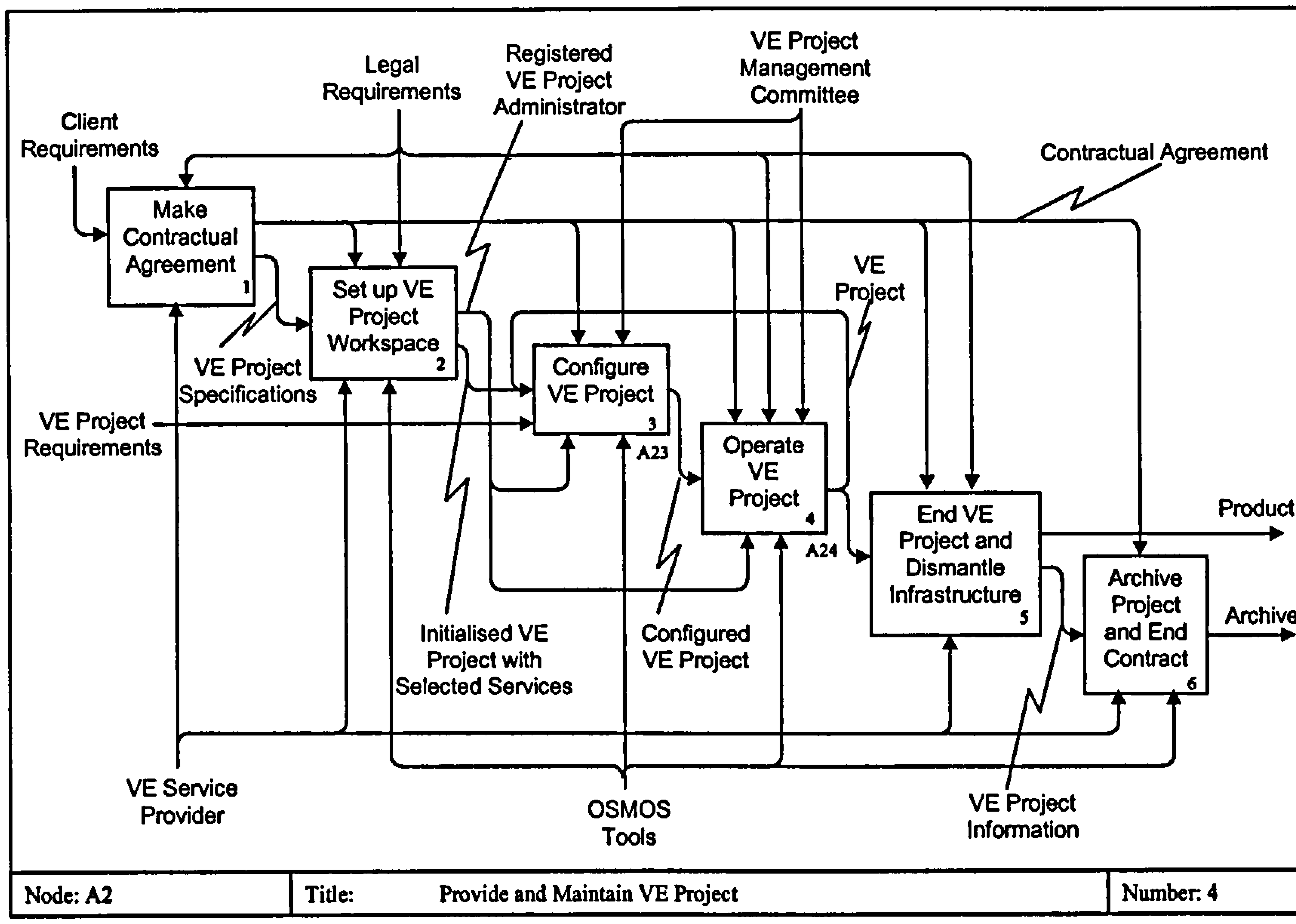


Figure 16: Node A2 – Provide and Maintain VE Project

Make Contractual Agreement – this activity involves the actions required in the formation of a contractual agreement between a Client and the VE Service Provider relating to the operation of a VE Project. The input to the activity is the Client Requirements for the proposed VE Project, and it is controlled by the Legal Requirements. The outputs from the activity are the Contractual Agreement, which forms a control over the other five activities in this node, and the VE Project Specifications satisfied under the Contractual Agreement. The VE Service Provider performs the activity.

Set up VE Project Workspace – this activity allows the VE Service Provider to allot the necessary servers, computer resources, logging facilities, required VE and Third Party Services etc., to a VE Project once a Contractual Agreement has been made. The activity takes the VE Project specifications as its input, and is controlled by both the Contractual Agreement and the Legal Requirements. Within the activity a VE Project Administrator will be registered and the VE Project will be initialised with the services selected for its operation. Output from the project therefore, includes the

Registered VE Project Administrator (who performs the *Operate VE Project* activity), and the initialised VE Project with its selected services. The VE Service Provider, using the OSMOS Tools performs the activity.

Configure VE Project – this activity includes all the actions required to configure the VE Project established under the terms of the Contractual Agreement from its initialisation to its actual launch. Inputs to the activity are the VE Project Requirements, the Initialised VE Project with Selected Services and also, potentially, already operational VE Projects. (This is because a VE Project that is already in operation will require re-configuring after certain events such as changes to access rights, actors, etc.). The activity is controlled by the terms of the Contractual Agreement, and the VE Project Management Committee. Output from the activity is the configured VE Project. The VE Project Administrator performs the activity using the OSMOS Tools. The activity decomposes to Node A23 (Figure 17).

Operate VE Project - this activity represents all the actions required to operate a VE Project, in terms of Actors, Roles, Access Rights, and Services. Its input is the Configured VE Project, and the Contractual Agreement, Legal Requirements, and the VE Project Management Committee control it. Output from the activity is the VE Project (in its operational phase). The VE Project Administrator performs the activity using the OSMOS Tools. The activity decomposes to node A24 (Figure 18).

End VE Project and Dismantle Infrastructure – this activity occurs at the end of the VE Project's lifecycle and represents the actions required to complete dissolution of the current VE Project. The VE Project is the input, and the Contractual Agreement and Legal Requirements control the activity. The outputs include the Product (or service) created by the VE Project and all of the information generated and created by the VE Project. The VE Service Provider is responsible for carrying out the activity.

Archive Project and End Contract – at the end of the VE Project lifecycle the VE Project information is archived (and distributed, reused, disseminated, etc.) according to the Contractual Agreement, and the contract is ended. The input to the activity is information (to be archived). The terms of the Contractual Agreement control the activity, and the output is the information archive. The VE Service Provider performs the activity using the OSMOS Tools.

Node A23 (Figure 17) consists of six activities that are carried out to configure a VE Project that has been set up under the terms of a Contractual Agreement.

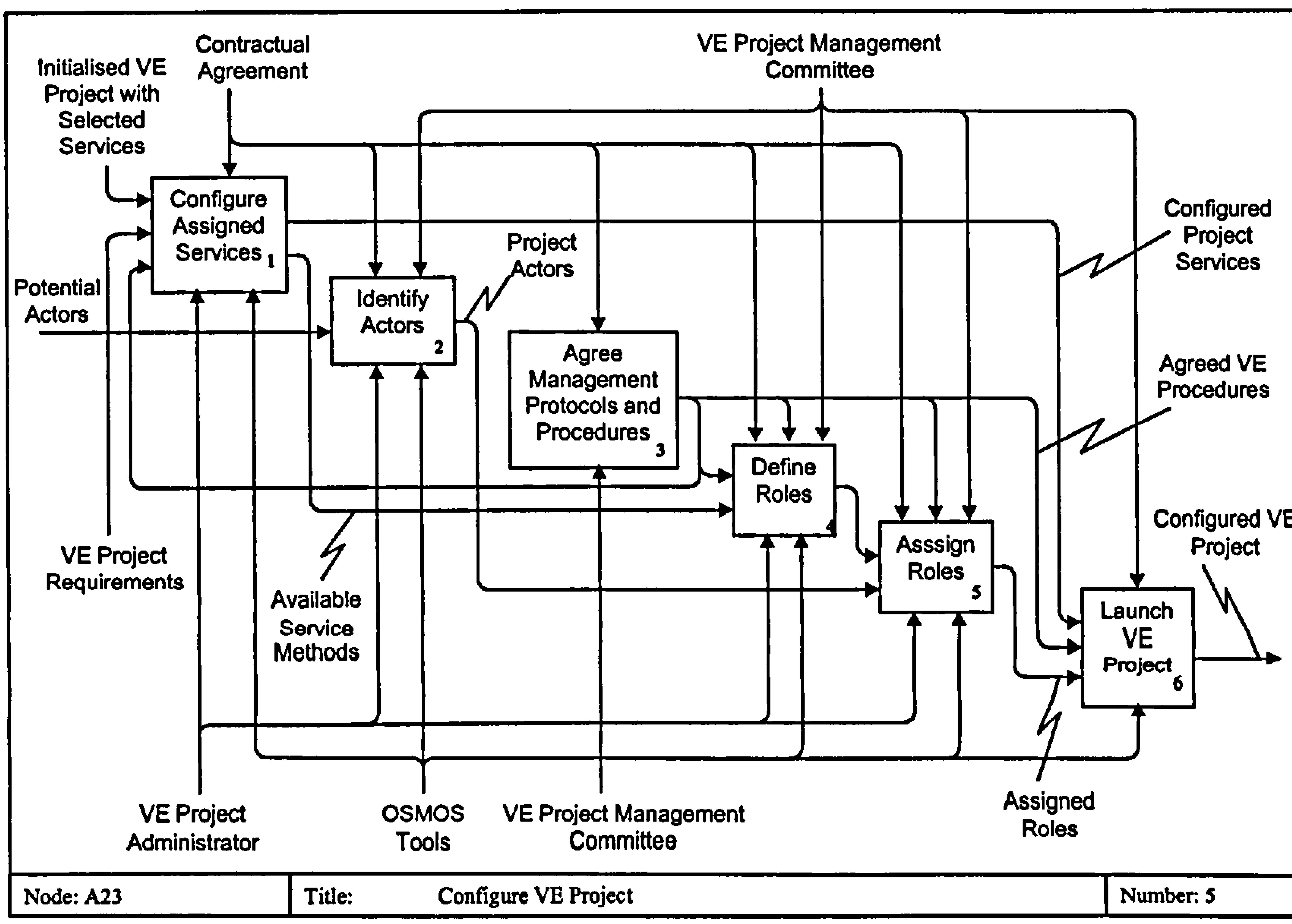


Figure 17: Node A23 – Configure VE Project

Configure Assigned Services – this activity allows the VE Project Administrator to configure the VE Services and other Third Party Services assigned to the VE Project to meet the needs Project Requirements. Inputs to the activity include the initialised VE Project with the services selected and assigned to it, the VE Project Requirements, and the agreed VE Procedures from the *Agree Management Protocols and Procedures* activity. The activity is controlled by the terms of the Contractual Agreement. The outputs from the activity are Configured VE Project Services and the Service Methods available to them. The VE Project Administrator performs the activity using the OSMOS Tools.

Identify Actors – this activity represents the actions required to nominate and confirm the Actors to be involved in the specified VE Project. All potential Actors form the input. The output is the designated VE Project Actors, to whom specific Roles can be assigned for the project. The activity is controlled by the Project Management Committee and the terms of the Contractual Agreement, and is performed by the VE Project Administrator using the OSMOS Tools.

Agree Management Protocols and Procedures – this activity represents the actions required to decide and agree upon the *modus operandi* of the VE Project (e.g. code of behaviour, responsibilities, course of action etc.). The output of the activity is the agreed VE Procedures (including document procedures, agreement regarding intellectual property rights (IPR) for work resulting from the VE Project, etc.). The activity is both controlled and performed by the Project Management Committee.

Define Roles – this activity represents the actions needed to identify and delineate the Roles within the specific VE Project. It takes the agreed VE Procedures for input. The output is precisely defined VE Project Roles that can then be assigned to the relevant Actors, with prescribed access rights and responsibilities. The Contractual Agreement, Agreed VE Procedures, and the Project Management Committee control the activity. The VE Project Administrator, using the OSMOS Tools performs the activity.

Assign Roles – this activity represents the actions needed to assign the Defined Roles to the Actors. Inputs to the activity are the Identified Actors for the project and the Roles as defined for the particular VE Project. The Contractual Agreement, Agreed VE Procedures, and the Project Management Committee control the activity. The VE Project Administrator, using the OSMOS Tools performs the activity.

Launch VE Project – this activity takes the Configured Project Services, Agreed VE Procedures and Assigned Roles, under the control of the Project Management Committee, to launch the specific VE Project. A Configured VE Project is the resultant output, and the VE Project Administrator, using the OSMOS Tools, performs the activity.

Node A24 of the model (Figure 18) consists of five activities required to operate a VE Project. All of the activities in this node take the Configured VE Project as an input, the Project Management Committee as a control, and are performed by the VE Project Administrator using the OSMOS Tools.

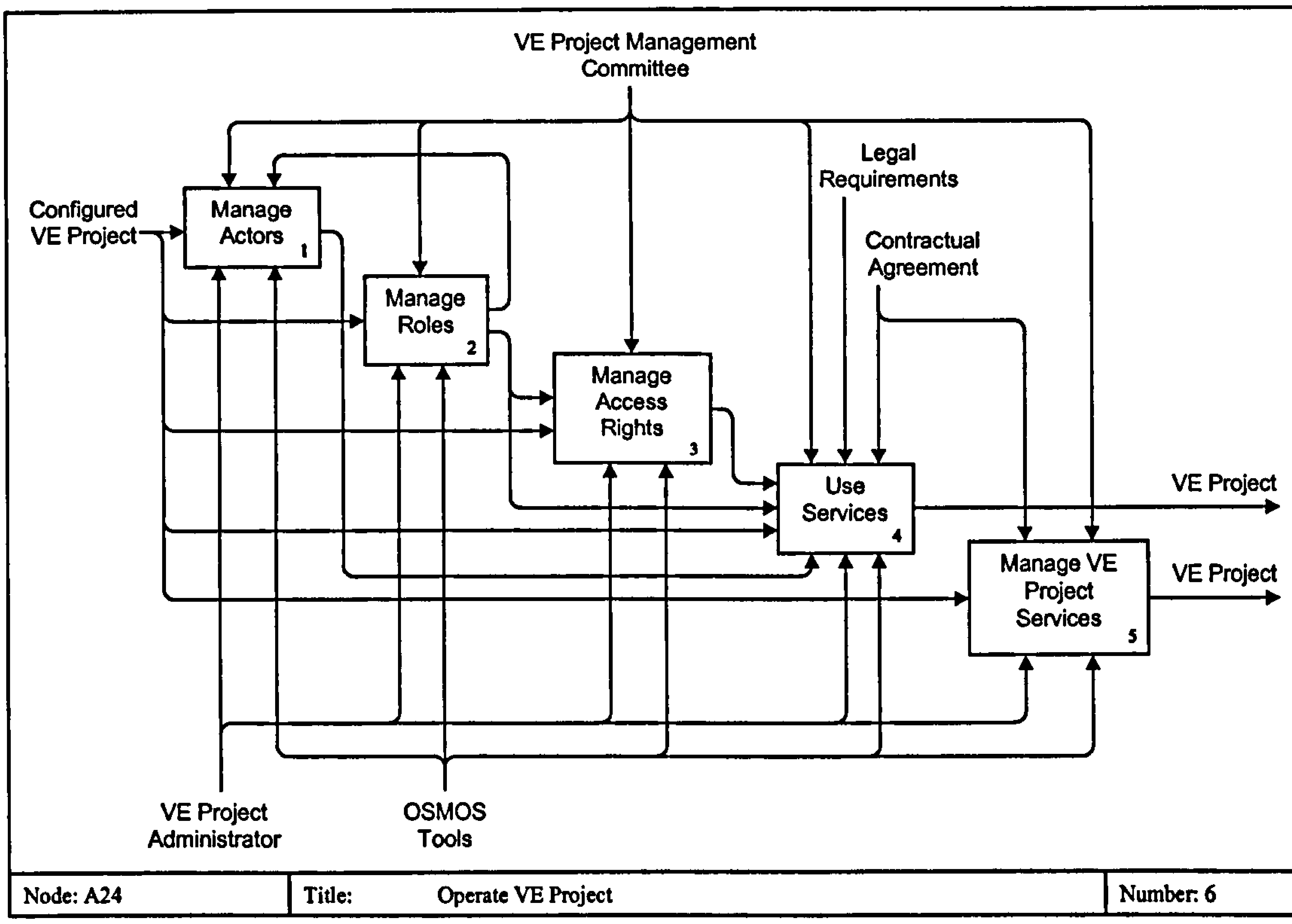


Figure 18: Node A24 – Operate VE Project

Manage Actors – this activity comprises the actions required to administer all actors participating in the current project. Actors and their Roles are closely related within a VE Project, and as Roles may need to be reassigned, or new Roles may be defined during the VE Project lifecycle, the output from the *Manage Roles* activity also forms a control on this activity. The output from the activity is Managed Actors.

Manage Roles – this activity comprises the actions required to administer the Roles as assigned to respective Actors. The output from the activity is Managed Roles.

Manage Access Rights – this activity represents the actions required to support the information needs of the Actors participating in the VE Project (e.g. sharing, exchange, communication, dissemination, archiving, workflow and scheduling), in terms of Access Rights attached to Roles in the VE Project. As well as the Configured VE Project, the activity also takes the Managed Roles as input. The output from the activity is Managed Access Rights.

Use Services – this activity includes all the actions required for the Actors to be able to use the VE Services and Third Party Services available to the specific VE Project. (This activity may also include the need for training in the use of unfamiliar software applications). As well as the Configured VE Project, the activity also takes the Managed Roles and their respective Access Rights as input, and the VE Project Actors also perform actions in the activity (using the services). Legal Requirements and the terms of the Contractual Agreement act as further controls to the activity. The output from the activity is the operational VE Project.

Manage VE Project Services – this comprises all the activities the VE Project Administrator needs to be able to perform to ensure the Assigned Services for the specific VE Project are available to the Actors of that project, thus enabling continuation of the operational VE Project.

4.4 Conclusion

This chapter presented the methods and overall results of the requirement capture phase with respect to digitally enabling the construction VE. After some initial problems, a consistent method for describing and detailing the current processes and procedures within the industrial organisations was established. This resulted in a set of IDEF0 models from which the overall high-level process specification to support the construction VE was developed. This was achieved through abstractions of the initial models, but also taking into account the actual inefficiencies and other issues gleaned from the analyses. This ensures that the resultant model is robust and pragmatic, rather than being a theoretical vision of the ideal processes for the VE.

The Researcher was not aware of other publicly available generic process models specifically relating to the VE at the time of the development of the GVEPM.

From the results of the VOSTER cluster (VOSTER, 2003b), however, it is clear that other projects made quite similar models, also focusing on management and understanding of the VE at a human actor level, and definition of processes/rules for management at the human level in terms of the system definition. The Researcher firmly believes, therefore, that the resultant high-level specification is grounded in 'real world' needs, and is generic enough to be used throughout the construction industry (and possibly also in other industrial sectors).

The analysis also revealed a set of three perceived VE Roles required to create, operate, evolve, and ultimately dissolve an authentic construction VE, which take into account the need for provision (and indeed maintenance) of integrated ICT tools and services.

From the development of the GVEPM, the VE solution can now be specified and developed, and these objectives form the content of the following chapter.

Chapter 5
Proposed VE Solution

Specifying the digital construction VE Solution; Development of the construction VE prototype;

5.1 Introduction

In reference to the virtual team model from the literature (Section 2.3.4.1), the GVEPM can be seen to address the real world purpose in the VE. From the high-level processes it is necessary to determine the low level functionality of the technology to enable the VE, which in turn addresses the required links for virtual team working.

This chapter presents the construction VE solution as realised within the central case study of the thesis (the OSMOS project). The first part of the chapter initially presents the continuation of the modelling methodology to specify the functionality of the OSMOS VE solution, and is followed with descriptions of models elaborated to provide the business functionality of the solution, and the OSMOS API. The second part of the chapter describes the development of the VE platform, the technologies used, the way in which integration and interoperability have been addressed, and the developed tools and OSMOS compliant Third Party Services.

5.2 Specifying the digital construction VE Solution

It is worth mentioning that both prior to, and throughout, the processes of specifying and prototyping the VE solution, a close watch was kept on the literature regarding emerging ICT. This review served the two main purposes of ensuring not only that informed decisions were made regarding the technologies employed to realise the solution, but also to facilitate understanding of the advanced ICT concepts for everyone involved in the project. It is interesting to note that this review also highlighted some of the security issues that need to be considered in the VE, and introduced some technologies used for exchanging data (including XML).

The use of a Java-based approach to implement the VE solution was decided at an early stage of the project. This decision was not made lightly; indeed other options were also researched and considered (including Microsoft technologies and a CORBA-based solution). Java provides many advantages as a whole, especially that of offering the ability of the VE solution to be deployed on any system connected to the Internet, regardless of platform choices. Such an implementation would also utilise the many APIs that Java inherently provides, which is important considering the key objective of integration. The consortium made a key decision to use and adopt open source standards and technologies.

5.2.1 Definition of the Use Cases

Having defined the GVEPM (Chapter 4), each of the nodes at the lowest levels of the IDEF0 model were further decomposed and described as a set of Use Cases, i.e. a set of textual descriptions at the business level, of how the VE platform would be used. Furthermore some of the resultant Use Cases were decomposed into smaller Use Cases if they were found to be too complex. An example Use Case, from the registration of a Role on a Project (GVEPM node A242 Manage Roles, Figure 18 above) is provided in Figure 19. This shows how the Manage Roles process was broken down into a number of individual Use Cases. Each Use Case was then described in a textual format that stated who performed it and what the actor expected the VE system to do. The example given is for the Register ProjectRole Use Case.

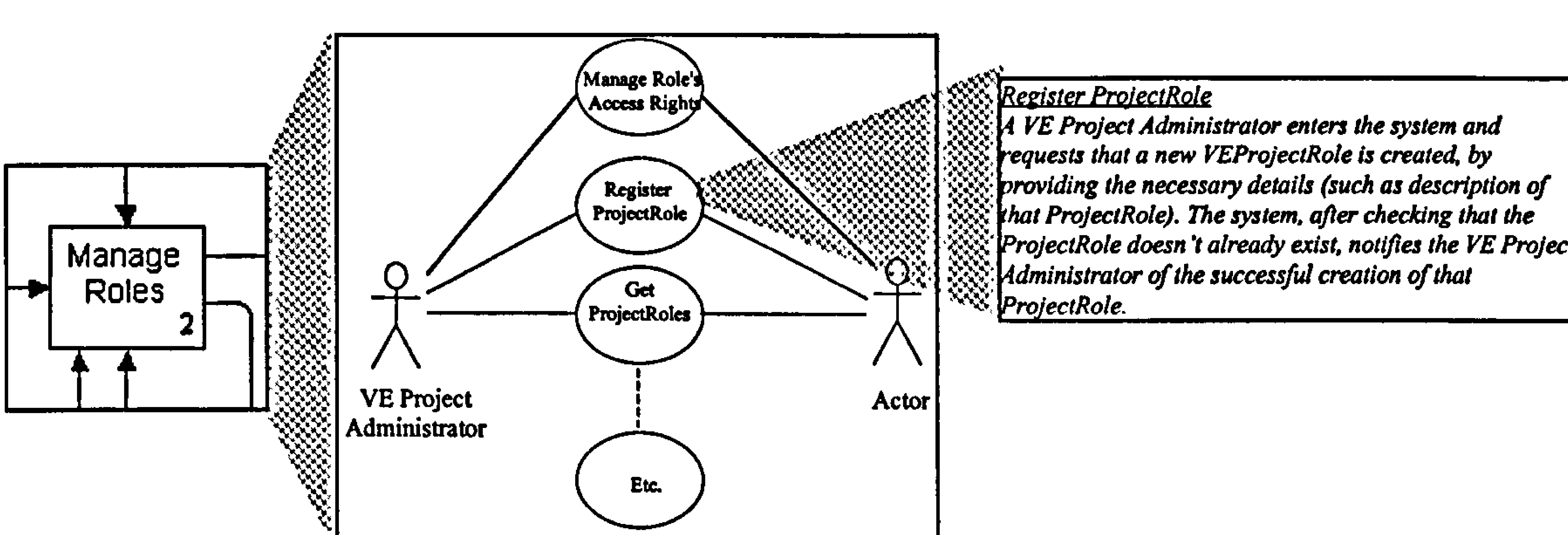


Figure 19: From process models to Use Case descriptions

5.2.2 From Use Cases to System Design

From the point that the Use Cases were defined, the OSMOS consortium used an Object-Oriented approach to system design, which itself is a subset of the Rational Unified Process (Rational Corporation, 2001), using the Unified Modelling Language (UML) (Object Management Group, 1999). This approach is widely known and accepted within the Information Systems community, and not described in detail here (see Barker, 2000, for an overview and Bennett *et al.*, 1999, for a detailed exploration of the design process). However, a brief overview of the process is given before presenting the results of the design phase as a set of conceptual models.

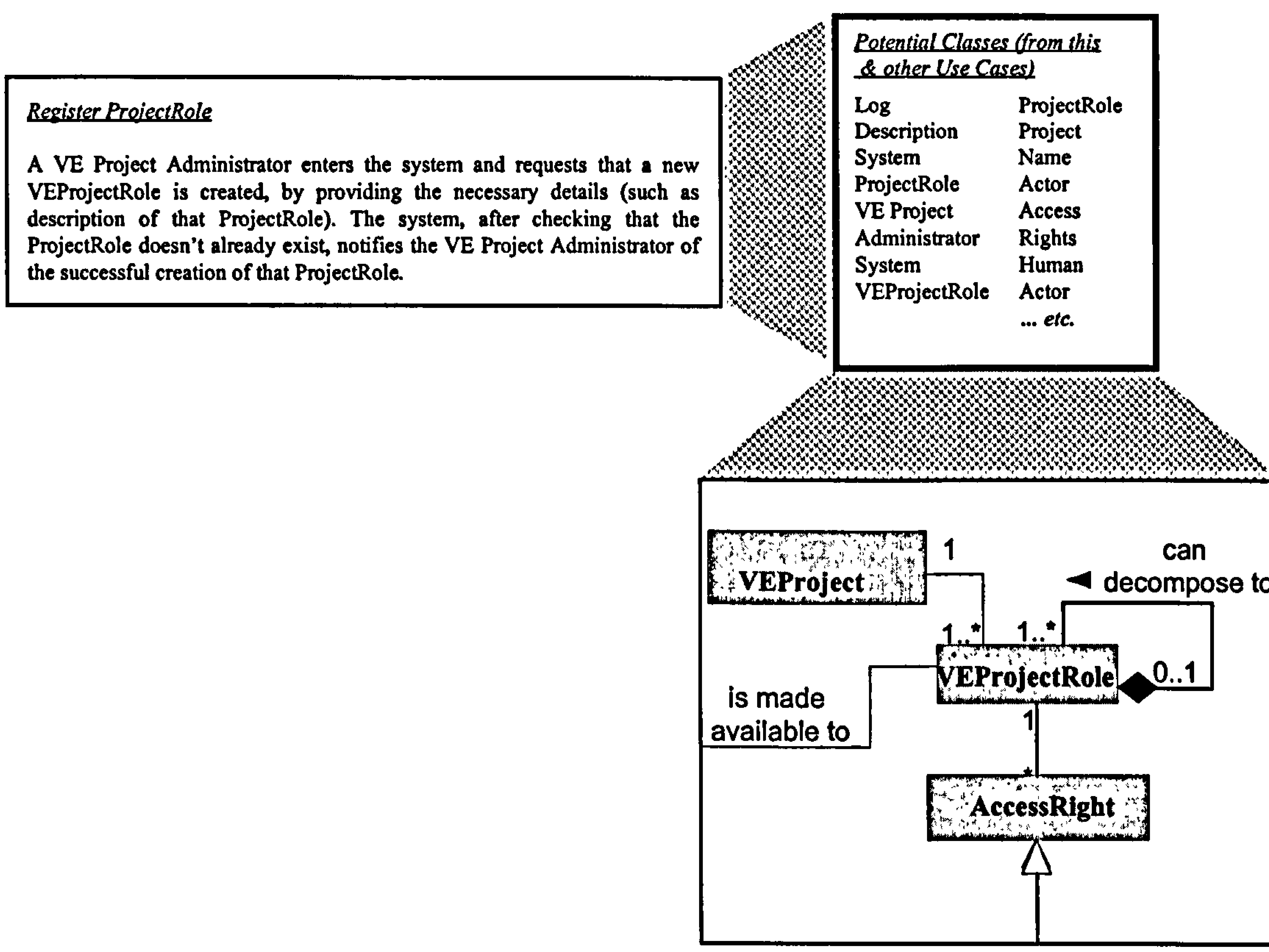


Figure 20: From Use Case descriptions to Conceptual Models

Firstly, as shown in Figure 20, the textual descriptions of the Use Cases were examined through Noun Phrase Analysis. The nouns were extracted from such textual descriptions, grouped together and arranged into a list of potential classes that could be used within the system. This list was then analysed to remove repeating or similar names, potential attributes and actual Actors (human users or external systems), which left a list of classes of objects that would be required by the VE system. The resulting classes were then used in the conceptual modelling and design of the system. Relationships between such classes were examined and discussed based upon the Use Cases, which helped in the design to define the attributes and relationships between classes of objects.

In parallel to this effort, each Use Case was also analysed to decide how the classes and objects discovered above would interact within the VE system, to satisfy the expectations of the calling Actor. The results of such analysis were presented as a set of UML Sequence Diagrams, one per Use Case, such as the example given in Figure 21.

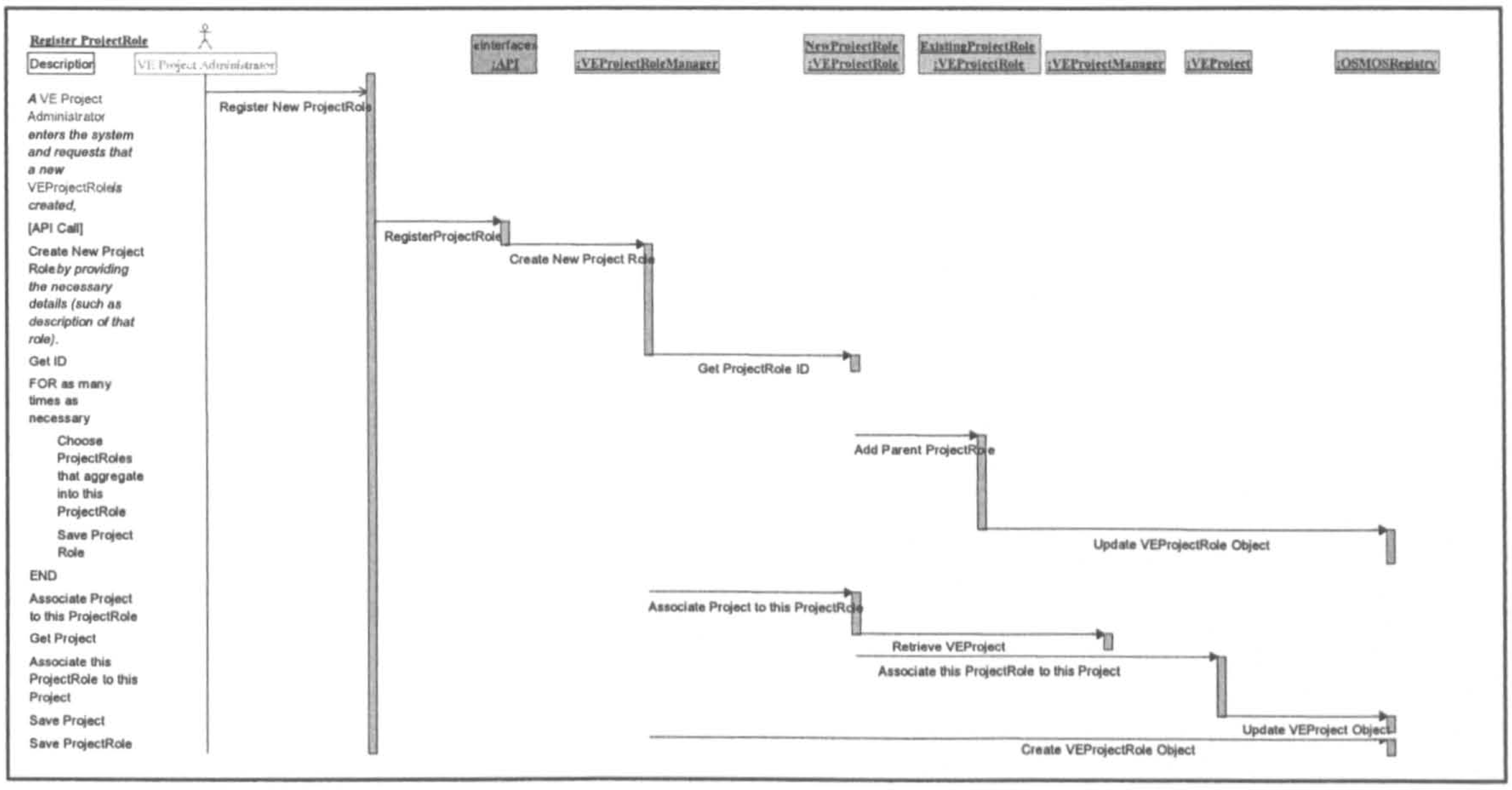


Figure 21: From Use Case descriptions to technical design

These diagrams aided in deciding upon the methods or services provided by such objects. In addition, careful analysis of such diagrams helped in the definition of the API by considering the architecture of the VE system at this stage, and further classes required for purely technical reasons (e.g. a Database object that may be required for persistent storage of other objects in the system).

Indeed, the approach of producing these models in parallel with the Sequence Diagrams raised a number of questions within the Sequence Diagrams that were answered by working on the Conceptual Models, and vice versa. Consequently this process was iterated, producing considerable benefits such as increased stability and validity. The outputs from one task are presented here: the OSMOS Conceptual Models and the OSMOS API.

5.2.3 The OSMOS Conceptual Models

The Conceptual Models show the underlying philosophies and business logic that would be enforced by the implemented solution within the context of a VE. The models evolved from the analysis and design phases above, but were also strongly influenced by the careful analysis and simplification of relevant parts of the models produced in two other projects: COMMIT (Brown et al., 1996) and CONDOR (Rezgui and Cooper, 1998).

5.2.3.1 OSMOS High-Level Security Service

The OSMOS High-Level Security Model is concerned with the management of Actors, Projects and the overall provision of the VE. It attempts to address some of the primary issues that are central to management of a VE such as: rights & responsibilities and contractual obligations.

An Actor (see Figure 22) is an electronic representation of a user in the VE system. There are two types of Actors: OrganisationActors, which represent organisations and other legal entities within a VE, for example a Company, and HumanActors, which represent individual people who work for an OrganisationActor. In the second case, the usual information is held about a user, such as name, address, email address, telephone number, etc. However, as will be discussed below, it also contains information about what Subscription objects the particular user holds (i.e. for which InformationMetadata objects that user wants to be notified of changes).

More importantly, to make the administration of enforcing DefaultAccessRights to particular objects easier, a user can only interact with any object in the OSMOS VE architecture through the ProjectRoles (s)he has been allocated. An Actor must hold at least one ProjectRole.

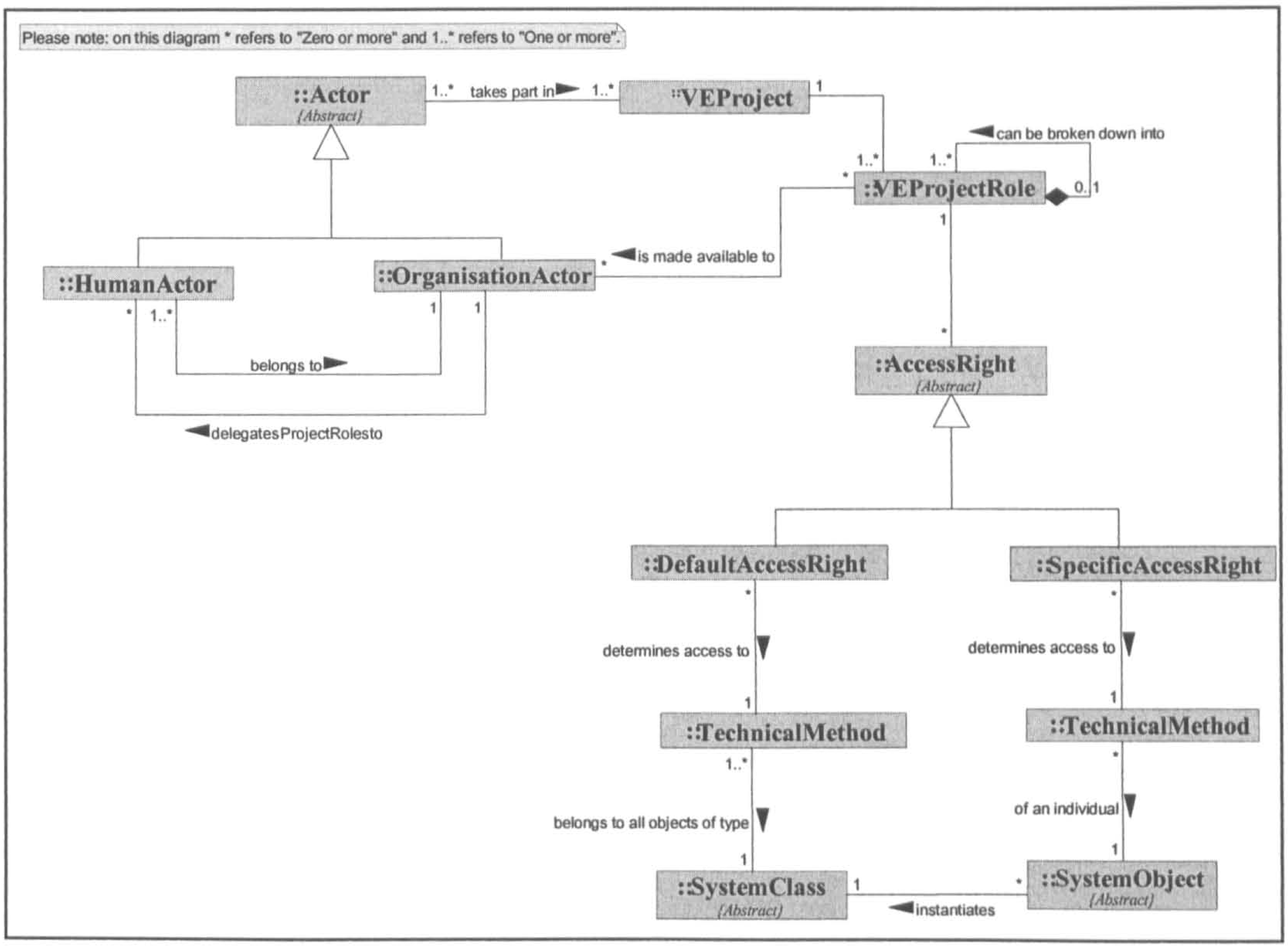


Figure 22: OSMOS High Level Security Model (Class Diagram)

A VEProject corresponds to an actual ProjectRole that is held within a VE (or VEProject), such as 'Project Manager', 'Client', 'Secretary', and so on. This is vital because it allows the OSMOS System to capture some semantics about who performed a task within the VE and the ProjectRole in which they performed this task, and is also used to enforce access rights (AccessRights) to certain methods, functions, options, etc (TechnicalMethods) on a particular SystemObject or service.

ProjectRoles are actually assigned to OrganisationActors. This is to clarify that the Organisation is contractually responsible, in a construction project, to deliver goods and services. It is HumanActors that, through their daily work, allow the OrganisationActor to do this. Therefore, it makes more sense to assign ProjectRoles to OrganisationActors, and then allow the OrganisationActor to decide who, in their company, will carry out each ProjectRole on behalf of the organisation. ProjectRoles are defined entirely for the VE Project in question, as they would differ on a project-to-project basis.

The vast majority of objects within the OSMOS VE Architecture inherit from the SystemObject object, which allows control over the access to any Operation of any object within the system, for anyone holding a particular ProjectRole. This is vital because control of access will also be required to objects within the OSMOS architecture that are not directly related to InformationObject-type objects being managed. This enforces desired rules, for example a user will be unable to modify his or her Actor profile to assign himself or herself a ProjectRole of VE Administrator, or to modify access rights for ProjectRoles in general. Allowing permission to invoke this operation only to users holding the ProjectRole of Project Administrator can enforce this.

The alternative to this is controlling access based upon Actors themselves. However, during the lifetime of a VE it is more likely that users will change frequently whereas the ProjectRoles held by those users would stay relatively static. Therefore, the VE will be easier to administer in terms of access rights if these are based upon ProjectRoles and ProjectRoles are assigned to Actors. To illustrate this concept, taking an object of type InformationVersionMetadata called 'D2.1', for example, one of the Operations of this object could be 'OpenDocument(). It may be desirable to allow all users holding the ProjectRoles of 'Architect', 'Client' and 'Project Manager' to be able to open this document. However, it may be undesirable to allow those that hold the ProjectRole of 'Secretary' to do so. Firstly, the 'OpenDocument()' operation finds out the ProjectRoles assigned to the user who has logged in, and checks if (s)he is authorised to invoke this operation. If the user is authorised then the document is opened; otherwise the user is presented with an unauthorised action message. Therefore, using DefaultAccessRight objects, for the 'D2.1' object, those holding a ProjectRole of 'Architect', 'Client' or 'Project Manager' can invoke the method 'OpenDocument()', whilst those holding the ProjectRole of 'Secretary' cannot, and this is automatically enforced when the 'OpenDocument()' operation is called. In cases where an Actor holds more than one

ProjectRole, then of course each ProjectRole needs to be checked to see if access is granted.

The whole concept of deciding access rights based on ProjectRoles, rather than directly on VEParticipants, and also to base access rights on TechnicalMethods instead of the usual CRUD (Create, Read, Update and Delete) metaphor used in the majority of IT-based systems, allows the VE to limit access to operations based on their meaning rather than how those operations are carried out. This approach was successfully demonstrated in the information management models of the COMMIT (Brown et al., 1996) and CONDOR (Rezgui and Cooper, 1998) projects. The AccessRights extends this, although the discussion here concentrates on two specific classes that inherit from AccessRight.

An AccessRight, as discussed above, is either a DefaultAccessRight or a SpecificAccessRight. The DefaultAccessRight allows access for a particular ProjectRole to a particular method for all objects that are instances of a particular class. For example, all users holding the ProjectRole of 'VE Manager' may be allowed to call the 'modifyProjectRole()' operation on all objects of the class VEParticipant; whilst not allowing any other user holding a different ProjectRole to do this. However, there may be occasions where all users that are holding a certain ProjectRole, e.g. 'Project Manager', will need to be able to call that same method, 'modifyProjectRole()', on a particular instance of the class VEParticipant, e.g. 'Joe Smith'. This can be done by using the SpecificAccessRight as well as the default right presented above. So, in this example, all 'VE Managers' and 'Project Managers' can call the 'modifyProjectRole()' in 'Joe Smith', whereas only 'VE Managers' can call the same method in any other VE Participant object. When discussing access to a particular method of a particular object for a particular ProjectRole, therefore, a SpecificAccessRight will override that object's DefaultAccessRight. If the former does not exist, then the latter will apply. Every class should have a set of DefaultAccessRights for each of the ProjectRoles within the VE architecture.

5.2.3.2 OSMOS Information Management Service

The OSMOS Information Management Model is split across two separate diagrams for ease of explanation. The first (Figure 23) covers three of the four main areas supported by the model: information versioning, information ownership and semantic relationships between information, the second (Figure 24) details information classification.

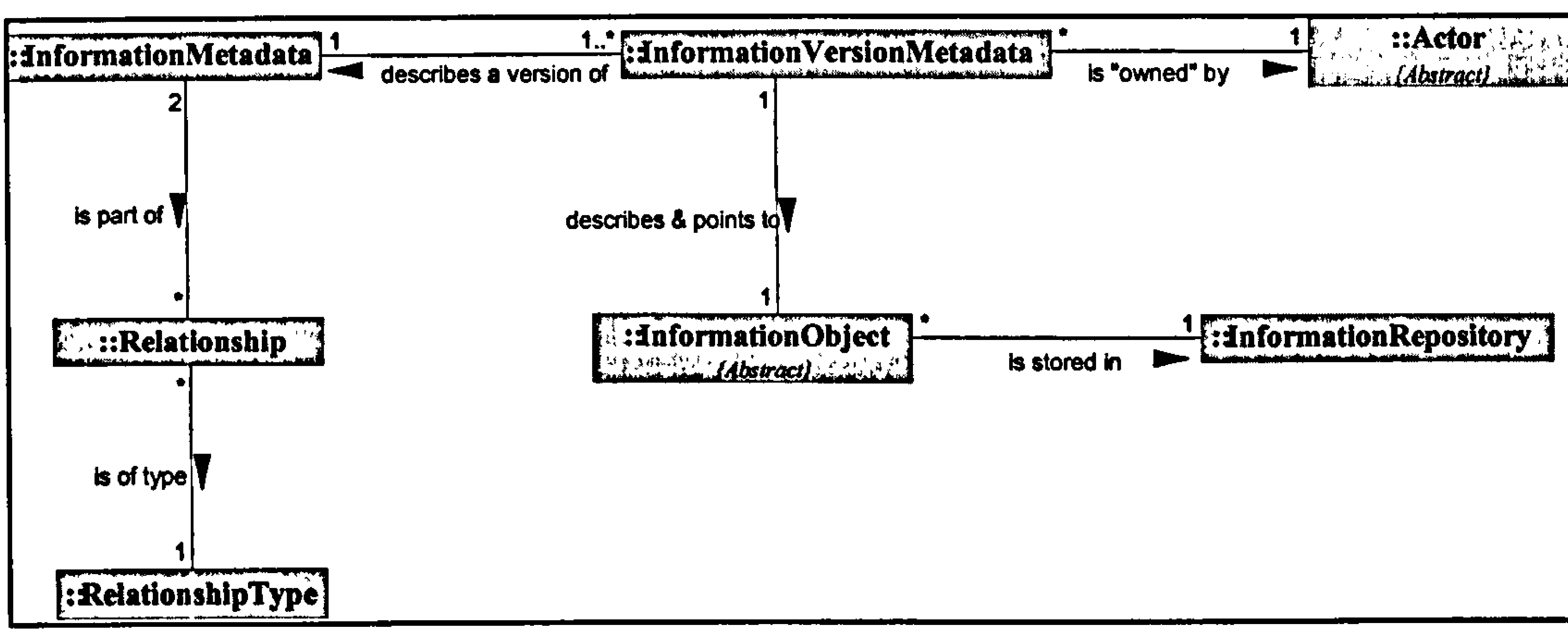


Figure 23: OSMOS Information Management Model (Class Diagram)

An InformationObject could be a word processor document, an IFC File, a spreadsheet, a CAD drawing, etc. The server of the VE Service Provider does not store such files. It simply holds metadata-type descriptions of these objects, and a reference to where they are actually stored. These objects are actually stored in a Document Management System provided by a Third-Party Service Provider, such as SGTi at Derbi for certain types of document, or a Product Model Server for other types. An InformationMetadata object is stored within the VE Service Provider's server. It contains a description of what that object is, who uploaded it, where it is stored, the date/time, keywords, a list of 'subscribers' and 'owners' of that object, etc. This metadata information is stored in an InformationMetadata object that is stored in the VE Service Provider server's Registry.

<u>*Information versioning*</u>

The model supports Versioning of Information. Contrary to what is written above the location of where the document is stored is actually held in an

InformationVersionMetadata object, along with other metadata that is specific to that version (such as a brief description of what has changed in the new version, date/time of upload, version number, etc). Each InformationVersionMetadata object can only be referenced to one InformationVersion object (which itself can have many InformationVersionMetadata objects describing its many versions). In this way, every single version of every piece of information that passes through OSMOS is stored for reference purposes (and is therefore available in the event of contractual or legal disputes).

Information ownership

An InformationVersionMetadata object also holds a reference to an Actor object. This is to signify that the document the InformationMetadata object describes is 'owned' by that particular Actor. This Actor can then define the AccessRights for that particular object if (s)he so desires. This feature would be important if workflow services were to be included in the VE (as Ownership could then imply Responsibility for a certain piece of information at a certain point within a workflow).

Semantic relationships between information

In earlier designs (Harvey et al., 2001), only two types of Relationship between information (or InformationMetadata objects) were defined. These were either Aggregation or Reference type relationships. This enforcement was seen to be too restrictive as an individual project may have a requirement for other sorts of relationship that are specific to that project.

The final model therefore generalised the concept of a Relationship, so that RelationshipTypes can be defined at the Project level. Each instance of a RelationshipType, a Relationship object, can then be formed between two InformationMetadata objects, which is where the semantics of that relationship can be captured. Indeed, examples of RelationshipType objects could themselves be 'aggregation' and 'reference'.

An object (InformationMetadata) is said to have an 'Aggregation Relationship' when it conceptually contains, or is part of, another object

(InformationMetadata). Although indicating a direct Association or Aggregation relationship in UML could have shown this, using this method means that it would have been impossible to show how the semantics behind this relationship would be captured in the model. The ability to capture the semantics behind an aggregation relationship is vital to allow the user to state, if applicable, how the first InformationMetadata object is related to the second InformationMetadata object. This knowledge, unless explicitly stated, can be lost when a user who wasn't closely involved in the creation of these objects reads the document at a later stage in the project. One example of such a relationship could be an aggregation relationship between a Car and an Engine object. The semantics that need to be captured about this relationship would be something along the lines of "The car contains an engine because without the engine, the car wouldn't move!"

Similarly the notion of a 'Reference Relationship' is present. Such a relationship comes into play when one object (InformationMetadata) needs to refer to another. Again, although indicating a direct Association relationship in UML could have shown this, using this method means that it would have been impossible to show how the semantics behind this relationship would be captured. The implicit knowledge that can be captured and stored about this relationship is again of tremendous potential value to aid the understanding of users, especially if they are new to the VE. The ability to capture the semantics with added value for the business behind this relationship is vital to allow the user to state, if applicable, how and why the first InformationMetadata object is related to the second InformationMetadata object. One example of such a relationship could be a reference relationship between a word processor document and a spreadsheet. The semantics that need to be captured about this relationship would be for example "This document refers to financial data, this is available in: ". Because relationships are defined at the InformationMetadata as opposed to the InformationVersionMetadata level, they 'automatically' cascade down the line when new versions of documents, etc. are produced.

A final, slightly more complex, feature of the OSMOS Information Management Model is that of Information Classification. This has evolved from the

InformationElementSemanticClassification class that was proposed in the first iteration of OSMOS (Harvey et al., 2001). Based upon the feedback from the end-users, it was felt that this area needed to be revised thoroughly and more explicitly defined at the modelling stage.

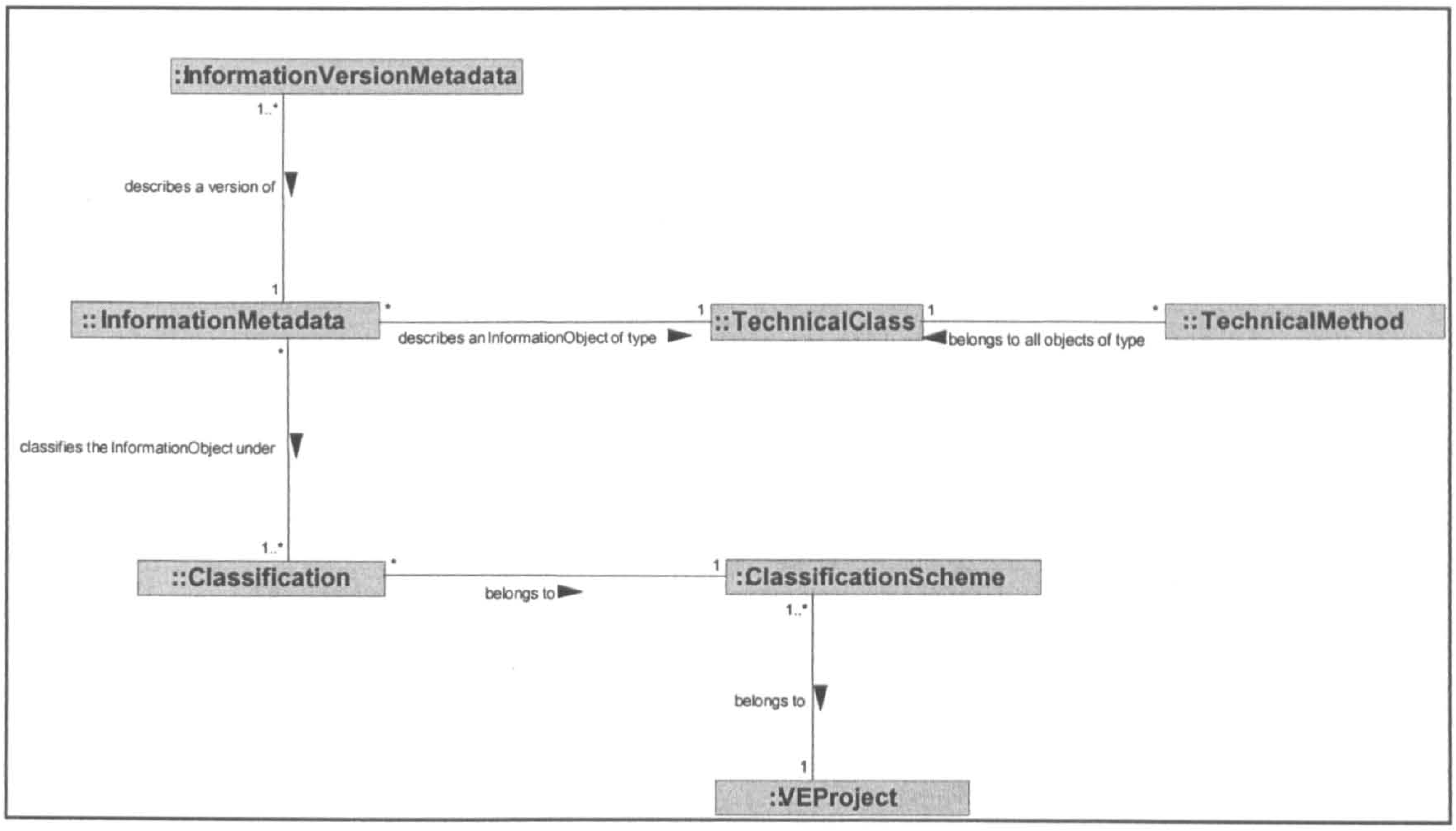


Figure 24: OSMOS Information Classification Model (Class Diagram)

<u>*Information classification*</u>

Information can be classified in a number of ways on a project. An object (for example a word processor document) could be classified by its status (e.g. draft, released), by project-specific identifiers such as work packages (e.g. WP1, WP2, WP3), by its type (e.g. MSWord Document), by the project's iteration (e.g. 1, 2) or by its semantics (e.g. Project Deliverable). The problem is that such classification schemes change on a project-by-project basis, depending on how the VE members agree to manage their data.

The Classification Model (Figure 24) was developed to support this fact. It allows the user to view the information held by a VE Project based upon certain criteria. These criteria are based upon ClassificationSchemes defined at the VE

Project level. Taking the scenario mentioned above, examples of ClassificationSchemes include Workpackage Number, Semantics, Status, Type of Document and Iteration. For each of these schemes, a set of Classifications would be defined at the VE Project level, such that classifications for 'Status' could be Draft, Work in Progress, Approved, Unclassified, Signed Off and Delivered. For 'Workpackage Number' they could be 1, 2, 3, 4, Unclassified, 5 and 6 and so on.

The Model states that for every piece of information managed by OSMOS, its InformationMetadata object must be referenced to one Classification object for each ClassificationScheme. As new versions of the information object are produced over the course of the project, then the object's author updates the Classifications accordingly. This therefore allows different Actors to have different views of the same information that is managed by the OSMOS Server.

To conclude, the OSMOS Information Management model allows the VE to integrate a set of repositories as information datawarehouses (the 'Third-Party Service Provider' servers discussed above) and make them accessible to the applications, end-users and OSMOS VE Services. The OSMOS Information Management Service provides added value to those repositories, by allowing those who take part in projects to locate, then view, all of the information held in a project; to specify relationships between information; to classify information; and to track and manage versioning (including describing the differences between versions) of information, regardless of the physical location and technical structure of such objects or files.

In addition, the final iteration of OSMOS looked at further integration of the OSMOS Communications Service with the Information Management Services, because it was felt that project information is valid regardless of the form in which it is transferred (e.g. as an e-mail, fax, document, etc). Messages should therefore be handled in much the same way as other types of information managed within OSMOS.

5.2.4 The OSMOS Core Services API

In addition to the aforementioned models, the OSMOS API defines a set of API calls for the High Level Security Service, the Information Management Service, the Service Manager Service and the message-based communication service. This API is technologically neutral and, as discussed below, can be invoked in a variety of ways.

5.2.4.1 OSMOS High Level Security Service

The OSMOS High Level Security Service was, for a number of technical reasons (such as efficiency, easier documentation, etc), split into a number of smaller services:

- The **ActorManagementService** deals with management of Actors, both Human and Entity
- The **OSMOSSecurityService** provides "high-level" API calls, such as for management and checking of Default Access Rights.
- The **ProjectManagementService** provides API calls for management of Projects on the server.
- The **ProjectRoleManagementService** provides API calls for the management of ProjectRoles on Projects on the server.

These APIs provide all the functionality that has been utilised in the OSMOS Web-based VE Server and VE Project Management tools (see section 5.3.1.5).

5.2.4.2 OSMOS Information Management Services

The OSMOS Information Management Service provides a number of API calls for managing Information within projects on the OSMOS Server. The OSMOS Web-based Information Browser makes use of this API. For a number of technical reasons (such as efficiency, easier documentation, etc), this was split into a number of smaller services which all rely on the InformationMetadataService and (to some extent) the OSMOS High Level Security Services.

- The **CrossReferencingService** deals with the handling of relationships between different InformationMetadata objects.

- The **InformationMetadataService** provides API calls that deal with the management of metadata about information held within a Project. The documents/objects themselves described by this metadata are stored on EDMS or other Third Party Services. It also deals with multiple versions and references the Class of such documents.
- The **ObjectClassificaitonService** provides API calls for allowing projects to classify their own information (i.e. InformationMetadata).
- The **RepositoryManagementService** provides a set of API calls for the management of built-in file/document/object repositories on the OSMOS VE Service Provider Server.

5.2.4.3 OSMOS ServiceManager Services

The OSMOS Service Manager provides a number of API calls for managing the integration of Core and Third Party Services within the OSMOS Server. Because of its nature, this service is highly integrated into the framework of the OSMOS VE Service Provider Server. The Service Manager is not used for managing access to services and methods for individual Projects (this is done using the OSMOSProjectManagementService), or for defining access rights allowing Actors access to such services (this is done using the OSMOSHighLevelSecurityService). The Service Manager API consists in the methods of the Service Manager component.

5.2.4.4 OSMOS Message-based Communication Service

The OSMOS Message-based Communication Service is offered by the means of a Communication Service Manager that provides Communication Services to OSMOS projects. These Services can be configured for a project at the role level, by the VE Project Administrator, or at the user level by the user.

5.3 Development of the construction VE prototype

The models presented in the previous sections served to provide a conceptualisation decomposed from and supporting the high-level process specification described in Chapter 4. With these models in place, the prototype VE platform and tools could be developed ready for testing and evaluation. As indicated in the previous sections, the underlying modelling underwent iterative and incremental development (as did the high-level process modelling). This procedure was of course true for the development of the technology itself. This section of the chapter presents the final prototype development.

5.3.1 Development of the VE Service Provider server and API

The OSMOS VE platform federates services inside a common framework, and allows their use and collaboration. The services are often distributed, heterogeneous programs, and developed by several companies. The OSMOS framework handles two categories of Services: Core Services and Third Party Services (TPS).

5.3.1.1 Core Vs. Third Party Services

Core Services

The Core Services are the heart of the OSMOS VE framework. They are VE Service Provider components designed, developed and maintained by OSMOS VE framework providers. They provide common functionalities for every OSMOS-enabled VE information system, such as Actors Management, Roles Management, Projects Management, and so on, by implementing the OSMOS APIs.

The API and the business logic as designed in the Sequence Diagrams were implemented as a set of Java interfaces and objects. These objects were persisted into MySQL, a freely available and standards-compliant Relational DBMS (available for free download for many platforms at http://www.mysql.com). The mapping between Java objects and relational tables was provided by the open source Castor package (available for free download for any platform that supports Java at http://castor.exolab.org). Everything (except MySQL) runs in a standard Java Virtual Machine (available for free download for any platform from http://java.sun.com) and has been tested extensively on Windows and Linux platforms.

Third Party Services (TPS)

TPS are Third-Party Service Provider applications made available via the World Wide Web. They provide high-level tools (Facilities Management, Building-oriented EDM, etc.) to the VE Client end-user to enable working in the VE, and they rely on the OSMOS Core Services to work within an OSMOS framework (using features such as Cross-Referencing, Access Rights Management, Actors Management, etc.) The OSMOS framework is an entry point for accessing TPS, and the user, according to his or her role will use them transparently in the VE.

5.3.1.2 System Architecture

The VE Service Provider Server is made up of Core Services, TPS and an 'Execution Framework' for these services, allowing their collaboration and access. As noted above the Core Services were implemented as Java Objects and the TPS as Web-enabled applications. A closer look at the underlying infrastructure of the VE Service Provider Server, also known as the OSMOS Service Manager, is now presented.

The Service Manager is a VE Service Provider Server software component whose role is to handle Core and TPS Services as described above. The OSMOS Services 'registration' process will be used to illustrate this. When a Core or TPS Service is to be included in an OSMOS framework, the administrator of the VE Service Provider Server has to register it into the Service Manager. For Core Services, the registration process is the binding of an Object Reference into the Service Manager. Once the reference is known, any Object can be used transparently as a Core Service. For TPS, the VE Service Provider Administrator has to provide an XML API (describing their published methods) and register this into the Service Manager. The TPS Web Site is then made available from the OSMOS framework. This approach is similar to the Web Services Description Language (WSDL) concept that has emerged with the SOAP technology from the World Wide Web Consortium (http://www.w3c.org).

The Service Manager is fully dynamic, and it allows run-time registration (or de-registration) of both Core and TPS Services. It also provides some Introspection (also known as Reflection) features, allowing Run Time Type Information about registered Core and TPS Services such as the methods and parameters that they support. The invocation of methods on both Core and Third Party Services is also provided by the Service Manager (using Delegation), so that clients do not have to manage the underlying Services directly.

5.3.1.3 Accessing the OSMOS API over the Internet

All the programs described above are Java Objects, local to the Java Virtual Machine (JVM) where they are running. A mechanism allowing remote access to the OSMOS API had also to be implemented. It was decided to implement a 'Gateway' to the VE Service Provider Server by using the Java Remote Method Invocation (RMI) technology. This powerful Distributed Objects feature, included by default within the Java Language, allows the creation of Server Objects that are available to Client Objects running in a separate JVM, regardless of the location, i.e. making these objects available transparently over a network or the Internet.

The OSMOS API Invoker is a remotely available Server Object that allows access to the OSMOS API over the Internet, by invoking methods on the Service Manager registered Core and Third Party Services. When a client invokes a method of the OSMOS API, the OSMOS API Invoker delegates the invocation to the Service Manager, and then sends back the return of the call to the client. The OSMOS API Invoker also helps to handle security issues. It is the only entry point to the VE Service Provider Server (including Core and TPS APIs), and it relies on the OSMOS Security Service to do Access Rights Checking for each invocation on the OSMOS APIs. So, if an invocation cannot be granted, the OSMOS API Invoker rejects it by throwing a specific Exception.

5.3.1.4 Interoperability Issues – The 'X' Layer

Since the beginning of the VE platform development it was realised that the OSMOS framework had to provide technology-neutral access to the VE Service Provider Server. As shown above, the framework is entirely Java based and accessible by only the OSMOS API Invoker. To overcome this an interoperable layer based on XML was built on top of this component. The key concept is to describe method calls in XML and receive the returns in XML as well. Using this mechanism, any client can express an XML method description, invoke it, and handle the result of the invocation. This approach again is strongly inspired from the SOAP and XML-RPC specifications from the World Wide Web Consortium, who had the idea of describing and executing procedural calls using XML to hide any implementation detail to the client. At the time of development SOAP was not fully mature.

Using the HTTP protocol to carry these XML messages provides a simple request-reply mechanism, similar to the invocation of a method. Thus, the 'X' Layer is implemented as a Java Web Server, serving OSMOS-specific requests only. It accepts HTTP requests containing valid OSMOS method descriptions and invokes the methods using the OSMOS API Invoker over RMI.

Below is a simple example of an XML method invocation description (for authentication of a user):

```
<XMLRequest>
    <user_id>ROLE_A_ADMINISTRATOR</user_id>
    <project_id>SERVER_ADMINISTRATION</project_id>
    <service_type>CS</service_type>
    <service_name>ActorManager</service_name>
    <method>
        <name>authenticateUser</name>
        <params>
        <param>
        <name>login</name>
        <value>mylogin</value>
        </param>
        <param>
        <name>password</name>
        <value>mybirthdate</value>
        </param>
        </params>
    </method>
</XMLRequest>
```

Since clients can invoke methods using XML, the returned values for these methods also have to be formatted in XML.

The methods of the Core Services (i.e. OSMOS API Calls) return Java objects or values. Thus, a mechanism allows the OSMOS framework to convert these Java types into XML documents. A 'Java-to-XML' converter was written so that return values, including 'Business Objects' of the OSMOS API such as HumanActor, Project and OSMOS Client can be expressed and handled in XML. When the 'X' Layer receives an XML request, it:

- Handles and parses the request, finding out which Core Service, method and parameters have to be invoked;
- Invokes the requested method (using the OSMOS API Invoker);
- Gets the invocation returned value (Java object);
- Converts it to an XML message using the Java-to-XML converter;
- Sends back the XML message to the caller.

Using this mechanism, the invocation of a method on a TPS can be entirely realised using XML. The response of the invocation example would then be like this:

<osmos_response><result><value>TRUE </value></result></osmos_response>

TPS are Web enabled, and thereby the return type of a method invocation is a string, usually containing HTML or XML. In the OSMOS case, they will always return HTML because OSMOS targeted Third Party Services are classical Web Sites and not Web Services. Thus, the return does not need to be converted to XML in opposition with Core Services invocations.

Invoking a Third Party Service using the OSMOS API Invoker returns a Java object wrapping the HTTP response as a string. The 'X' Layer then receives the content of the reply and returns it to the caller. Therefore, when the 'X' Layer receives an XML invocation request, it:

- Handles and parses the request, finding out which Service and method has to be invoked;
- Invokes the requested method (using the OSMOS API Invoker);
- Extracts the HTML resulting of the HTTP request that was sent to the target Web Site;
- Sends back the HTML message to the caller.

The caller then extracts the HTML from the response and handles the result, usually by displaying the HTML page. By using these mechanisms, the 'X' Layer provides a simple and technologically independent access to the whole OSMOS API.

5.3.1.5 OSMOS tools (reference implementation)

Several tools have been developed that provide users with access to the OSMOS platform. The tools basically make calls to the OSMOS API and invoke required methods to deliver a given functionality. It should be noted that these tools only constitute reference implementations. With OSMOS API response delivery in XML, such tools can easily be customised using templates, style sheets, etc.

VE Service Provider Server Tool

This tool (implemented using Java Swing classes) provides functionality to a OSMOS VE Service Provider Server Administrator to manage the server. Available functionality includes:

- Service management and API invocation logging;
- Core service registration and deregistration;
- TPS registration and deregistration;
- X layer registration and deregistration;
- TPS monitoring service.

VE Server Administration Tool

This tool (presented using Java Server Pages) is a web-based environment for facilitating the configuration and maintenance of the VE Service Provider server. It is to be noted that this tool is a simple interface to relevant API calls for initialising a VE project. The basic functionality provided by this tool includes:

- Set-up, initialisation, and removal of VE projects;
- Registration of organisations and employees;
- Configuration of access to core and third party services;
- Audit trailing and monitoring of usage patterns;
- System backups.

VE Project Administration Tool

This tool (Figure 25) is basically a subset of the VE Server Administration tool and is developed in particular to configure and manage any VE project. Once a project has been set up, control is passed over to a "VE Project Administrator" who then uses this tool to configure and manage it. Some of the basic functionality offered by this tool includes:

- Creation, definition, maintenance and deletion of instances of OSMOS objects such as: VE participants, Project roles, Technical classifications, Information metadata, Information repositories, etc.
- Creation, modification, and deletion of relationships between different project specific objects
- Management of VE participant organisation metadata, e.g. employees, roles, access rights, etc.

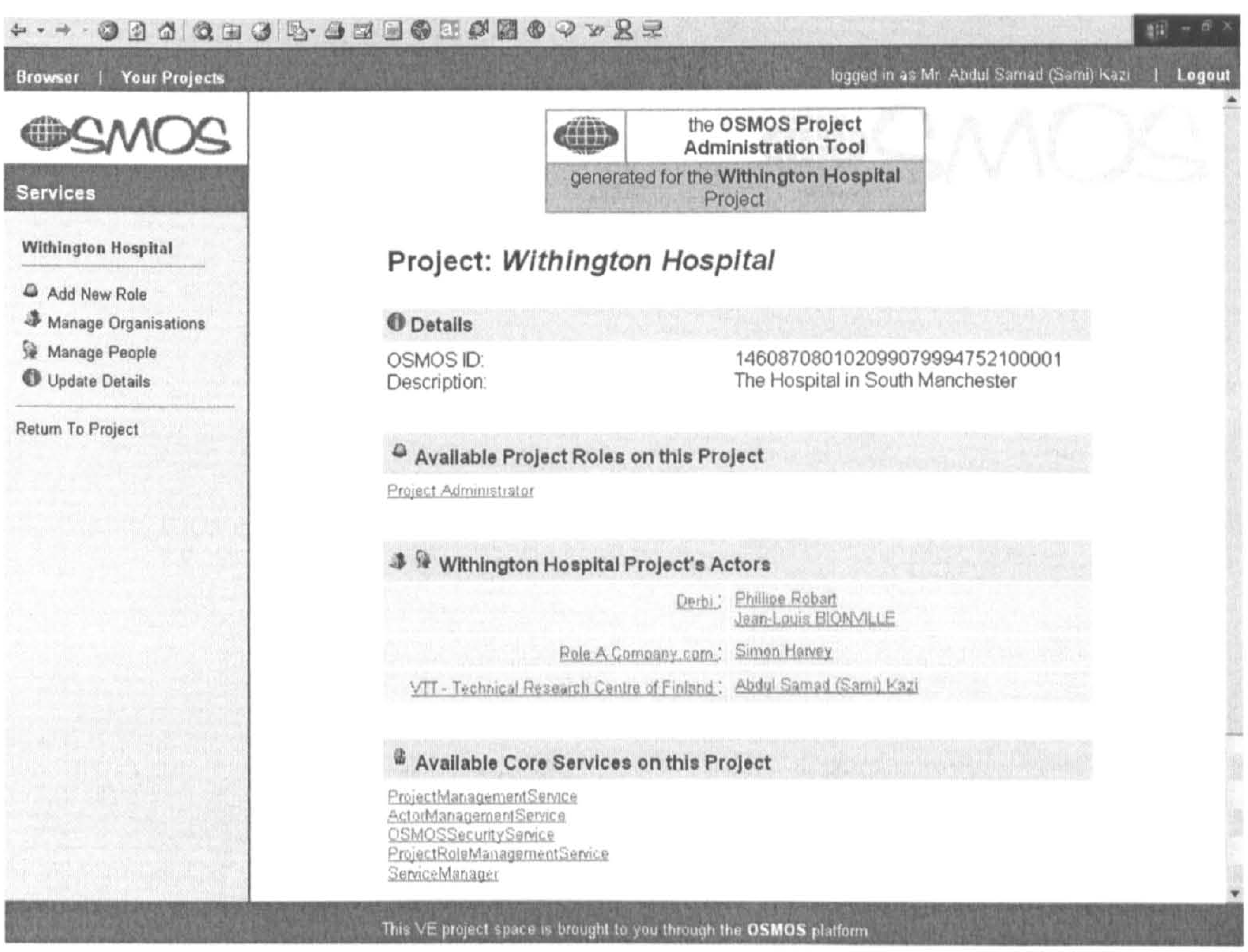


Figure 25: VE Project Administration Tool

5.3.2 Development of the Third-Party Service Provider Services

Third-Party Service Provider services may be integrated at any time into the OSMOS framework through TPS registration offered through the VE Service Provider Server tool. Here a TPS may be registered, and its available methods and associated parameters identified. Figure 26 shows a screen shot of an early-developed TPS registration interface.

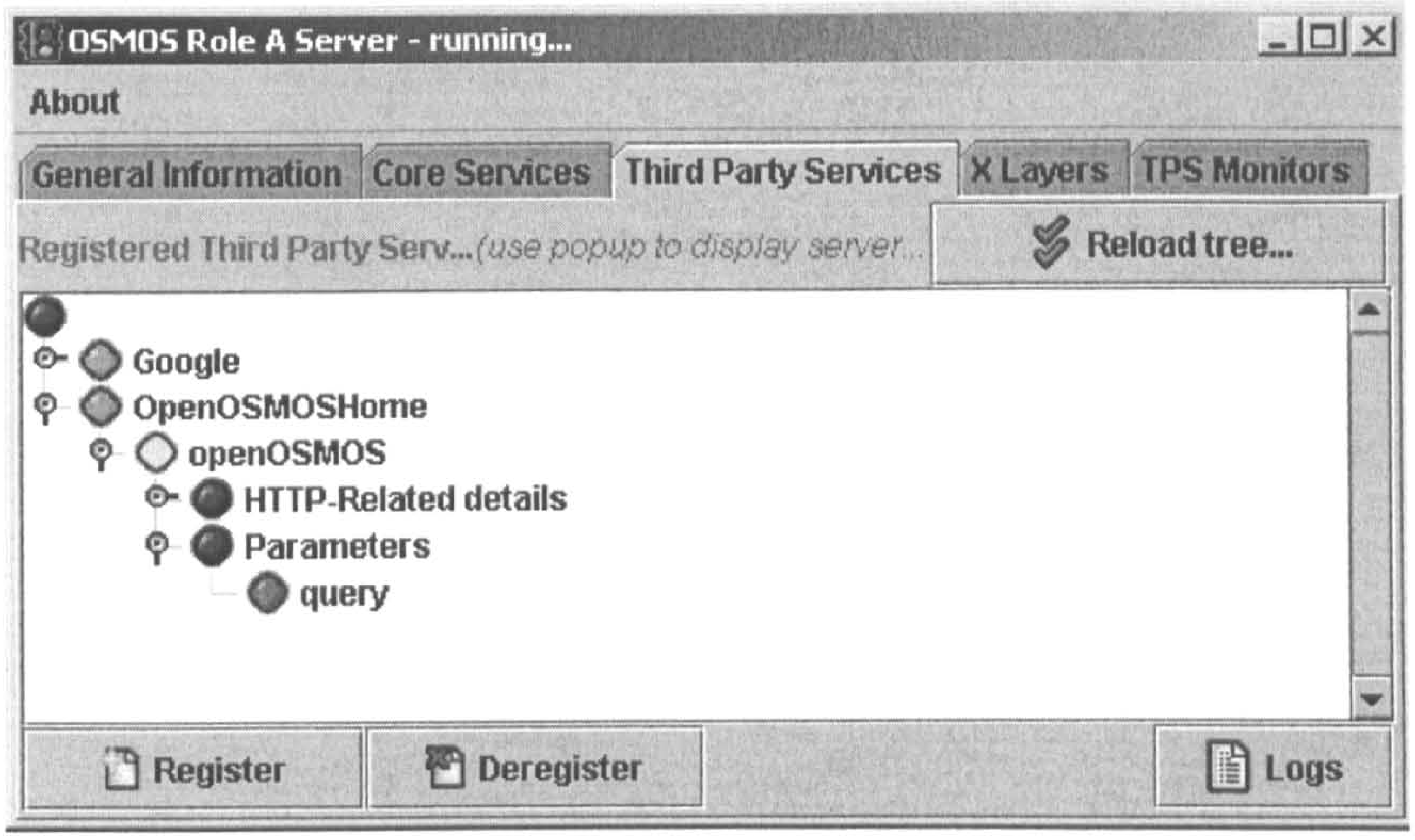


Figure 26: Third Party Service (TPS) registration

Once a TPS has been registered the service is no different than an OSMOS Core Service from the perspective of the end-user (VE participant). The actual difference is that method invocation on the service takes place at the service provider (Third-Party Service Provider) end rather than at the OSMOS VE Service Provider. An example of the same is shown in Figure 27, where the services developed by two OSMOS partners are 'plugged in' to the OSMOS core.

Within OSMOS, two of the partners made their services available to OSMOS clients. The services offered are 'OSMOS compliant' as they have a capability of invoking methods of the OSMOS API and vice versa. In a similar fashion, other services may also be adapted (through wrappers) and be made OSMOS compliant.

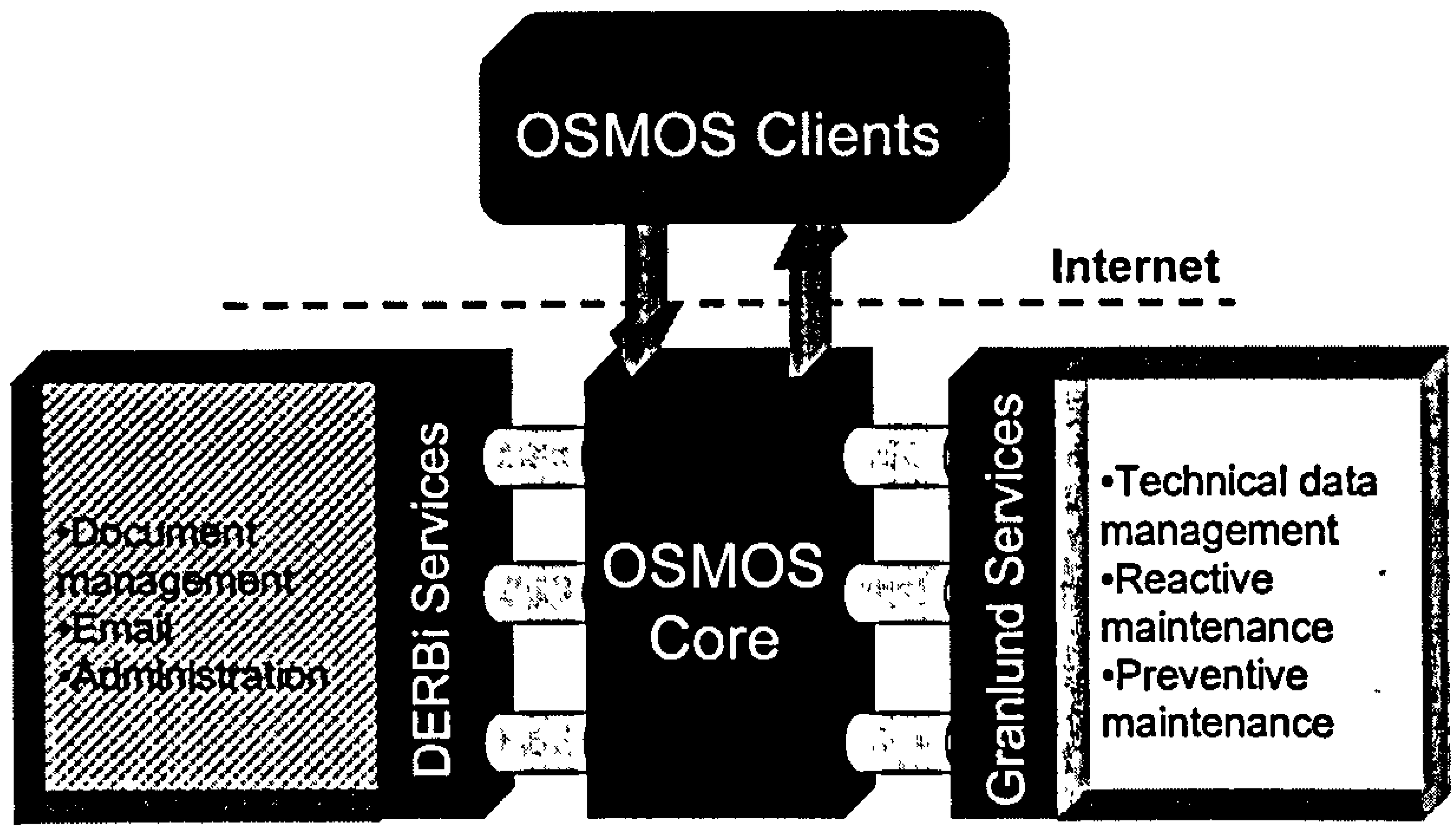


Figure 27: OSMOS Core and OSMOS compliant TPS services provided by the OSMOS partners

The TPS developed under and made available to OSMOS, relate to document management and FM provided by DERBi in France and Granlund in Finland respectively. These services are briefly described below.

5.3.2.1 DERBi, France

DERBi offers OSMOS compliant services for electronic document management and email based communications targeted to the construction industry. The document management service allows documents to be stored on the basis of a defined codification mechanism that can be later used for easy document retrieval, while the email based communication service provides an interface for clients to communicate and share documents. The main functionalities of the services include:

Electronic document management service:

- Store documents on a server
- Search for documents using simple criteria
- Access document meta-information
- Retrieve documents
- Create document folders
- Manage document versions

<u>*Email based communication service:*</u>

- Email consultation
- Send emails
- Retrieve emails

5.3.2.2 Granlund, Finland

Granlund offers OSMOS compliant services targeted for building users and maintenance companies to use for FM. Concentration is on those services that clearly have a need for location independent functionality and thus are suitable in the form of web-based services. Provided services target technical data management and both reactive and preventive maintenance. The main functionalities offered include:

<u>*Technical data management services:*</u>

- Add/Edit/Delete object
- Edit object attributes
- Edit object instructions

<u>*Reactive maintenance services:*</u>

- Add a service request
- Get service requests
- Confirm a service request

<u>*Preventive maintenance service:*</u>

- Print weekly work order

5.4 Conclusion

This chapter presented the specification and development of the construction VE prototype solution. Following the development of the high-level process model, the modelling methodology was completed using an Object-Oriented approach to system design and specification. OSMOS Conceptual Models were developed to specify the High-Level Security and Information Management services and the technologically neutral API. The proposed VE solution was developed in Java, using XML over HTTP API calls via the 'X' Layer middleware technology.

Reference implementations were developed for the OSMOS VE tools and TPS were made available for integration and interoperation via the OSMOS framework.

Following the development of the tools and services as described in this chapter, the following chapter includes presentation of the results from the final field trials and evaluation of the proposed VE solution.

Chapter 6
Results

IT and construction questionnaire results; Interview results; Testing and evaluation of the VE prototype

6.1 Introduction

It was stated in Chapter 2 that the main research question that the thesis is aiming to answer demands the study of the human and organisational aspects involved in technological change, and not merely the technology itself, i.e. the constant theme of conducting 'real world' research. The previous two chapters take into account the purpose, links, and lifecycle of the VE. It is imperative therefore also to closely address the 'people' dimension, both in their current situation, and as far as possible in a simulation of what the future situation could be.

This chapter therefore presents the results from the various surveys incorporated in the research methodology (Chapter 3). In the first section the results from the 'profiling' questionnaire are presented. The second section then describes the qualitative results obtained from the interviews conducted in the second iteration of OSMOS. Thirdly, the chapter offers a detailed presentation of the final field trials held in the OSMOS project to test the proposed VE solution in simulated real world scenarios, and a synthesis of the results obtained.

6.2 IT and construction questionnaire results

The principal aim of the questionnaire survey was to create an initial profile of the OSMOS industrial end-user organisations with respect to the areas likely to be impacted by the introduction of a digitally enabled VE solution. As mentioned in Chapter 3, the Researcher faced great resistance to the questionnaire, the result of which was that the number of responses received was so small that there was little need for in-depth statistical analysis. The results presented here, therefore, include only those with enough statistical significance to be reliable, and the results are presented according to the categories in the questionnaire. Table 8 summarises the return rate of completed questionnaires across the three organisations: 77 questionnaires were distributed, 59 were returned completed with none spoiled, and each organisation managed a return rate in excess of 65%, at an average of 77% overall. The results are presented according to the questionnaire section categories. (A copy of the questionnaire can be found in Appendix 1).

Organisation	Number sent out	Number of responses	Percentage return
Derbi	25	19	76%
JM	27	18	67%
Granlund	25	22	88%
Cumulative	77	59	77%

Table 8: Questionnaires return statistics

6.2.1 General Information

Overall the responses indicated that the people surveyed covered a diverse selection of specialities in a multi-disciplinary environment, with over 50% of the respondents having some form of managerial and/or leadership responsibilities (the questionnaire was directed to employees at the operational/tactical level of the organisations).

Question 1.9 asked the respondents to list the main factors they think are critical to the future growth and success of their company, and to rank them in order of importance. This question was answered by 68% of the respondents. It elicited qualitative responses, which could be categorised into four main areas:

- *Human Resources* – factors including knowledge and training, motivation, and competence.
- *Organisation / Process* – factors including teamwork, political decisions and customer relations.
- *Production* – factors including costs, market knowledge and product development.

- *Technology* – factors including new technologies and information management.

Up to four factors were indicated by the individuals who responded, with the majority (88%) giving at least two. The overall factors concerning production were perceived to be the most important, followed closely by the predominantly human factors covered by the human resources and organisation/process categories. Technology, however, was perceived to be of least importance in terms of these categories, with only 11% suggesting any factors at all.

6.2.2 Information Technology

All of the respondents indicated that they use computers in their work with 86% using Office applications, and only 42% using computers for project management. 88% of the respondents indicated that computer training was available to everyone in the company. It is interesting to note that the areas of greatest need for training were indicated as Office software applications and project management tools. The project management tools result is expected, as this was the category with the lowest computer usage. However, the Office software proving to be the highest training need of all, yet also the category most used, puts into question the efficiency of use of the employees' everyday applications.

6.2.3 Teamwork

Results from this section of the questionnaire show that the vast majority of people (86%) work as a member of a team or teams. Furthermore, 84% said that they work as a member of a team on a daily basis. These figures are perhaps not surprising given the nature of construction work, but it is important to analyse how people work together in teams, their views about teamwork, and common problems they face.

Question 3.5 asked 'How would you characterise working in teams in your organisation?' The Researchers was eliciting simple adjectives in response to this question. 61% of the respondents answered this question. The answers were initially categorised into positive and negative responses received, and 80% proved to be positive. The following question asks 'what teamwork problems have you had to deal with?' 53% of the respondents gave replies to this question. Once again these replies were grouped in the analysis process, and can be found to fit within three broad categories:

- *Information* – factors including distributed information handling, managing information, and lack of information.
- *Organisation* – factors including time scheduling, and meetings.
- *People* – factors including communication, availability of people, and individualism.

A significant 71% of the answers could be categorised into the people category. Availability of people was the most common problem, poor communication, progress reporting, and finding the right team members were also included. Surprisingly, however, answers also included 'differing opinions', 'lack of formality', and 'individuals causing trouble'. Once again this analysis shows that the emphasis is on human and organisational issues, but the references to individualism suggest that perhaps there is a lack of understanding in the methods and ethos of teamwork.

Question 3.10 asked 'Which of the following methods does your team use for communications within the team?' Ten options were given including the non-specific option 'other'. Figure 28 shows the five significant categories indicated from those available and how the responses compare in percentage terms.

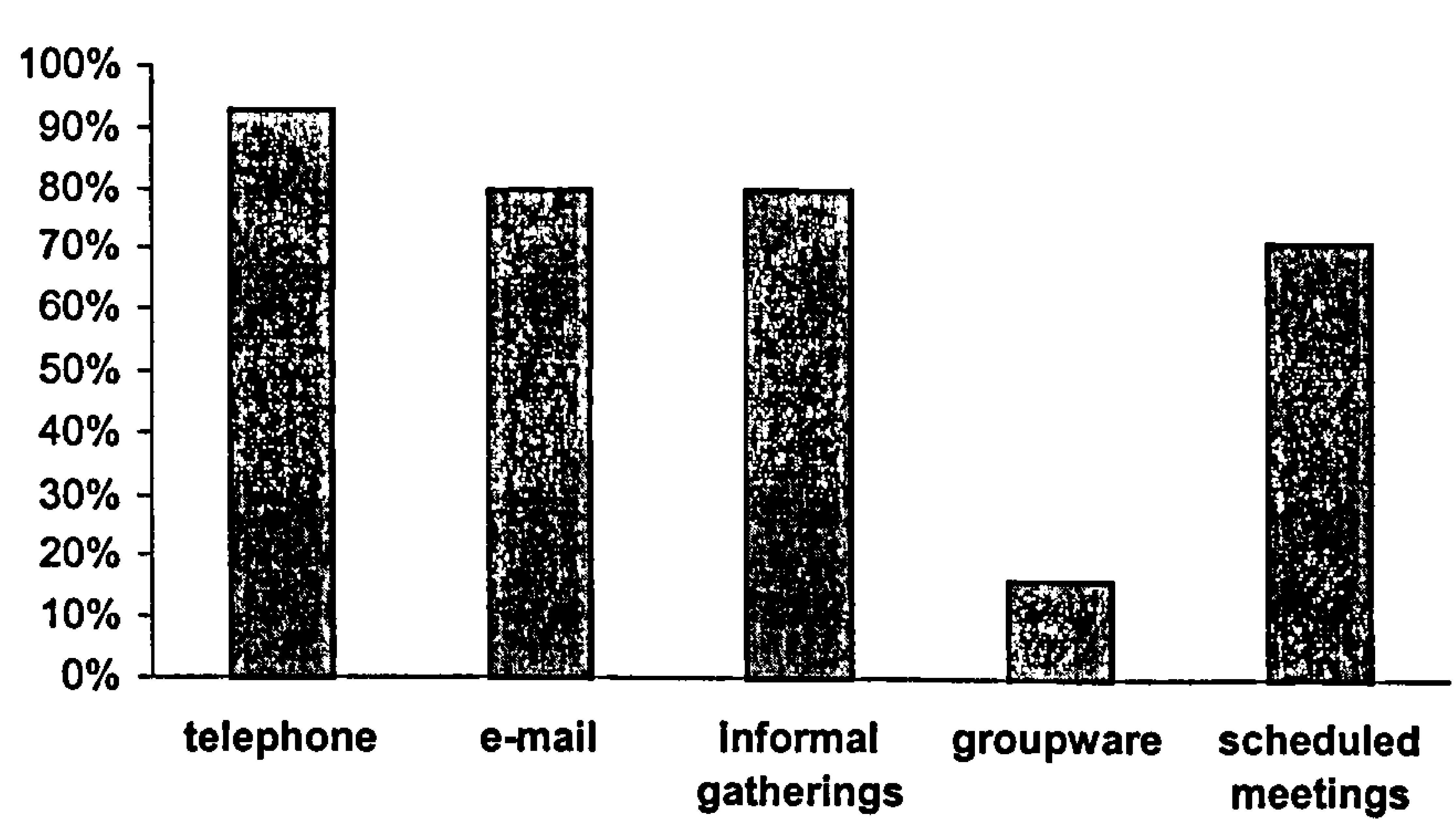


Figure 28: Communication methods within the team

Clearly, almost everyone uses the telephone and a significant percentage use e-mail. It is interesting to note that as many people rely on informal gatherings as they do on e-mail, and more so than scheduled meetings. It can be seen from Figure 28 that few people currently use groupware. The unfamiliarity suggests that in designing collaboration tools great consideration should be given to usability aspects. Furthermore this also points to potential future training needs.

Question 3.15 asks 'What problems do you experience with the information you share?' 53% responded to this question and the answers were once again grouped into more general categories:

- *Information* – factors including volume of information and information management.
- *People* – factors including people's involvement in processes, and skills.
- *Technology* – factors including hardware and software.

In terms of the volume of information a paradox emerged: whilst some people mentioned information overload, others noted that there is too little information being shared. Versioning and storage problems were significant, exacerbated by incompatibility and formatting difficulties. Differing communications methods and use of computers were also perceived as problematic. The human issues included differing levels of IT skills, and people not checking their e-mails. Again the responses here point out the importance of people and process issues, but equally technical virtual working problems regarding information sharing and collaboration.

6.2.4 Business Environment

Question 4.4 then asks 'What is the most difficult aspect of your job?' Once again the answers were grouped into categories:

- *Information* – factors including information management and categorising.
- *People* – factors including training and personnel management.
- *Time* – factors including scheduling and time management.

It is noticeable here that technology does not feature as a specific category in the analysis, but is included as part of the technical/economic/human mix in the people category. Information concerns include searching for and keeping track of information, secrecy of communications, and stressing the level of importance of information. People aspects include specific learning such as with databases and keeping up with technologies in general, plus motivation of personnel. The predominant aspects here (57%), however, relate to time. Short time scales and time management, simultaneous management of projects, and problems with scheduling are all-important and appear to leave a lack of time for adequate training. Once again, the fundamental concerns of the process owners reach beyond the need for technology, and human and organisational factors emerge as areas of greatest concern.

6.2.5 Business Processes and Organisational Change

Regarding business processes 98% of the respondents answered that they are aware of the business processes related with their jobs, with only 5% indicating a score of less than 4 on a 6 point Likert scale (increasing awareness from 1 to 6).

53% of the respondents answered that they had faced a major change in the organisation in the previous 24 months, with only 10% of these indicating technology changes. In terms of attitudes to change 74% responded to the question relating to their attitude to change, with 87% indicating that they had a positive attitude. In comparison 75% responded to the question relating to the company's attitude to change, with only 73% of those indicating positive.

6.2.6 Knowledge Management

Question 6.9 asks 'How do you feel about the idea of an *internally* shared database of knowledge?' Question 6.10 asks 'How do you feel about the idea of an *externally* shared database of knowledge?' Answering these questions required marking a box in a group that scales from 'not at all happy' to 'very happy' and 97% of the participants answered these questions. Figure 29 and Figure 30 show the range of answers returned to these questions.

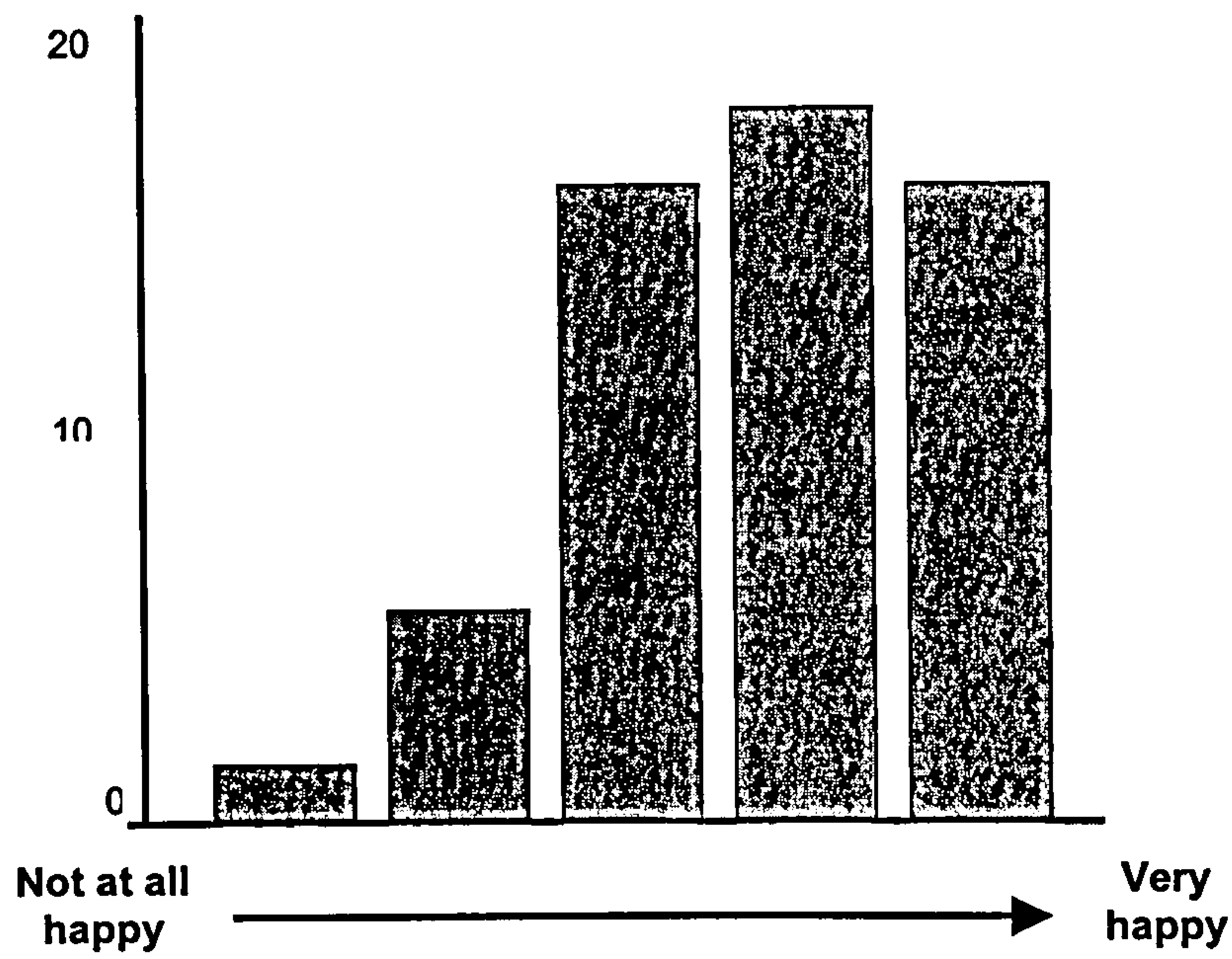


Figure 29: Feelings regarding an internally shared database of knowledge

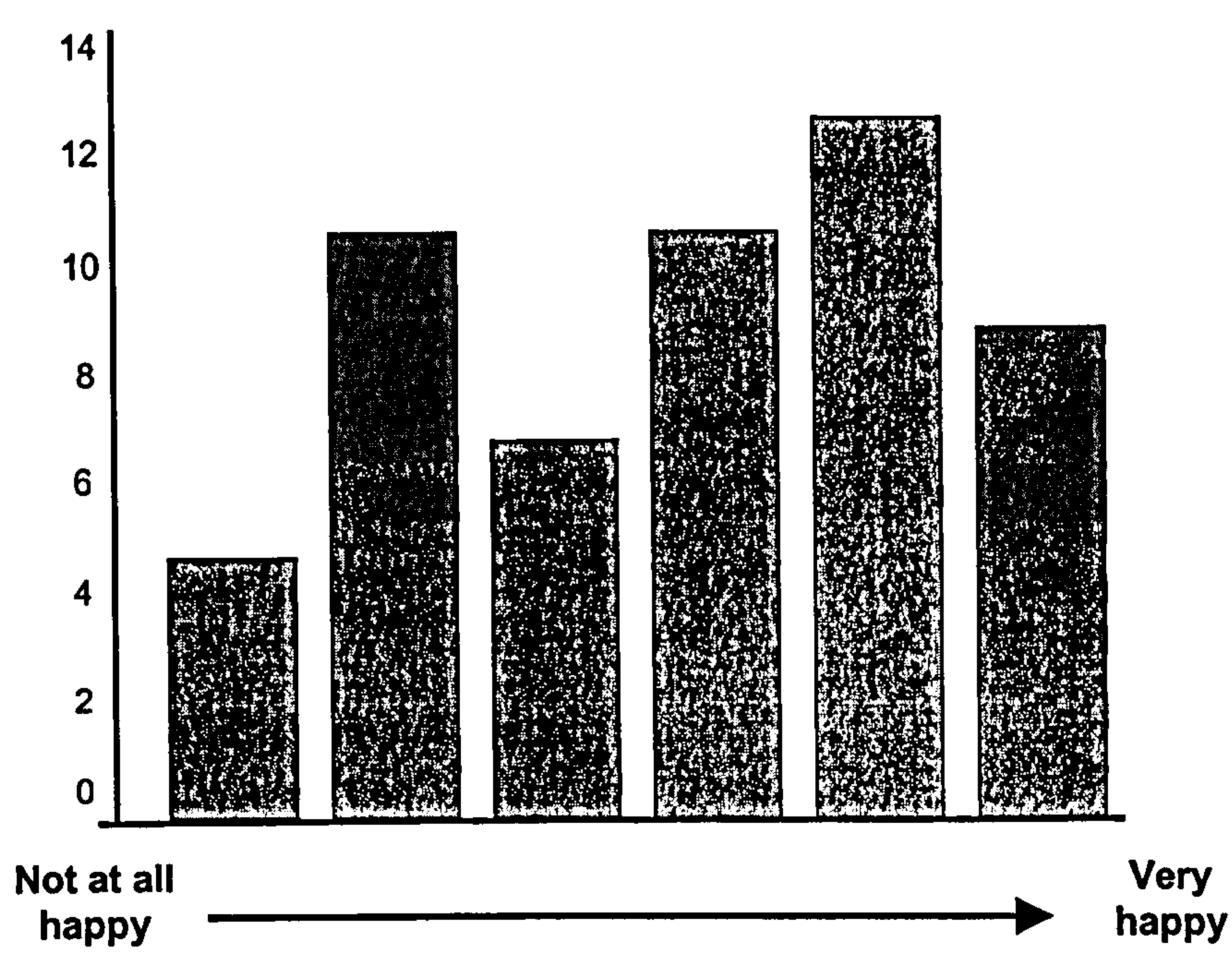


Figure 30: Feelings regarding an externally shared database of knowledge

It is noticeable that the graph in Figure 29 trends strongly towards 'very happy' compared with the graph in Figure 30, which shows a more even spread of responses. Overall, however, these results show a healthy tendency towards the need for information and knowledge sharing. This finding corresponds well with the concerns and importance attached to these issues in earlier questions above.

Despite the problems faced in carrying out the survey, and the relatively poor level of reliable results, the questionnaire was successful in achieving the profiling aim. Furthermore the results that were reliable (i.e. statistically significant within the sample), gave the Researcher positive feed forward to the requirement capture for the second iteration of the project, and were useful as a triangulation method with the interviews.

6.3 Interview results

As described in Chapter 3 (3.4.5.2) the Researcher conducted interviews in all three of the industrial partner organisations. Each of the interviews was recorded on audiotape. This ensured that no details were missed in the later analysis, and equally as importantly allowed the Researcher freedom to make additional notes based on the non-verbal cues received. The analysis followed an interactive process of data collection, data display, data reduction, and drawing/verifying conclusions (Miles and Huberman, 1994). This section presents the analysed results from the interview transcripts. They are grouped according to the four themes in the interview guide (Appendix 2) and per company. The interviews were conducted with senior people within the organisations, including owners. Although it is clear throughout the thesis which organisations were involved in the OSMOS project, the interviews were conducted in an ethical manner in which anonymity was assured. The results are therefore recorded under sobriquets.

6.3.1 Business Environment

6.3.1.1 Company A

The work is project based, team working is the dominant method, in small teams, and the environment is not one of strict hierarchy. There is a general manager, but the communication channels are open, which allows good interpersonal communication and co-operation. It is worth noting that working in teams is in itself perceived as a way of motivating people, as an interviewee commented:

> *'Because the teams are very small we can have a very direct management and speak to each person for two or three minutes every day about what he's doing, and what he will be doing in one month. This is good for keeping motivation'*

Sharing information and experience from other projects seems to be a common practice in this company. This climate supports the exchange of information and direct communication, which ultimately has a positive impact on the project work and motivation levels. All of the interviewees highlighted the importance of general meetings where every group has the opportunity to present their activities and projects. The interviewees stressed that these meetings act as ways of solving problems, sharing information and knowledge, increasing team spirit and standardising procedures and process, thus contributing to quality assessment.

6.3.1.2 Company B

This company's structure is also based on teamwork; the structure is flat, though there are managers and team roles such as team leaders and members with clarified responsibilities and roles. A third of the interviewees highlighted the fact that the team 'spirit' supports the functioning of the team. Although all of the interviewees feel that working in teams is a good way of dealing with construction projects, they highlighted problems with the formation of groups. The formation of teams depends on resources, analysis of skills, availability and workload. The main problem is availability of employees. One team leader described the process of formatting the team:

> *'When I need to create a team, I have a list of all the available people and what they are doing, how much they have to do each week, and I know the skills of different people. I can see who is available in terms of time, and whether they have the necessary skills. The biggest problem is when the best person for the job simply has no available time'*

The way people are motivated in the organisation is well explained in this company. The interviewees mentioned various ways of motivating group members.

Apart from the common motivators such as salaries and working conditions, the senior members who took part in the interviews emphasised meaningful and challenging work, and level of autonomy as the best motivators in team working:

> *'In order to motivate people the first thing is to check what kinds of things they are doing. It's important to give them things they are interested in'*

Training opportunities are available in the company and employees can choose their courses according to the project needs. Interviewees stressed that training aims to cover a broad area of expertise allowing both technical and management aspects to be included. The choice of training courses is based on individual needs and team roles and responsibilities. On-the-job training, where more experienced members of staff can share their expertise and experience, was preferred, though sometimes it is very difficult to offer such training to less experienced people due to hectic timetables. There is no structured way of sharing 'lessons learned' or other information and as a result each project depends on the way people co-operate with each other and on the member's expertise and experience. Although the culture of the company is very open, innovation is not supported through business processes. Although senior management listen and take into consideration suggestions and comments, the company's culture does not encourage enough new and innovative ways of working and co-operating.

6.3.1.3 Company C

The organisational structure is flat, which facilitates communication and decision-making. According to the participants, this flat structure and a quite open culture encourage and facilitate innovation. All the daily operations evolve around teams and projects. It is clear that the company encourage and increase motivation by introducing more interesting work. Although there is no formal training schedule, people can choose their training programme and they are encouraged to undertake training courses (though these are mainly technical).

6.3.2 IT in construction

6.3.2.1 Company A

IT applications are widely used, and although e-mail is widely known and used there is no full integration and communication among the subsidiary companies. This creates many problems and the employees are working toward setting up a server to enable wide communication and exchange of documents and information. One interviewee described the communication process in the company:

> *'There are still a lot of problems of communication for two reasons. We have one man one screen, the IT part is quite good, but the problem is that we don't have the tools to communicate easily within the company and that's a big problem. I can give an example of this: there are three subsidiaries of the company that are working for the same client, yet the three directors of those subsidiaries don't know they are working for the same client. This is an internal problem but it can have repercussions to the exterior, and to the relations we have with the client. We don't have an Intranet network here. We have a network where we can share printers, etc., but it's not easy to send a message to another person internally. We also have some problems with the Internet because all the subsidiaries are independent, and each subsidiary has personal access to the Internet. The company is aiming to have just one server for all the companies. An Intranet would be useful. We have a little paper, which contains some information, but the problem is that it's printed I think six times a year, and that's not enough. With an Intranet you can capture information easily and more frequently'.*

Some processes such as drawing production are computerised whilst others are not, which creates difficulties. All the interviewees agreed that business processes need to be changed and then automated. Some long-standing employees were reluctant to use new technological applications, whilst younger employees respond positively to a continuously changing environment. Overall, the level and frequency of use of computers has dramatically increased during recent years and the company culture is quite supportive to new technologies, though it does take time to change:

> *'For the global organisation of the company, communication for very simple thing, and all the things that we don't pay attention to because 'they've always been done that way', could be very much improved if we use the new technologies'*

6.3.2.2 Company B

Age appears to have a major impact on the use of computers in this company, with the interviewees highlighting the fact that younger employees feel more confident with the use of computers and have better basic skills than their older colleagues. This may affect attitudes toward introduction to new technologies and use of software. The company's policy aims at offering structured training, allowing all the employees to benefit and eventually adapt to a continuously changing world. In some cases training is compulsory because older employees need to learn how to use new software that is crucial for their daily operations.

The various levels of use of technology cause problems in team working. For example, older employees are used to drawing on paper whilst younger employees use AutoCad in order to produce their designs. As a result, it is difficult to create a co-operative climate among teams due to friction from different ways of working, different mentalities and approaches. Age is not the only factor that creates tension in teams regarding the use of technology. Sophistication and complexity of software also create tension in relationships because some people (e.g. engineers) are able to use them adequately but others cannot cope with their requirements.

6.3.2.3 Company C

IT applications are widely used in projects in this company. The interviewees stressed the need for user friendly and easy to use technology tools, and indeed to achieve a paperless office where the employees can deal with their daily operations without delays. There is no structured way of sharing knowledge and information and disseminating lessons learned from previous projects, which can negatively affected the final product or service. However, the interviewees highlighted the role of the company Intranet where employees are able to share news and information.

6.3.3 Integrated services

6.3.3.1 Company A

The interviewees viewed as very ineffective the methods for sharing information, exchanging knowledge and disseminating information. Storage and distribution of information is not based on an effective system supported by technological applications. The following is from an interview with a senior manager:

> *'If we want to look for something in the text, in the specification, and find different projects dealing with the same thing, there is no means today except for asking people. This is unreliable, and time consuming and you don't really find the information you want. I feel sure that the first company in building engineering that will have a really efficient system to do that will improve its productivity. A lot of legacy information is in people's heads, and with staff turnover and people not talking enough to one another a lot of information is lost. If we want to create a new museum for example, and use information from all the museums built by the different subsidiary companies, there is no means today. You would give a phone call to each different company, and maybe three months later you would have only a part of the answer. If we had a system to ask a question to an organised database instead, it would be really efficient'.*

There are many problems in the relationships/semantics among documents containing various pieces of information. One interviewee stated:

> *'For example, between the specifications of electricity and the specifications of HVAC, there is different information that is produced by the one and used by the other. There is an electrical list with all the devices, and you find the equivalent, which is not exactly the same document, but if we change something in the first document, it should immediately create a modification on the other. What is important for us is not the process between the one and the other, but the link, which should create something like an automatic Table of Contents'*

There is no notification of changes in documents and employees need to communicate via telephone in order to get answers on changes and latest versions. This way of working is quite ineffective because it relies on the physical presence, or availability, or indeed ability, of people to confirm the latest versions of documents. In addition there is no consistency among different companies and teams, for example there is no consistency in naming files indicating the relationship between the file and the paper document. Apart from notification of changes in documents automatic referencing is also needed:

> *'Sometimes people create a new project with information from an old one, but if there was another in between, and the information from that is more relevant than the one being used, information can be missed. If we could organise what we produce with automatic references, the right information would be used. Because everything is organised in standalone documents, a reference to a norm or another document is static. If it was a dynamic reference to something, we could change the address, and the different people with the same information could be informed immediately'*

E-mail was suggested by all as a way of giving notification of changes in documents. It is important to note here that participants also suggested incorporating a filter, which would be able to organise information in different categories indicating if the message is from, for example, the architect. All the participants agreed that some groups in the company are reluctant to use e-mail and other technological applications mainly because they are not familiar with the effective use of the systems. Age was seen to be a major factor, which differentiates groups in the company. It has to be noted here that some senior people in the company do not use computers. Although electronic diaries were suggested as something useful for the future, there were some concerns because some people don't trust technology and don't have the skills to use it effectively. Concerns were also expressed regarding information and knowledge sharing among subsidiaries. There is no strong culture supporting the unity of the group and as a result exchange of information and knowledge is not facilitated. Two of the participants suggested building a very structured repository for storing and disseminating knowledge and experiences.

6.3.3.2 Company B

All the daily operations evolve around teams and projects, with the communication process based on face-to-face meetings. It is difficult to schedule meetings and form teams because of the availability of each member. Electronic diaries were suggested as a way of improving communication and videoconferencing was regarded as something very useful because of the company's projects abroad.

Two of the interviewees argued that some information systems are complex and difficult to use, with age being a moderating factor. Young employees have the skills to operate computers easily and effectively, as opposed to older ones who do not have the time and the confidence to learn new programmes. Although e-mail is widely used, people don't feel confident to live in a paperless office. As a result, a minority in the company print e-mails and keep them in files, ignoring the electronic mail folders:

> *'We are still in computer work but with a lot of paper. In this company we have come quite a long way – we have a document management system where paper would be unnecessary, but still you have a memo of a meeting and every person prints it out and reads it from the paper rather than on the screen. If they used electronic methods they would have a file where they can access it at any time, rather than in a folder on a shelf'.*

It has to be noted here that the culture of the company is based on informal meetings where projects are discussed over coffee. Although there is an hierarchy and an organised decision making process, communication channels are open. As a result, the company's culture is characterised by trust and openness where people are not afraid of exchanging information and sharing their knowledge and expertise.

6.3.3.3 Company C

Sharing information and knowledge systems are not adequately developed. Although there are many ways of exchanging information such as e-mail, the intranet and Internet, there are many problems such as location of saved information, accessibility from outside, security and access. Two of the interviewees commented that the intranet is adequate and covers all the needs of existing projects, yet they prefer to print documents related to projects and keep them in files. All of the drawings are produced electronically and all information relating to the projects are in electronic form. The participants highlighted the fact that people need to search for documents in the intranet, but the searching is time consuming and it is difficult to find the storage location. Versioning is also problematic. The process should be improved and made user-friendlier.

E-mail is used for notification of changes to documents but it is ineffective because not everyone checks their e-mail every day. A database can be checked for changes of documents but it is complicated and time consuming. The interviewees felt that the company needs a notification system, and a portal or a common interface would facilitate this. Meetings can be difficult to set up because of busy schedules, employees being involved in different projects and groups concurrently, and as a result it is difficult to find mutually convenient meeting times. A popular solution suggested from all the participants was the electronic diary. Participants indicate that technology is the way forward and they would like to see electronic time booking/electronic diary, instant notification of changes in documents and drawings, and videoconferencing facilities integrated in their system in the future.

6.3.4 Organisational change

6.3.4.1 Company A

There have been many technological changes in this company. Some years ago everything was on paper, but now all drawings are produced electronically. Although some people resisted this change, the need for production without delays and errors was intense and as a result there were many dramatic changes. According to one interviewee:

> *'Some of the older people who had the drawing skills had some difficulties with the change and they didn't want to use the software. This was sometimes a problem because they had this habit to go back to the old method each time, and we had to tell them again that this was the new way of working'*

There were many problems with the document management systems because there was no structured way of registering and retrieving a document. All the documents had to go through administration for registration and before being sent outside the company. Today new software enables the above process with direct registration and retrieval. There is a low degree of resistance to technological change in the company, thus technology implementations are usually successful. However, all interviewees agreed that it is very difficult to make people work with computers in the same way. It is also difficult to convince some groups of people to co-operate and use the new technology because of previous failures of the system, but there is communication of strategic plans from senior management to people involved or affected by the change. An interviewee presents an example:

> *' When we introduced the system of Internet access for all the engineers they were very happy. But because of the system problems they were very disappointed, so they went back to their old methods. So now, if we want to use all of these tools – Internet, e-mail, etc. – we have to demonstrate that they are really viable'*

6.3.4.2 Company B

This company continuously deals with changes. Although the company has grown quickly over the last decade, there is resistance to change mainly because of the continuous introduction of changes and some previous failures in change implementation. Two interviewees suggested involving people more in decision-making and strategic planning. Although many changes regarding both technological and management issues were introduced, the pace of change is still slow. Again, the age problem and differences in computer skills create tensions, which become more intense in a changing context. The open communication channels can support continuous change in this company. Changes are discussed in meetings and employees can comment on changes related to their daily operations and jobs. As commented:

> *'I do think that the people who are going to be affected by change have the correct level of involvement, the way it was done in our department was the right one I think. We discussed it in our department meeting – the good sides and the bad sides, and how it would affect our work in a year or so. After that discussion everyone was convinced that the profits were so big that some initial discomfort would not be so bad. Without this discussion, however, there could have been much more resistance'*

6.3.4.3 Company C

This company also faces many changes and the coping strategies are based on explaining the need for change, involving people from the beginning and analysing the impact of change on their jobs. The flat structure of the company and the open communication channels facilitate the adaptation to continuous technological changes. It has to be noted here that large-scale changes are always less welcome than small scale ones. Again age is seen as a factor affecting change implementation. As one interviewee commented:

> *'When I started at this company there was no e-mail, and not everyone had a computer. There was no intranet or Internet either. There was some resistance with the move towards doing so much of our work using computers, but this was mostly from the older people'*

6.3.5 Comparison of results between organisations

The interview process (and indeed the questionnaire) research methods have combined human and organisational factors with technological considerations, in order to work towards answering the research questions of the thesis. This section draws comparisons from the above results between the different companies.

In all three companies the business environment shows key elements of team working in a project based environment, which is not strictly hierarchical. Furthermore, team working is seen as a positive factor in engendering motivation in company A, and company B views team spirit as positively supporting the functioning of the team; both company B and company C suggesting that people are motivated by the opportunity for more interesting work in an autonomous setting. Company A emphasises the importance of good communication, seeing this as a cultural issue rather than just a technological consideration, though it is significant that under the heading of 'IT in construction' company A notes a lack of communication among subsidiary companies. From this technological perspective, communication is linked with information sharing and in all three companies, the efficacy of information sharing is put into question, with company C and company B noting no structured way of sharing lessons learned between projects. Whilst email is widely used as a communication and sharing method, there is a general feeling that the technology is not used to its fullest extent, the moderating factor of age being noted widely as a cultural issue regarding technological use and indeed change. Each of the companies has faced considerable change in recent years, with varying degrees of acceptance, and admitting a need for early involvement of users at all levels as a positive aid. Both the technological and cultural issues suggested as important for future progress by the participants point to a need for improved consideration of the ways in which training is offered within the companies.

The semi-structured nature of the interviews allowed the respondents to speak feely of issues of concern and in triangulating the results with those from the questionnaires, four key themes of information sharing, organisational culture and team working, acceptance of change, and training emerge. These themes are further discussed in Chapter 7, Section 7.4.1.

6.4 Testing and evaluation of the VE prototype

As noted in Chapter 3 (section 3.4.5.3), field trials were conducted towards the end of each of the three iterations of the OSMOS project. The field trials therefore allowed incremental evaluation of the proposed VE solution as the development progressed, and the results from the first two sets of field trials provided important feed forward to the ongoing development process in the following iterations.

This section describes and presents the results of the final field trials, which were held in France, Finland and Sweden.

6.4.1 Field trials descriptions

6.4.1.1 Field trial in France

The French field trials took place in the training room of Derbi at the OTH headquarters in Paris on Friday 8 February 2002. Two sessions were organised, one held in the morning, the other in the afternoon, involving professionals who were chosen based on their professional experience and skills. The target of the field trials was to test a range of value added services to construction professionals available via the OSMOS VE web-platform, with selected scenarios representing significant processes of the building lifecycle. The scope of the trials was the whole building lifecycle, according to the objectives of OSMOS, involving all three of the OSMOS roles (*VE Service Provider*, *Third Party Service Provider*, and *VE Client*: see Chapter 4, section 4.2.3).

The tools used in the field trial included the internet-based OSMOS Server Administration Tool and OSMOS VE Project Administration Tool, accessed through a commercial web navigator, with the OSMOS middleware solution providing the communication and interaction mechanisms necessary for the integration of third party services (TPS) and the secure, tracked and transparent management of information. TPS tools used included the SGTi EDMS developed by Derbi and the Ryhti FM system developed by Granlund, both of which were accessible via OSMOS by all VE participants.

The first session of the field trials involved IT professionals who are experienced in the management and use of electronic platforms supporting VE. These professionals participated in the development of SGTi tools, one of them administers the SGTi servers, and the other is responsible for the support and training of SGTi clients.

The second session involved professionals from the construction industry that have some knowledge of ICT. They are experienced in managing construction projects and teams both at the design and site works stages. They either co-ordinate the work as project managers or are involved in the project as participants. They represent the VE Clients, the professionals who will sign up to an OSMOS VE.

The sessions were organized according to the following agenda:

1. Presentation of the OSMOS project: objectives, methodology, concepts and results
2. Presentation of the trials objectives
3. Unrolling of the scenarios using the OSMOS platform
4. Evaluation and discussion using the user and observer evaluation forms

A set of "educational" slides was used to present the project and the objectives of the trials (items 1 and 2 above). The OSMOS platform was hosted on DERBi's LAN.

The roles used in the field trials scenario were as follows:

- VE Server Administrator – providing, maintaining and administering the OSMOS platform;
- Third Party Service Provider – providing OSMOS compliant business tools that are plugged in to the OSMOS platform;
- VE Project Administrator – managing the VE project, defining and assigning the roles held by the VE participants;
- VE Project participants – actors from the construction industry that are involved and participate in the VE, whether organisations or people.

6.4.1.2 Field trial in Finland

The Finnish field trial was conducted at Elisa Oyj, one of the largest telecommunication companies in Finland. Elisa has over 7000 employees and a large technical facility management (FM) database that contains detailed FM data from over 400 different facilities. The field trials were performed over three days at the end of January 2002. Eight people representing the building owner, a maintenance company and a FM consulting company participated in the test. The target of the field trial was to test the setting up of a VE, access to and usage of web-based FM tools and interaction between different actors in a role-based FM environment. The field trial was mainly performed in a real production environment with 'live' data; however, the VE Manager tool used for configuration of the VE was partly tested with a copy of the 'live' data.

The tools used in the field trial were the GranlundWeb browser, a web-based, OSMOS-enabled information-browsing tool used to access the RyhtiWeb FM services, and the Granlund VEM (VE Manager), an implementation of the web-based OSMOS Virtual Enterprise Management Tool.

The testing scenario was that of setting up a VE, and communicating FM problem request messages to the RyhtiWeb tool using the Helpdesk service. The

Helpdesk was selected because it involves communication between actors holding several different roles. The Maintenance service was also tested during the field trial.

The set up for the field trial involved actors from three different organisations:

- Elisa Oyj (Building owner and building users)
- ISS Palvelut Oy (Maintenance company)
- Olof Granlund Oy (Facility management consultant)

The project ('object group' in the RyhtiWeb terminology) was limited to span the FM services of a single office building in the centre of Helsinki. Within the project, the VE manager defined five different roles using the Granlund VEM tool:

- VE Manager (Granlund)
- Facility Manager (Elisa)
- Building User (Elisa)
- Maintenance Manager (ISS Palvelut)
- Maintenance Worker (ISS Palvelut)

The eight actors involved in the field trial were added to the VE using the Granlund VEM tool. All the actors were given usernames and passwords, and information for title, forename and surname were recorded. The users were assigned to the project and they were given roles with access to different Helpdesk functionality. Some of the roles also included access to other FM services like the Maintenance service, the Document service and the Technical Data Management service.

During the field trials actors holding the different roles interacted with the FM System in the following way:

VE Manager

- Create a project (object group) for the selected office building
- Create 5 roles with appropriate access to RyhtiWeb FM services
- Create 8 users and assign roles to the users
- Assign the users to the project

Building User

- Add several facility management maintenance requests
- Monitor the progress of the requests

Maintenance Manager

- Create work orders from the maintenance requests and dispatch them to the maintenance worker in charge
- Monitor the progress of the work orders
- Add ad hoc tasks

Maintenance Worker:

- Handle work orders and report work done
- Report ad hoc tasks performed
- Print weekly work orders based on the maintenance plan

The Facility Manager had full access to the Helpdesk, Maintenance, Document and Technical Data Management services for browsing and reporting data and monitoring interaction between the other participants.

6.4.1.3 Field trial in Sweden

The Swedish field trial was performed at Carasoft's office in Stockholm. Carasoft AB is an established IT company, specialised in document management. They develop systems for LANs, the Internet and WAP. The objective of the field trial was to show that it is possible for different end users in the same project to work with different tools and still communicate. The tools in the trial were: Document bank system (a Document Management Service based on Carasoft's software that is used by JM in real life projects); User workstations (OSMOS Client) with a web browser and IMAP-enabled email software client (Microsoft Outlook).

The field trial scenario followed a workflow in which a working order containing instructions to complete a painting job in a new apartment was completed. This scenario was chosen because it often occurs in an ordinary project and it also involves many actors who can benefit from easier communication methods.

In total there were five people who performed the field trial. Each of the attendees represented a specialised function in JM. These people have responsibility for JM's IT development, JM's document management, and other internal processes. Two of the people also represented a construction project organisation.

The field trial started with a presentation of background information regarding what JM has done before and the projects the company faces in the next three years. At the end of the trial a discussion was held on how JM can use the knowledge and the results from the trial in the company's future development. Carasoft then presented their future plans with their products, and how the help of the OSMOS project will improve them.

The roles for the actors involved in the trial were:

- Project Manager
- Sub-Contractor
- Future Building Owner
- Current Building Owner

The focus of JM in the OSMOS project is as an end-user organisation, and as such the actual provision of the VE was not tested in the trial. The project group was already set up in an OSMOS server at the commencement of the trial and a service provider would administer this. The main focus during the field trial was the ability of the project members to work using the tools that they normally use and are familiar with, and still be able to exchange the necessary data required within the scenario.

The sub contractor (in this case the painter) changed the status in a work order, which he reached through an internet-based document management system. When the status had been changed the new building owner then confirmed that the constructor could be paid. The confirmed order was recognised by the current building owner's controller, who accepted the invoice for payment.

This workflow scenario passed the data through different systems, triggering actions from each partner, whilst they successfully used their usual tools for exchanging the data. This demonstration was important for the end users, showing them that the task is possible using the tools that they already know (e.g. low entry-level) to handle project information.

6.4.2 Description of the Interfaces Used for the Field trials

This section provides some illustrations of the interfaces used and tested in the trials. Third party services (TPS) were used in all three of the field trials, whether through full integration of the tools, or as OSMOS 'aware' versions. Testing of the VE server administration and the provision of TPS took place in the French and Finnish field trials but not in the Swedish trial.

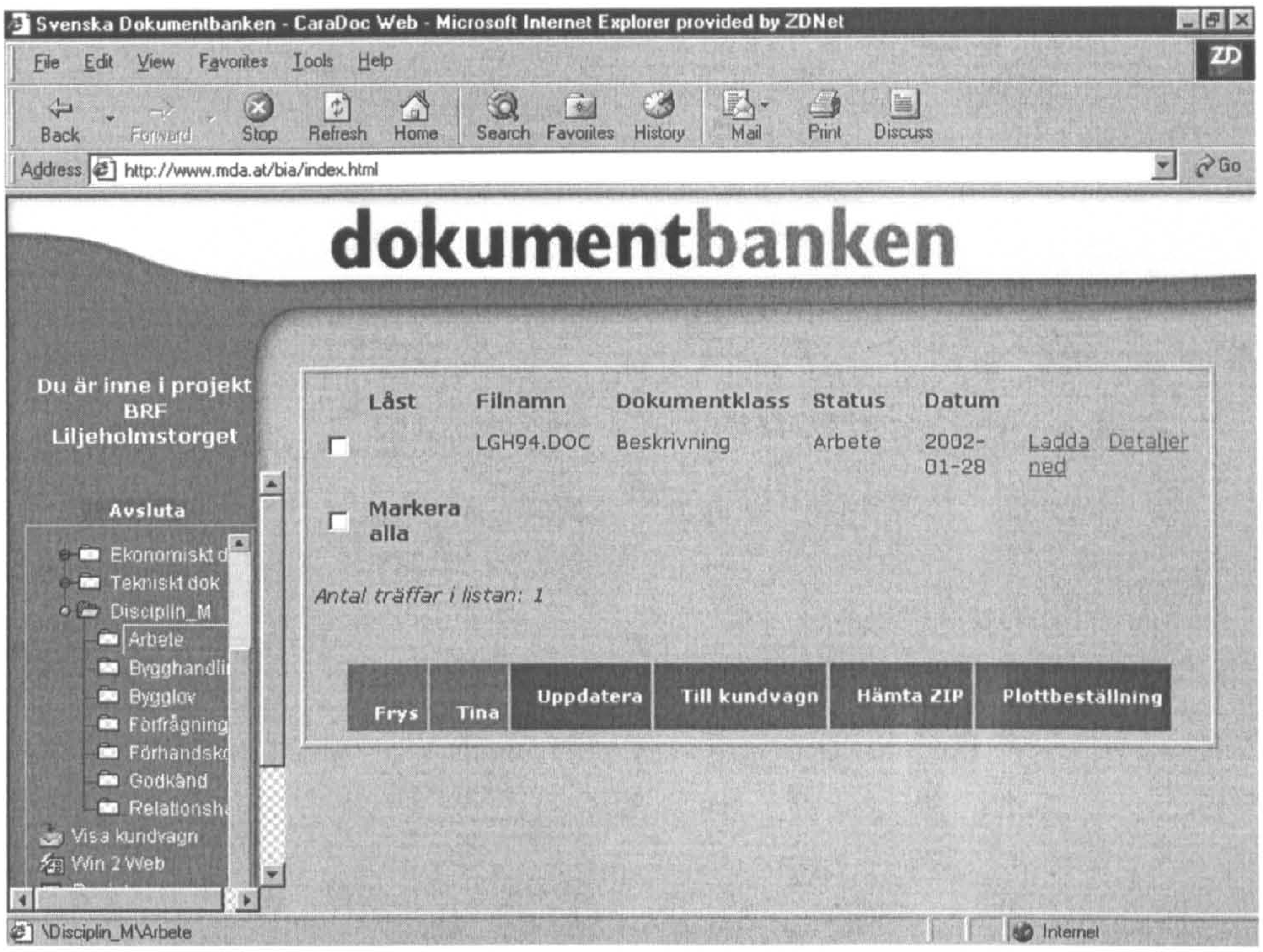


Figure 31: User interface of the Document bank tool

As noted before, the field trial in Sweden was conducted purely from the users' perspective and the VE had already been set up with the appropriate TPS. Figure 31 and Figure 32 illustrate that the tools used in the Swedish field trial were indeed OSMOS aware; Figure 31 above shows the Document bank EDMS as it was used to make a search for the correct document in the field trial. Figure 32 then illustrates the same tool being accessed through the OSMOS web-based information browser (WIB) interface.

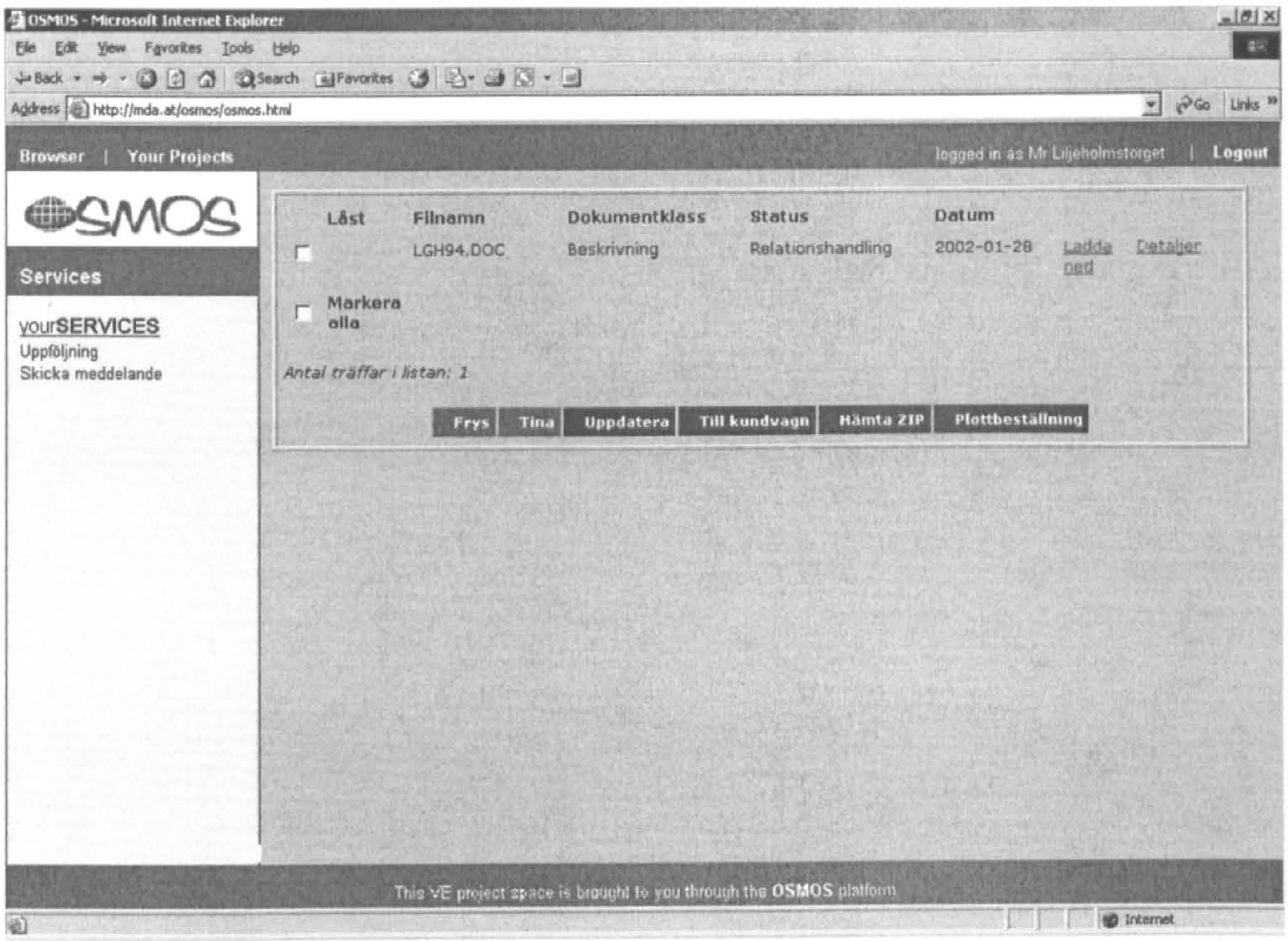


Figure 32: The Document bank tool accessed via OSMOS

The successful integration of TPS is further illustrated below as applied in the French and Finnish field trials, with the different organisations testing varying implementations of their respective tools. Figure 33 shows the interface used in the French field trial for registration of new TPS. This tool is a version of the reference implementation. From this interface the HTTP-related details of documents held within SGTi are visible, together with the parameters – both static and dynamic – required for the passing of information via the OSMOS core. Figure 34 in turn illustrates the interface available to the VE Server Administrator in the French trial.

In the Finnish field trial the user interface was modified and made more organisation specific, following a similar design layout to that of the Ryhti FM tool with which the personnel are already familiar. This is illustrated in Figure 35, showing the Granlund Virtual Enterprise Manager tool allowing TPS methods to be assigned to the 'Administrator' role. This use of familiar interfaces was an important distinction in these final field trials, compared to the trials in the previous iterations.

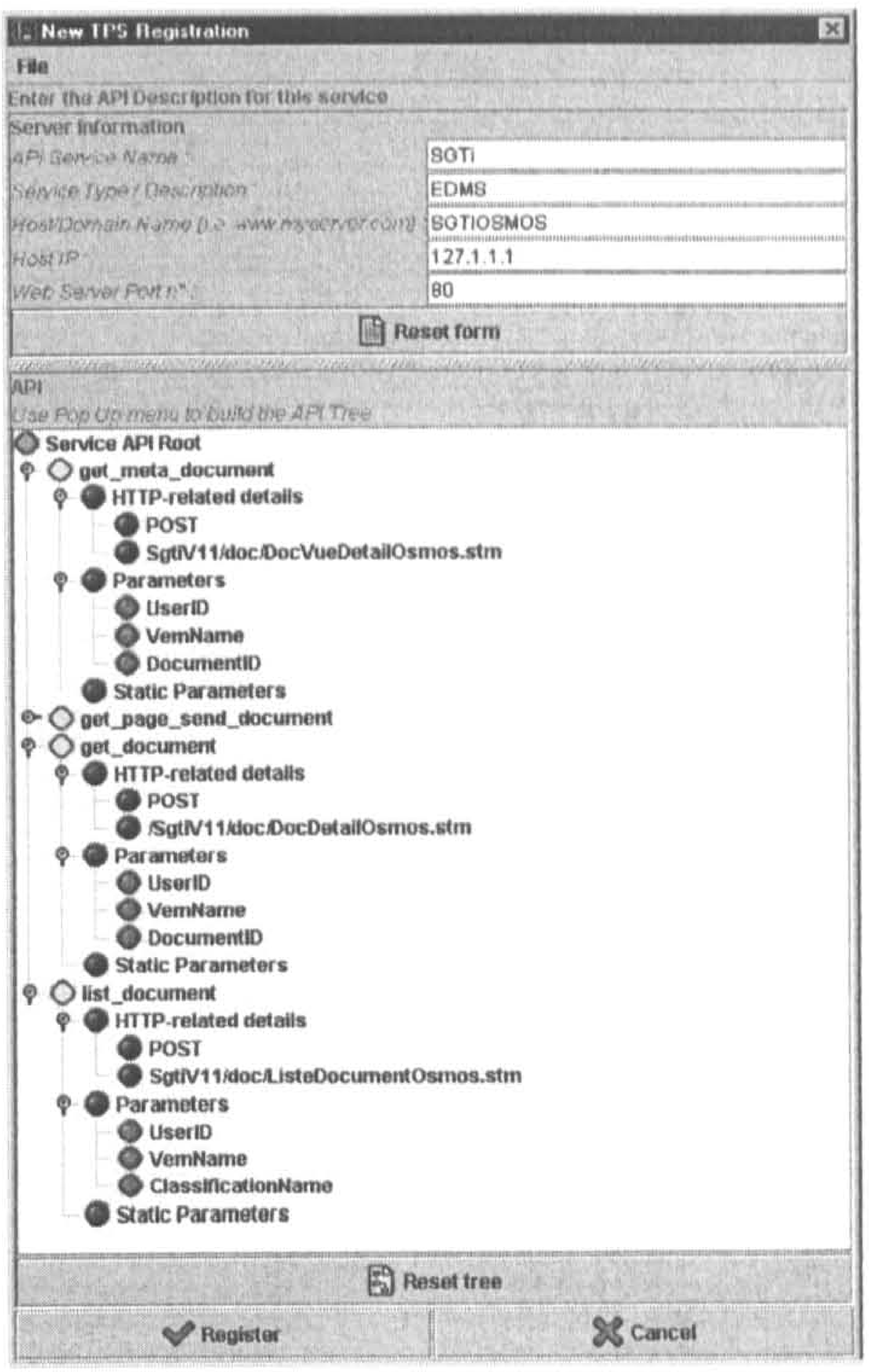


Figure 33: Interface for registration of TPS in the French trial

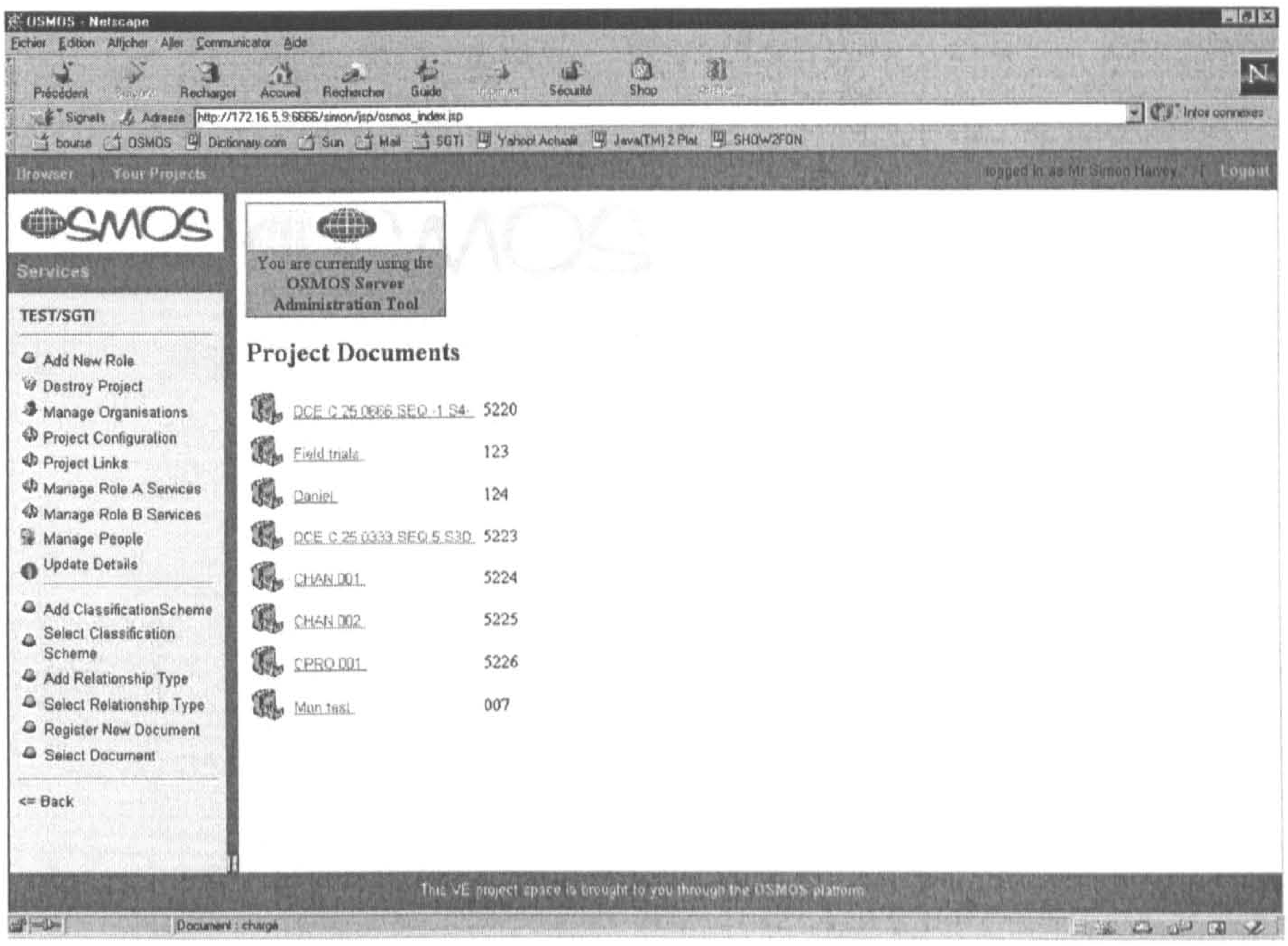


Figure 34: VE Server Administrator interface in the French trial

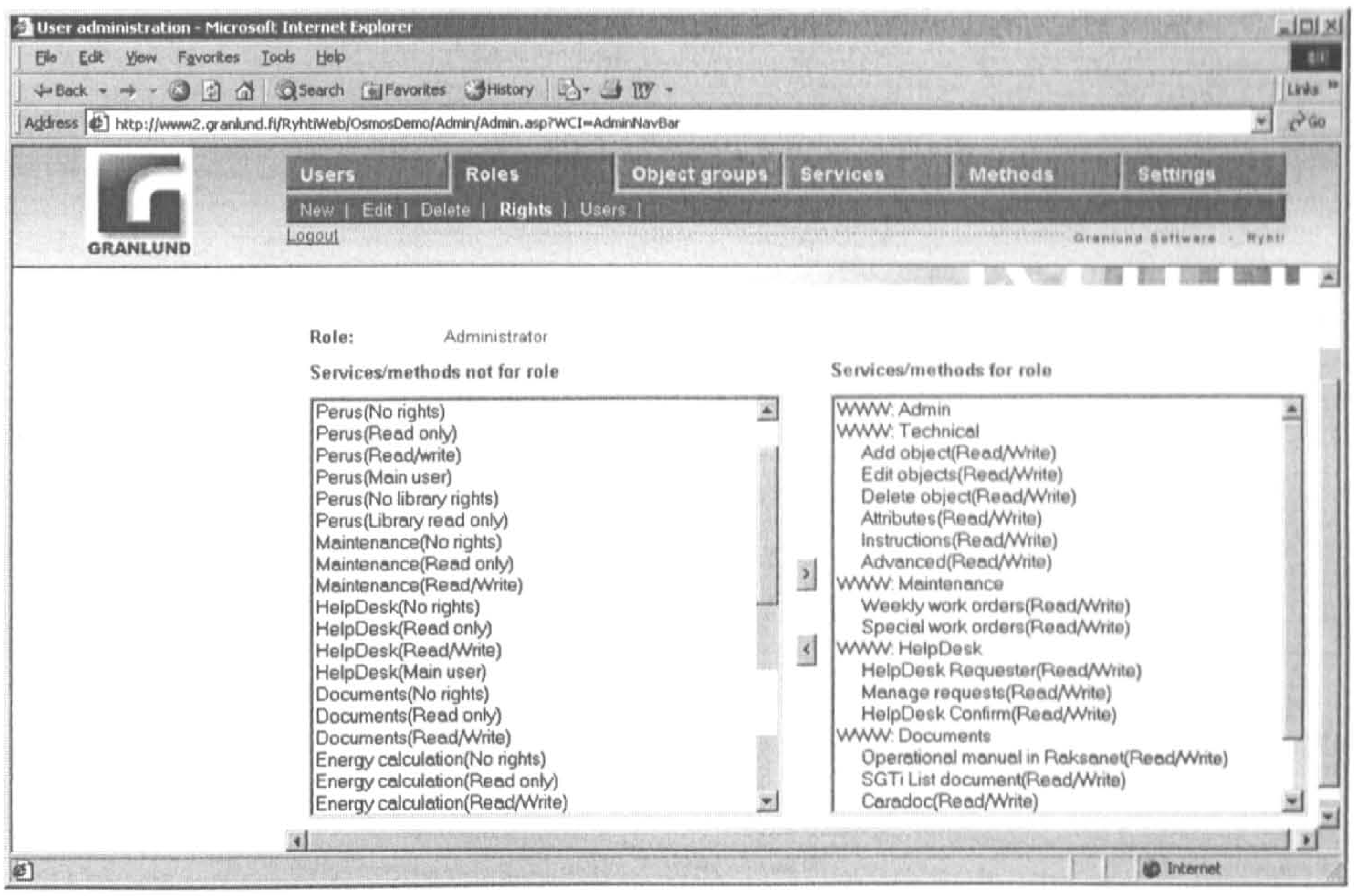


Figure 35: Granlund implementation of the VE Manager tool

A comparison of Figure 31, Figure 36 and Figure 37 illustrates well the use in the field trials of tools that participants already use in Sweden, Finland and France respectively.

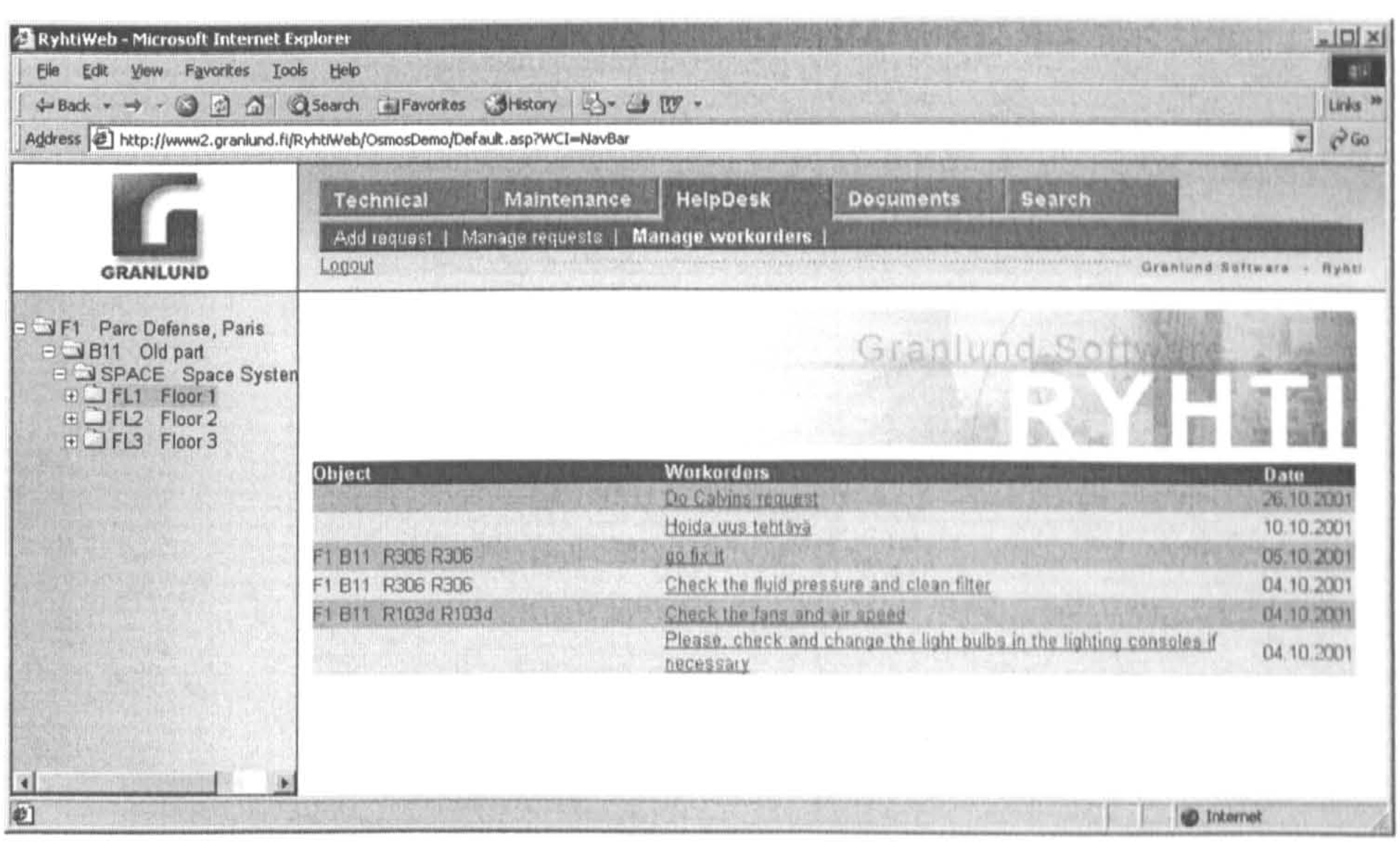


Figure 36: Granlund web browser showing Ryhti Helpdesk

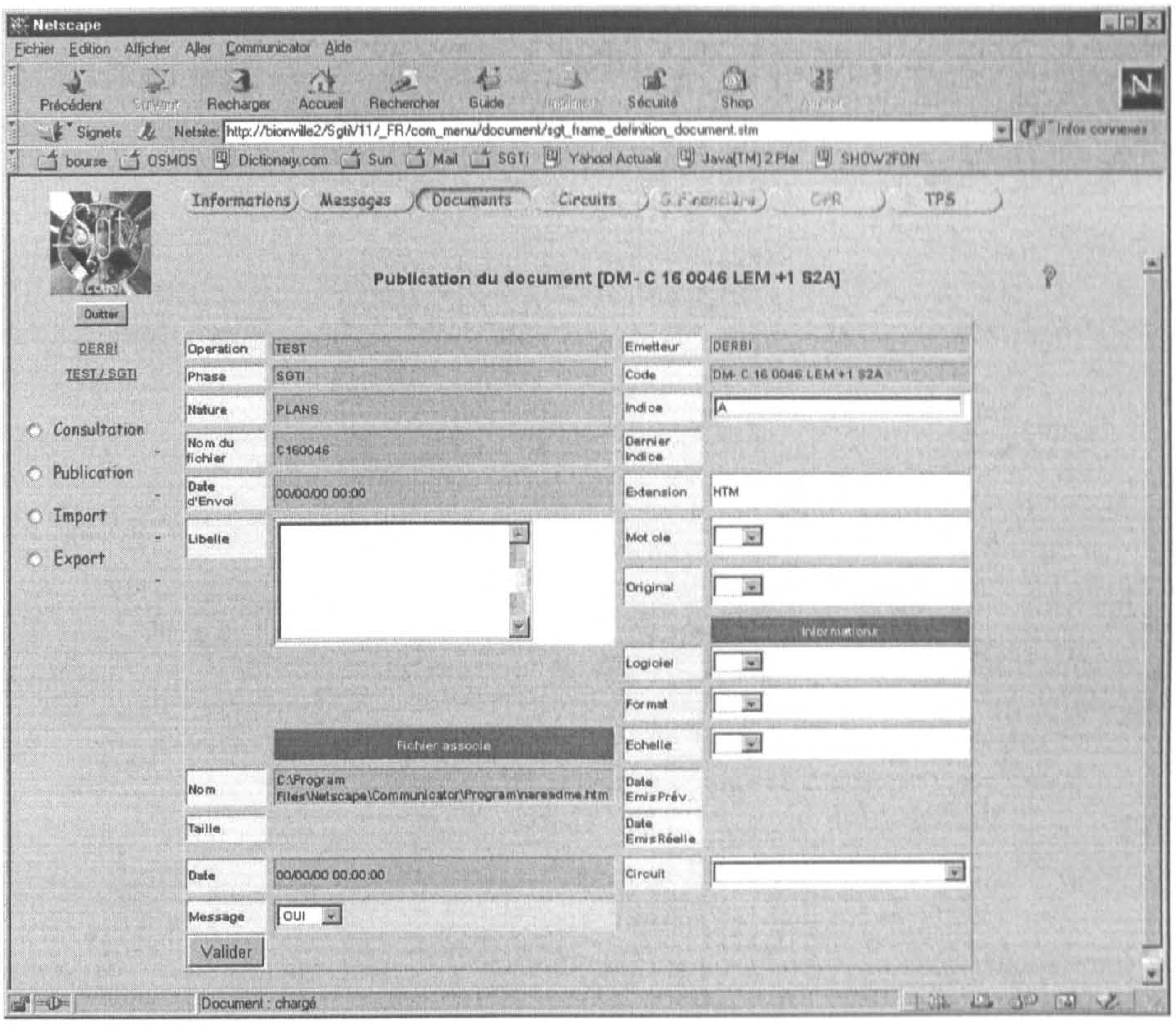


Figure 37: The SGTi web-based interface

6.4.3 Synthesis of the Field Trials Evaluation Results

The results reported below are divided into two main sections. The first section provides results from the VE Server Administrator and Third Party Service Provider evaluation forms (see Appendix 3). This section is divided into two sub-sections for the field trials in France and Finland. The following section reports the results from the VE Project Administrator and User evaluation forms (see Appendix 4), and is subdivided into sections for the trials in France, Finland and Sweden respectively. For the French and Finnish trials an amalgamation of the responses from the user evaluation forms and the additional information gained from the observer evaluation forms (see Appendix 5) is presented. The results are grouped under the category headings from the particular evaluation forms, with the further heading 'business benefits' reporting the responses to the generalised question included in each of the user evaluation forms.

6.4.3.1 Synthesis of the VE Server Administrator and TPS Provider results

Table 9 below presents a summary of the results from the field trials. The table is organised by the country in which they were held and categorised by the evaluation form criteria.

Criterion	France	Finland
Integration	Easy integration of OSMOS tools into existing architecture. Easy integration of own tools into OSMOS architecture. Other services can be added quickly. Improved availability of services and increased exposure. Difficult maintenance of TPS. System enables efficient management of IT support for the VE. Improvements required in terms of user-friendliness. Good high-level security.	Easy integration of OSMOS tools into existing architecture. Some difficulty with integration of own tools into OSMOS architecture. Other services can be added quickly. Increased exposure of services through successful integration and implementation. Difficult maintenance of TPS. System enables efficient management of IT support for the VE. No requirement for improvements in user-friendliness. Good security.
Training	Training required, preferably under a structured training programme.	Low training requirement
Business benefits	1. Ability to attract more clients 2. Increased client satisfaction/improved team working 3. Improved project management	1. Improved day-to-day operations 2. Ability to attract more clients

Table 9: Summary of VE Server and TPS Provider results by country

Whilst the French field trial reported that the integration of TPS is very well designed and implemented, in Finland the process proved slightly less easy. However, the Finnish trial then reported that once integration was achieved it would allow greater exposure of the company's services. This is an important result in terms of the aims of the OSMOS approach, and one that has not been able to be tested until the field trials of this final iteration. As shown throughout the thesis, one of the fundamental objectives in the VE is integration and interoperability of ICT. It is significant therefore that in both the French and Finnish field trials integration to the OSMOS platform of TPS was achieved successfully. The notion of making such services available quickly in a plug-and-play fashion does not preclude the fact that initial integration of a service to the OSMOS platform may take some time. However, once this has been achieved for a particular service then that service can be quickly deployed in any VE that wishes to work via the OSMOS platform. These trials have positively proved the concept, with Granlund's Ryhti tool being integrated in the Finnish trial and both Derbi's SGTi EDMS and Rythi being integrated in the French trial. (Furthermore it is worth noting that although the integration process was not directly tested in the Swedish field trial, the Document bank EDMS was also successfully made OSMOS aware). Some work may still be required on the part of the TPS providers to enable easier maintenance of the integrated services, but in business terms both field trials report that integration of their tools to the OSMOS platform would improve their exposure upon implementation of an OSMOS powered VE.

In the French trial it was noted that there were still some concerns over the 'user-friendliness' of the interface. Similar remarks did not result from the Finnish trial however. In the first two iterations of the project the field trials reported such problems, but it was noted that the tools being tested at those times were reference implementations only. The results from these current field trials show the importance of the VE Service Provider companies developing their own specific user interfaces: for the Finnish field trial Granlund had developed their own interface, whilst for the French trial the reference implementations of the OSMOS tools were used again.

In terms of security of confidential and contractual information the results have shown that there are no great concerns and the OSMOS Security Service functionality has proved adequate at a high level. It is worth noting that, as reported from the French field trial, security at a lower level is to some extent the responsibility of the service providers integrated into a specific VE platform.

The results from both of the field trials show that it is felt that some training will be necessary for companies wishing to use the OSMOS platform. This is also an important outcome, especially if a company has to consider whether or not to introduce a formal training programme. It is noticeable however that the perceived need for training was lower in the Finnish field trial results, and this again may be attributable to the fact that the tools being used for provision of the VE platform had been adapted and provided greater familiarity to the participants. For live implementation and exploitation of the OSMOS platform, documentation detailing the use of the system would have to be made available, and it is also clear that the companies offering TPS would have to provide some form of training material for end-users using their tools for the first time.

Inclusion to the VE Server Administrator and TPS Provider evaluation form of the generic question regarding potential business benefits proved to be a useful exercise in the validation of the OSMOS approach. The ability to attract more clients was clearly the most important business benefit across the two sets of results, which is in business terms, a significant consideration indeed.

6.4.3.2 Synthesis of the VE Project Administrator and User results

Table 10 below presents a summary of the results from the field trials organised by the country in which they were held and categorised by the evaluation form criteria. It is worth noting that due to the small number of responses from the Swedish field trial some of the results had to be treated with caution. In such cases the synthesis refers only to the French and Finnish results.

Overall, the results reported regarding the usability of the tools showed a very positive acceptance in Finland and above average acceptance in Sweden. The only real dissatisfaction came from the French results. There were some concerns regarding user-friendliness of the interface and navigability, as there were from the VE Server evaluation results above. Again it is noticeable that where Granlund had used organisational implementations of the tools for the Finnish trial, the results were very positive. The main concern in terms of added-value of the OSMOS approach from these usability problems reported in the French trial is that there may be possible data inconsistency between OSMOS and the TPS. Such problems were not reported from either of the other two field trials. This suggests that it may be a problem relating to the integration of the tools rather than being a usability issue. The French field trial also questioned the ability of the system to manage large projects. The

Finnish field trial results showed quite the opposite of this, though this point is difficult to prove in field trials of this nature.

Criterion	France	Finland	Sweden
Usability	Good overall layout but not easy to use. Difficult to navigate. No search capabilities. Some errors reported, but easy recovery. Good response times. Questioned capability of managing large projects. Possible data inconsistencies.	Very easy to use. Very easy to navigate. No specific errors reported. Very good response times. Full confidence in ability to manage large projects.	Easy to use. Acceptable navigability. Some errors reported, but adequate recovery. Satisfactory response times.
Training	Training required, preferably under a structured training programme.	Training required, preferably under a structured training programme.	Training required, preferably under a structured training programme.
Job eff.	Improvements to daily work. No significant improvement in speed of working. Gains in quality of work. No significant efficiency gains Prepared to use the tools.	Improvements to daily work. Improvement in speed of working. Significant gains in quality of work. Good efficiency gains. Prepared to use the tools.	Improvements to daily work. Improvement in speed of working. Slight efficiency gains. Prepared to use the tools.
Org eff.	Faster set-up of project teams. Improve project management. Improved co-ordination. Good info management – simpler and faster access. Good security. Good improvement in info sharing. Good improvements to external communications. Support for multiple projects. Acceptable to clients. Increased competitiveness.	Considerably faster set-up of project teams. Strongly improve project management. Much better co-operation. Improved co-ordination. Good info management – simpler and faster access. Good security. Good improvement in info sharing. Good improvements to all communications. Support for multiple projects. Acceptable to clients. Increased competitiveness.	Improve project management. Improved co-operation. Improved co-ordination. Slightly simpler and faster access. Average security. Good improvement in info sharing. Good improvements to external communications. Support for multiple projects.
Business benefits	1. Improved project management. 2. Improved day-to-day operations. 3. Improved team working.	1. Improved project management. 2. Improved team working. 3. Improved day-to-day operations.	1. Improved project management. 2. Improved day-to-day operations.

Table 10: Summary of VE Project Administrator and User results by country

In viewing the synthesised results presented in the above table, and comparing the results from France, it may be argued that a contradiction emerges in the case of the usability and organisational effectiveness categories. For example in the 'usability' category "possible data inconsistencies" are reported, whereas in the 'organisational effectiveness' category, "good information management – simpler and faster access" is also reported. Philosophically a contradiction cannot exist, and it is only by checking the premises of the argument that an apparent contradiction can be seen not to exist. It should be noted, therefore, that the questions regarding 'usability' concern the ease of use, layout and arrangement, and navigation in the software. Questions are also included concerning the responsiveness of the system in terms of speed, error messages and return of information, and the overall functionality provided. It is almost inevitable that bugs will be found in any new software system, and this section was also intended to highlight any bugs and errors, and indicate their severity – i.e. how easily the user could recover from them. The questions in the 'organisational effectiveness' category, on the other hand, were constructed to validate the underlying processes of the GVEPM, which was the basis for the design and implementation of the tools, but equally importantly to validate the overall OSMOS approach in terms of added value and real business benefits.

As in the case of the VE Server and TPS Provider results, the results here showed full agreement that training would be required in a live implementation of the OSMOS powered VE. It is also agreed that the training provided should be in the form of a formal structured training programme. This outcome suggests an important business recommendation.

The results regarding questions concerning job effectiveness agreed overall that the OSMOS approach would improve the participants' working methods. This is borne out quite positively by the fact that all of the participants agreed that they would be prepared to use the tools in a live implementation. It is interesting to note that the results from the French field trial returned the second highest average score in this case. This suggests that the concerns expressed over the usability of the system are secondary compared to the overall processes that underlie the OSMOS approach.

The results suggest that implementation of the OSMOS approach would allow project teams to be set up more rapidly than the current methods employed. This result again shows a positive attainment of the overall OSMOS objective of the ability to deploy a flexible adapted teamwork solution in a limited amount of time. Furthermore all participants agreed that project management would be improved, indeed this proved overwhelmingly to be the most important business benefit that the respondents felt the approach would offer. In terms of co-operation in planning and scheduling resources the only concern was reported from the French trial. The comment made here that OSMOS seems to be useful for users involved in construction projects with external partners and that it is not really for internal use is valid, however as OSMOS is addressing the VE, co-operation in planning and scheduling resources would not be simply an internal issue anyway. As such, this concern should be treated with some caution in the overall results. All participants agreed that co-ordination of interactions between individuals and teams would be improved. These results are especially encouraging as these factors were found to be important concerns in the interviews (section 6.3 above). Collectively, the trials showed good results in terms of information management, sharing of information and its security in transmission, and support for communications. Indeed the participants all agreed that communications with external partners would be improved. All of these results are encouraging when considering the key challenges faced in the construction industry context.

In terms of the acceptability of the approach to the end-user organisations' clients and the possibility for improvements in competitiveness, the French and Finnish trials both showed positive responses. These questions can only be considered fully in terms of the OSMOS approach as a whole, and as both of these field trials tested the complete process the results are again very encouraging.

As the overall aim of this thesis is pragmatic, aiming to research real life working in the dynamic VEs of the construction industry, these positive responses regarding job and organisational effectiveness are an excellent result. It is also significant that the participants in all three of the trials felt that there would be business benefits gained through implementation of the OSMOS platform. Overall the results showed that improved project management would be the main benefit, followed by improved day-to-day working and improved team working.

6.5 Conclusion

This chapter presented the results obtained from the surveys and evaluation the Researcher has conducted. Despite the paucity of completed questionnaires, the results obtained fulfilled the purpose of providing the Researcher with initial profiles of the industrial organisations involved in the central case study of the thesis. They also formed the groundwork in the triangulation method prior to the interviews, which greatly enlarged the view of the state of construction organisations. The third thread, to which the previous surveys had had input – the field trials to evaluate the proposed VE solution – was also presented.

The following chapter aims to bring together all of the elements from this and the preceding chapters of the thesis.

Chapter 7
Discussion

Review of the problem; Review of the VE concept; Discussion of the research results; Towards the digitally enabled construction VE; Initial exploitation

7.1 Introduction

The preceding chapters of the thesis have presented the research from the point of the literature review through to the results gained from testing and evaluation of the proposed construction VE solution. The aim of this chapter is to draw all of the key elements together in a discussion to enable the research questions to be addressed.

The chapter begins by revisiting the problem addressed by the study, followed with a re-examination of the VE concept and the manner in which it has been employed in the research. There is then a discussion of the research results from the previous chapter, followed by a discussion of the potential benefits of adopting the proposed approach and the elaboration of business recommendations. The final section presents a successful 'real world' exploitation of some of the concepts.

7.2 Review of the problem

The literature regarding the VE indicates that as an organisational paradigm computer networks provide its support. As shown in Chapter 3 (section 3.3), the European construction industry faces the problem that whilst it operates its business like a VE, and has done so for some considerable time, it does not do so effectively, largely because (as the characteristics of the sector show) its ICT support for business processes is poor. These factors are the provenance of the subject matter of this thesis, i.e. digitally enabling the construction VE. The purpose of the thesis is to work towards a solution by answering four research questions that arise from this problem, and in order to answer these questions the Researcher aimed to fulfil eight research objectives (section 3.3.1).

7.3 Review of the VE concept

The first research objective was to clarify the concept of the VE, which was principally achieved through the literature review (Chapter 2). (As noted in Chapter 3 (section 3.4.1) literature review is a recursive process, and elements of the literature from which the Researcher clarified the VE concept were actually brought to his attention via involvement in the VOSTER project). Some of the key aspects of the VE that have proven to be central to the research are encapsulated in the VE types defined by Goransen (1999); the lifecycle model (Camarinha-Matos and Afsarmanesh, 1999a); the VE roles (e.g. Katzy and Obozinski, 1999); and the virtual team model (Lipnack and Stamps, 2000) (see section 2.3 for all of the aforementioned).

The thesis research indicates that in the construction industry the VE should be viewed as being that of Goransen's 'Type 1' wherein the aggregation is in response to an opportunity recognised by an entity that organises and creatively integrates partners with complementary, required core competencies. Or so, it is argued here, it *could* be if the appropriate digital VE infrastructure were available. The VE solution developed within the thesis case study (OSMOS) meets the needs of this scenario as it offers the (imperative) integration of partners capability via the model based nature of its design, integral to which is the definition of the required roles. The obvious limiting factor to this, given the nature of the construction industry, is that what is required is for some enterprising, non risk-averse champion to take on the pioneering role of that organising entity, equipped with such a VE solution.

With respect to the VE lifecycle, the OSMOS GVEPM took into account the complete lifecycle of the VE at a very high level. However, research from the VOSTER project (of which OSMOS is one of the clustered projects, but which only began three months prior to the completion of OSMOS) indicates that in the majority of research projects, in terms of VO life-cycle support, there is a clear focus on the 'creation' and 'operation' phases. The 'dissolution' phase remains almost untouched (Figure 38), and the actual functionality supported is rather limited (Camarinha-Matos, 2003). This is certainly true in the case of the OSMOS solution.

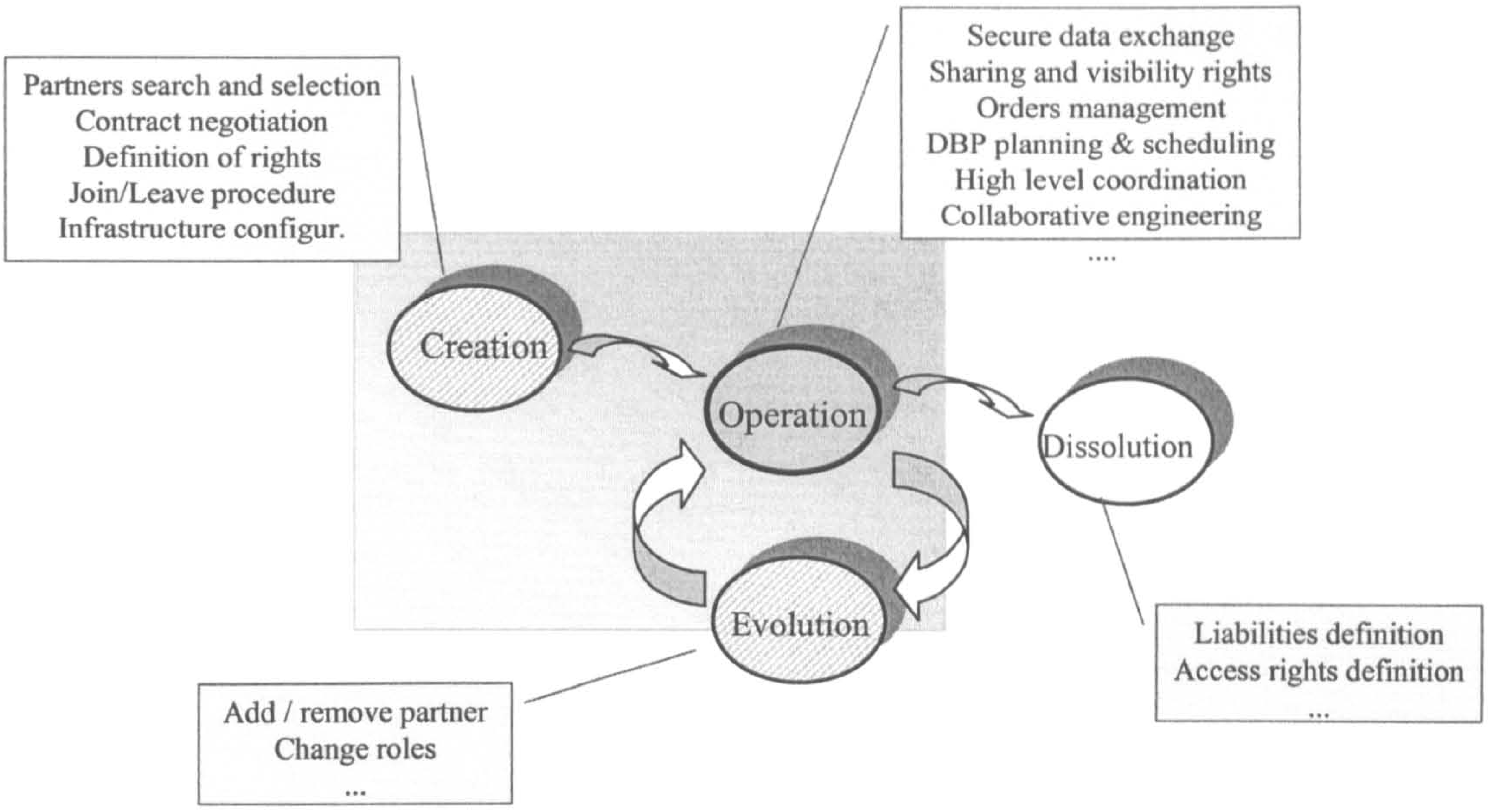


Figure 38: Functions in VO life-cycle support (Camarinha-Matos, 2003:13)

It is interesting to note, however, that the OSMOS consortium arrived at the concept of the VE Roles (*VE Service Provider*, *Third Party Service Provider*, and *VE Client*) quite independently of other research initiatives, which have reached similar conclusions on this.

The virtual teams element of the VE has been addressed in some considerable detail throughout the thesis, as have many of the other key characteristics of the VE concept, including integration and interoperability, horizontal organisational structure, contractual relationships, change caused by necessary ICT support, organisational flexibility, and so on. These aspects will be discussed at appropriate points in the remainder of this chapter.

7.4 Discussion of the research results

7.4.1 Emergence of key themes from the survey results

Virtual teams bring people together across disciplines, departments, functions, and geographical locations. ICT provides the platform, but ultimately it is the people that make the projects work. The importance of the human element and the way that people co-operate with each other has not been taken for granted in the research for this thesis. The results from the questionnaire and interview surveys, the literature review regarding the characteristics of the construction industry, and the analyses of intra- and inter-company requirements within the industrial end-user organisations, gave the Researcher a good understanding of the current practices, limitations and barriers in organisations and on projects, which satisfied the second objective of the thesis. Integrating the results from the questionnaire and interview surveys led to some key findings related to the business aspect of the VE. Indeed four main themes emerged (Chapter 6, Section 6.3.5):

Information sharing

Difficulties with information sharing proved to be faced by all of the OSMOS industrial organisations because of technical and business reasons. It is important to note that externally shared knowledge databases were seen as undesirable by far more of the participants in the surveys than internal ones. This is due to a lack of trust and clarification of objectives. Clearly technology has to play a very important role enabling communications and information sharing, supporting and improving business process and integrating services, but the role of culture is very important, particularly in the virtual context. There is a need for building organisations that will support information sharing and knowledge dissemination in virtual teams, and will openly facilitate learning. Explaining the strategic vision, encouraging participation and involvement and managing performance and linking it with the right rewards are three important steps toward enhancing information sharing.

Organisational Culture and team working

Characteristics of the 'participatory' type of culture such as horizontal structure, open communication channels, participation and involvement in decision-making, enhance sharing of information and facilitate virtual teams. The analysis of results indicated that teams in the construction industry face many problems including lack of availability and time planning. 'Bureaucratic' cultures cannot facilitate these cross-functional teams and as a result, they can hinder the change process. Motivation as part of the culture is an important finding from this research. High motivation levels and job satisfaction are critical success factors in any organisational environment and even more important in a VE. Introducing interesting work and a choice of various tasks within the same project are two important suggestions, which have been tested in two of the participating organisations with good results.

Acceptance of change

It is very interesting to note here that there were positive attitudes towards change. Although some of the end users faced continuous changes, some of which were not successful, the results indicated a positive climate toward that direction. This finding may be explained by the fact that there is dissatisfaction with the existing system, which underlines the need for change. However, there is a need for planned change in order to manage virtual teams, which are characterised by continuous changes. In terms of technological change age was found to be a strong moderating factor in each organisation. As may have been suspected, younger employees are able to use technology more effectively and are more open to new ways of working than their older colleagues. The difference between age groups in the frequency and capability of the use of technology causes tension in all the participating companies. Understanding people's fears and concerns, encouraging involvement and participation, and explaining the objectives of the change are the main targets in order to cope with potential resistance to change.

Training

The results indicated that training is important particularly in project management and software packages. On-the-job training is suggested as a feasible solution although there is the problem of hectic schedules and lack of availability. Another suggestion is to build and implement a training plan, which will take into consideration skills required for setting up virtual teams. To ensure success with such a plan, a needs analysis would be required, and clarification of job descriptions and team roles and responsibilities, and the organisation's strategic plans. Managers often express frustrations because many change projects do not evolve as intended, a reason for this being lack of training. Employees need to have education and support in order to cope with the requirements of the new technology.

To conclude, important strategies for coping with change include:

- Assessing organisational culture with an emphasis on informal and formal communication and structure;
- Supporting participation and involvement;
- Understanding of people's fears and concerns;
- Setting up a training strategy aiming at offering education and support.

7.4.2 Validating the proposed construction VE solution

7.4.2.1 Emergence of critical success factors for the evaluation

In the ICCI cluster project the Researcher has been involved in research into the methods used for modelling in construction related projects. It was discovered in the analysis of other projects' modelling methods that the relationship between the developed scenarios and the supported industry processes is rarely explicitly represented. The development of the detailed models in the OSMOS case study, based on the end-user organisations' actual processes is therefore somewhat unique amongst similar research efforts. The OSMOS tools tested in the field trials were based on models derived from the GVEPM (the provision of which satisfies the third objective of the thesis) and it was in the development of the GVEPM that the concept of the VE Roles (*VE Service Provider*, *Third Party Service Provider*, and *VE Client*) emerged.

The UML modelling phase, in the specification of the digital construction VE solution (the fourth objective), produced not only the functional processes for the VE Core Service, but also the OSMOS API. Another of the key factors in the concept of the VE is interoperability and integration of systems, and the OSMOS API is the main underlying technical development that enables this in the proposed solution. Bearing in mind the discussion from the literature regarding the 'closed' nature of commercially available tools to assist the construction industry in collaborative working, the capability for open integration of applications becomes even more significant. Furthermore, as one of the key themes emerging from the survey research relates to computer training, construction industry actors would benefit from a VE system that allowed the plugging in of tools with which they are already familiar, and also from a user-friendly interface through which to gain access to their tools.

From the above discussion a number of critical success factors emerged, which ultimately needed to be tested via the field trials:

1. **GVEPM** – as this model underlies the OSMOS solution, the field trials needed to be conducted in such a way that they validated the processes. These generic processes were derived from the current processes undertaken in the OSMOS end-user organisations, and rather than being a representation of ideal processes they represent the activities required to enable the construction VE.
2. **VE Roles** (*VE Service Provider*, *Third Party Service Provider*, and *VE Client*) – the validity of these was measured in the course of evaluating the GVEPM.
3. **The OSMOS API** – this was tested through the scenarios set up within the field trials in which services had to be made available. Successful rapid integration and use of the services provided had to be achieved to reach the real added-value for OSMOS VE Clients.
4. **Usability and acceptance** – these factors had to be met in order to ensure the successful take up of the construction VE tools in the real world.

It is clear from this discussion that the main aim of the approach taken was in the provision of services to VE Clients. As such companies in the real world will include SME, who may initially be sceptical of the benefits of the digital construction VE solution, and who may not have great experience in using ICT solutions, it was critical that the processes met real business needs. Furthermore it is critical that the use of the software can be learned as quickly as possible.

7.4.2.2 Validation of the field trials against the critical success factors

The synthesis of the evaluation results from the OSMOS field trials in Chapter 6 (Section 6.4.3) shows very positive results according to the criteria used for the evaluation process. The results can now be used to examine whether or not the above critical success factors were met:

1. **GVEPM** – the field trials in France and Finland tested as far as possible the complete set of processes in the model (the only noticeable exceptions being the activities involving the making of the contractual agreement for the VE project, agreeing management protocols and procedures, and ending of the VE project).

The results provided no arguments against the processes, and as the business benefits that would be expected to be gained show overwhelmingly that the approach will positively improve project management and working methods (both day-to-day operations and team working), the Researcher feels that the trials endorsed the processes in the model.

2. **VE Roles** (*VE Service Provider*, *Third Party Service Provider*, and *VE Client*) – the roles were accepted as a strong underlying concept within the consortium, and the participants in the field trials who were previously unfamiliar with the project also found agreement in the concept. The roles were of great significance to the development of the digital construction VE, however in real world implementations the actors involved would not need to refer to them in an explicit sense. Indeed in such implementations that may occur after completion of the project, whilst the roles are mutually exclusive in the underlying theory, it is unlikely that they will be exclusive to specific companies.
3. **The OSMOS API** – the field trials have shown successful integration of services to the OSMOS platform, with encouraging results all round. The potential existed within the field trials for any API call to be required, and the results have not shown any problems with the implemented software. The rapid integration and use of services has been proved possible from the trials.
4. **Usability and acceptance** – the field trials have shown positive acceptance of the approach by the users (especially where they were adapted by the OSMOS end-user organisations) and a high potential for acceptance by clients.

In terms of economical evaluation of the approach, and estimations of time saved, although these have not been specifically quantified the results show that they were considered and that they do not pose significant barriers or threats to real world implementation and a real world commercial offering of the digital construction VE following this approach.

The plug-and-play provision of third party services emerged as a unique selling point of the approach, key to which is a unique OSMOS API. The field trials have shown that this potential for plug and play is eminently attainable once a TPS has been successfully integrated once.

The development of the prototype, its deployment in the field trials, and the subsequent analysis of the trials satisfy the fifth, sixth, and seventh objectives of the thesis, and the first part of the eighth objective (analysis of the evaluation outcomes). The second part of the eighth objective was to elaborate business recommendations from the proposed solution.

7.5 Towards the digitally enabled construction VE

7.5.1 Discussion of the likely benefits of the proposed approach

It was shown in Chapter 4 (section 4.2.4), that during the modelling of the processes several current information and process inefficiencies were identified.

OTH/ Derbi identified set-up complexity as an inefficiency in the solutions that the company could at that time propose to organise virtual working, and for which an improvement was sought. A solution to these inefficiencies was seen to be a light SGTi version, integrating more and more services via the digitally enabled construction VE. The final field trials have shown that this is possible, as SGTi was integrated to the OSMOS platform and made available to all actors in the scenario in a plug-and-play fashion thanks to a standard default configuration in the OSMOS tools.

A further inefficiency, which led directly from this, was the need to provide actors with more than a limited number of services. In their practices at that time, Derbi had tried to imagine links between SGTi and Internet sites, but found that this would not give the dynamic effect expected by users. Here again the field trials, with the successful integration of more than one TPS, and availability across the Internet via web browsers, have proved that the proposed VE approach offers a more open and larger view. The benefit gained as a result of the integration via the OSMOS API is that the user is offered more services, which can evolve according to his/her changing needs. This in turn is also good business for the TPS provider, as the user will be invited to remain a client for these services.

The FM systems being delivered by Granlund at the time of the requirements capture were based on client server architecture, which proved problematic in large, geographically decentralised environments. The field trials also demonstrate that the proposed VE solution offers a strong benefit in addressing these inefficiencies through the integration of Ryhti, allowing VEs to be set up for any part of the FM process.

JM noted that there was a need for a system where all project information can be stored and be accessible for all participants in a project, regardless of whether the information was created internally or externally. The user must also be able to view the information regardless of the software in which it was created. Furthermore, the system also had to be easy to use since there are great variations in computer knowledge among users, both within JM and amongst the external consultants working for JM. The federation of different services through the OSMOS platform, especially when accessed through familiar interfaces, is a further benefit of adopting the approach of the proposed VE solution. This benefit addresses these inefficiency problems, which again was demonstrated successfully in the field trials.

The above gives some specific examples of benefits, and though it was partners within the OSMOS consortium who reported these inefficiencies, they are common problems throughout the industry. It is interesting to note that the results from the field trials (which were gleaned from participants who had no prior involvement in the OSMOS project) support these points and several others as well. From the OSMOS server set-up and TPS integration sessions of the field trials, positive benefits that emerge include the fact that the system allows other services for the VE to be added quickly, and that the approach would facilitate efficient management of the IT support required for a computer enabled VE. These benefits are important as they constitute sizeable time saving, and also make allowance for the fact that the end-users for whom the services are provided need not be concerned with the technical details, but can continue to work at their own core businesses. It is also significant from these results that the most important likely business benefit that emerged for people taking on these roles (which equate to the *VE Service Provider and Third Party Service Provider*), is the ability to attract more clients.

From the field trials sessions focused on the end-users several clear benefits of the OSMOS approach emerged. The most highly rated business benefit in terms of importance was shown to be significant improvement to project management. As the construction industry is highly project oriented, and the models underlying the approach align any one particular VE to a construction project at any stage of the lifecycle, this is certainly a feature from which the industry as a whole could benefit. The aim of achieving agility in the VE (faster set-up of project teams) has also been proved possible from the results of the field trials, and concomitant with this are the perceived improvements to team working and the potential for significantly improved external communications in a virtual environment. The results from the research carried out in the first two iterations of the project, showed clear concerns with scheduling and availability of human resources. By adopting the proposed approach and the business processes for explicitly identifying all potential actors in a particular VE Project and assigning clearly specified roles to those that will comprise the VE, these concerns can be met and allow clear identification of available resources. The results indicating that improvements would be found in day-to-day working are also beneficial, especially as the participants were not aware of the business process analysis work that underpinned the development of the tools, and bearing in mind that the survey research indicated that daily operations in organisations are often of greater concern to users than innovation and development activities.

Inefficiency in information sharing was also highlighted as a common problem from the survey research. Information overload is a perennial danger, but equally so is the potential for not receiving the specific information one directly needs. The field trials results indicated that all participants felt that the proposed VE solution would offer good improvements in the sharing of information. This benefit is attributable in no small measure to the access rights assigned to specified roles in the conceptual models.

Evidence is also provided from the field trials that the benefits of the approach are not restricted to the end users or service providers. There was a strong indication from the participants in the field trials that tested the entire approach that use of the system would be acceptable to their clients.

The clearest benefit that arises however is the plug-and-play provision of TPS, making such services available to other companies, particularly SME, who currently do not have access to specialised tools, possibly due to prohibitive costs. The OSMOS field trials have demonstrated the concept of making such provision with the result that the participants in the trials voted positively that they would be prepared to use the proposed construction VE approach in their work.

7.5.2 Business recommendations

The conceptual basis for the process involved in setting up and maintaining the construction VE through the OSMOS platform (the GVEPM) was validated through the field trials. This suggests the first organisational recommendation that can be made in the migration path to using the approach. As illustrated above, the process for setting up the computer enabled construction VE is less complex than the methods that had already been attempted prior to the OSMOS project. In defining and recommending the GVEPM, it is not the intention to prescribe a rigid methodology to be 'imposed' on the companies that wish to adopt such a VE solution or indeed the industry in general. Rather the intention is to show that the processes have been tested and accepted, and that adoption of those processes will facilitate the migration path. The GVEPM is grounded in actual real world process analyses, and as the proposed solution to digitally enabling the construction VE has been researched in full recognition of organisational theory elements, it is clear that for virtual team working to succeed, organisational flexibility is key. The researcher feels that the GVEPM can be viewed as a new 'paradigm' (note Kuhn, 1996; see section 3.2.1), but also that it is open to enhancement and improvement by those who wish to pursue it. As has been shown in the thesis, the VE relies on horizontal organisation with open communication channels, and so on. There is, however, always a requirement for control in organisations, whether they are traditionally formed or follow the VE paradigm. What has to be guarded against however is the potential for 'imposing' unwarranted control on organisations. Wilson (1999:676) notes that the virtual organisation, as a manifestation of industrial devolution, has resulted in a relentless managerial drive towards conformity in the demands of greater efficiency. This adoption of processes will inevitably mean some changes to working practices for organisations. Although the survey results revealed a generally positive attitude towards change in the OSMOS end-user organisations, this might not be the case elsewhere across the industry, and therefore training in, and awareness of, the possible need for a change management programme should be considered.

The GVEPM addresses the processes required for all roles within the proposed approach to the VE, whether an organisation is a VE provider, a TPS provider or an end-user of the system. In terms of TPS provision, the field trials have validated the ability for plug-and-play of a number of services. Recommendation must be made for the providers to ensure that adequate training in their use is made available for the clients of these services (i.e. the end-users). The trials also prove that the approach allows openness with regard to the integration of services, for example more than one EDMS can be made available. It is, therefore, advisable (and indeed prudent from a business point of view) that the TPS providers carry out there own SWOT analyses for the services they intend to provide.

From the VE Project administration perspective the processes in the GVEPM have shown to be beneficial in terms of configuration of the project and of course the management of actors. It was not possible, due to the limitations of scope, to fully model and test the activities involving the making of the contractual agreement for the VE project and agreeing the management protocols and procedures. However, the specific inclusion of these processes in the model ensure that the actors involved in any particular VE can be sure that their agreed methods of working control the necessary activities throughout, and are therefore adhered to integrally. (Although the Researcher has constantly been aware that contractual, IPR and legal issues will arise in the process of providing digital tools to enable the construction VE, it was outside the scope of the thesis to research deeply into the prevailing laws with regard to organisations and the potential litigation issues that may arise in collaborative work. Companies already working in the international arena should be aware of the requirements pertinent to their businesses in their own countries).

With reference to the four key themes that emerged from the synthesis of the research surveys (section 7.4.1), the field trials results showed strong benefits of the approach with regard to information management, sharing and communication. The methods built in to the OSMOS tools offer validated processes for assigning rights and roles within the organisations partaking to the VE, and the adoption of these processes constitutes a strong business recommendation in itself.

For organisations that hope to act as VE service providers using the proposed approach, a compelling recommendation is the implementation of their own user interfaces for the VE tools. This proved particularly successful in the Finnish field trial, and furthermore it can be seen as a positive recommendation for the real world uptake of the OSMOS approach as evidenced in section 7.6 below.

7.5.3 The need for training in the construction industry

The need for training in the construction industry has been recognised for quite some time (e.g. CEC, 1997; DETR, 1998). The results from the research in the thesis case study concur with this, and the Researcher contends that training is a problem in the industry that is still not being adequately addressed. Recommendations in terms of culture such as embracing change and ensuring motivation within teams, and the possible need for redesign or reengineering of processes for the digitally enabled VE paradigm reveal training issues as much as the need to train people in the use of new technologies. The survey results indicate that although employees have opportunities for training, they are generally devoted to, or certainly primarily focused on, technical issues. The results from the Researcher's survey and field trials work in the OSMOS case study, have fed directly to the ICCI project, in which the Researcher has recognised that training in many areas of organisation need to be addressed in the construction sector.

The proposed digital construction VE solution from OSMOS, and the developments in all of the projects clustered under the ICCI umbrella are research results at the cutting edge of technological development. Thus the prototypes developed offer companies in the sector a vision of the competitive advantage and other possibilities that the future promises. To achieve exploitation of advanced ICT requires not only the implementation of innovative technologies but also new working practices, organisational structures and cultures. The challenge therefore is to develop an equally compelling vision of these innovative ways of working. Individual skills are the root to achieving this, and individuals need the skills to use the new technology and adopt the new working practices as depicted in Figure 39.

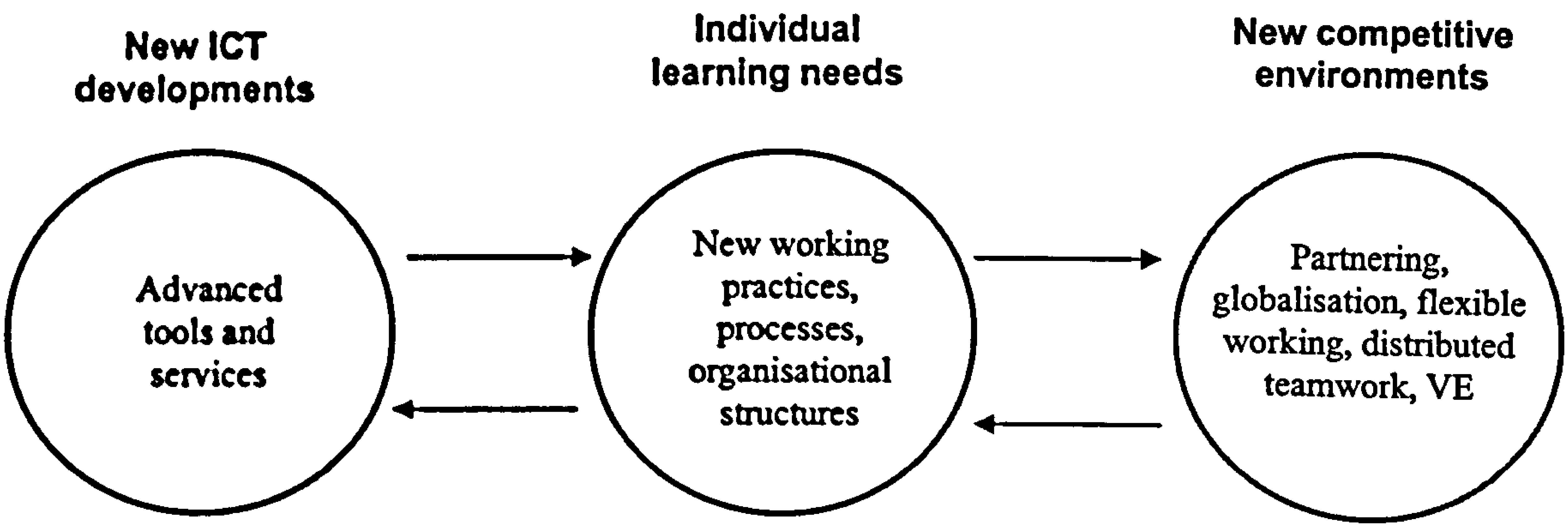


Figure 39: The learning challenge

To deliver the sought-after competitive advantage also requires that the speed of migration from the existing status quo to the envisioned future state is faster than that of other competitors. Fast-track migration requires accelerated learning to take place throughout the sector, for which a learning and training strategy is required to bridge the gap between what is current, and what is possible (Figure 40).

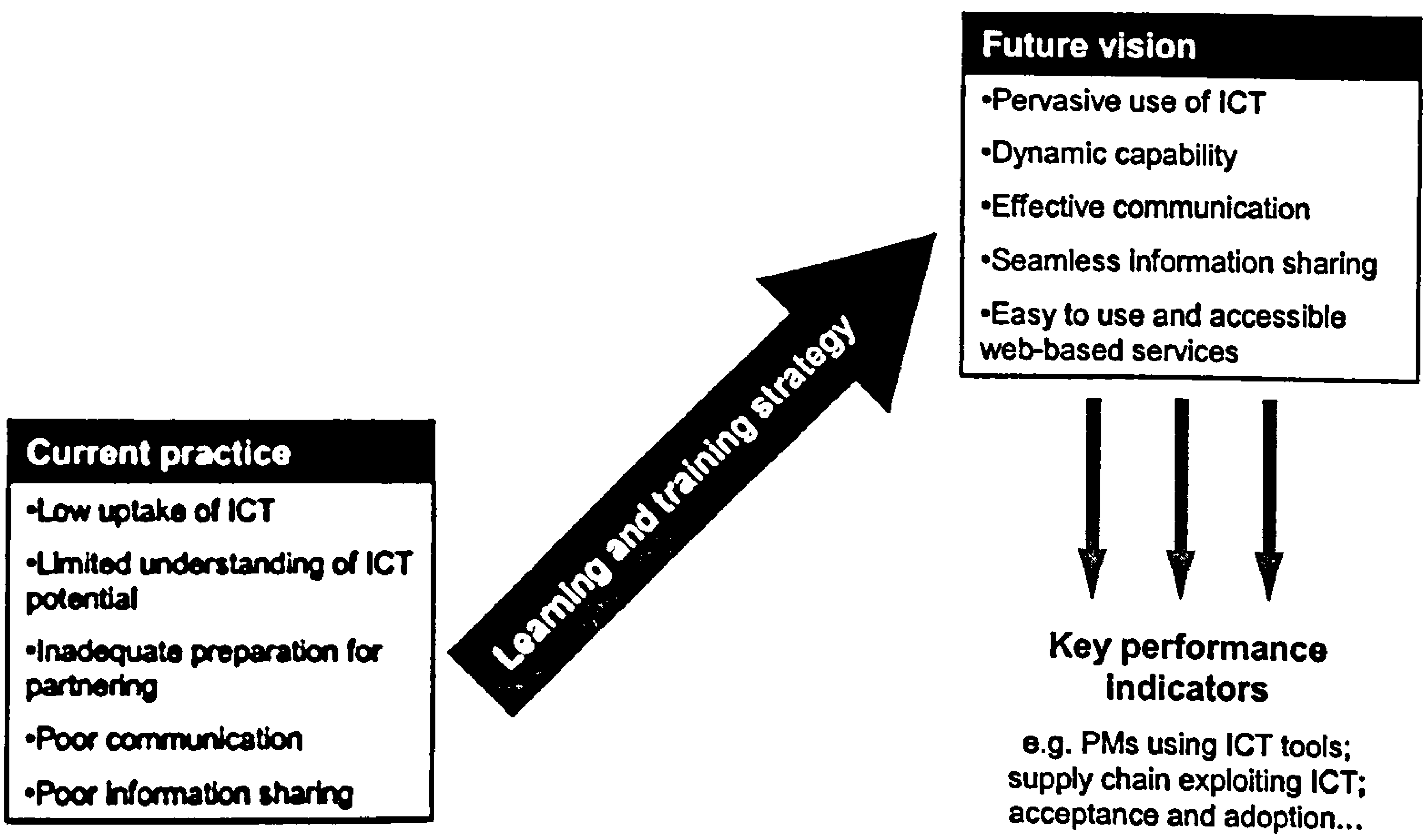


Figure 40: Learning and training gap plan

7.5.4 Decision aspects of business recommendations

The above sections indicate potential benefits of the advocated approach to digitally enabling the construction VE, and high-level business recommendations towards this. What is clearly emerging from the research is that much of the impetus towards adopting such an advanced solution will rely on decisions that need to be taken from the actors involved bearing in mind that learning and training is a key enabler to future success. This section offers a decision map that highlights the 'soft' factors that the Researcher believes should be taken into consideration as a result of the research presented here.

In order for the digitally enabled construction VE to be adopted appropriately and widely in the real world, an actor (or actors) would be required to accept the risk of being the first adopter of such an approach. According to the results the VE roles are accepted in the context of the field trials (and are apparently further validated by similar approaches from other studies whose results were not available until around the same time as the results from the OSMOS case study). The primary roles that require adoption are those of VE Service Provider and TPS Provider, as without these there is no possibility of VE Project Administrators or Users. In terms of whether or not an actor subscribes to the approach of a User, the decisions to be made will largely depend on the provisions made by the VE Service Provider(s) and TPS Provider(s), and whether or not the potential User sees a clear business benefit from adopting the approach. (This of course can also only be assessed in real terms once actors have decided to provide the necessary services, and would become a much easier decision to make based on the experience of early adopters).

Assuming that an actor has decided to become a prime mover in adopting the advocated approach and making available a VE platform, further considerations then have to be made in terms of the two roles VE Service Provider and VE Project Administrator. In terms of the role of VE Service Provider decisions naturally need to be made regarding technological provision, to ensure that the necessary tools and infrastructure are available, and such decisions would need to be aligned to the technical requirements of potential TPS Providers. Equally, actors intending to adopt the role of VE Project Administrator (who may not necessarily also be VE Service Providers) would also have to make decisions concerning technology, including the organisation's personnel's ability to use it, acceptance of the tools, etc. However, the concerns here are the decisions that need to be considered with respect to the 'soft' issues highlighted from the research and considered within the business recommendations. Figure 41 graphically maps these decisions.

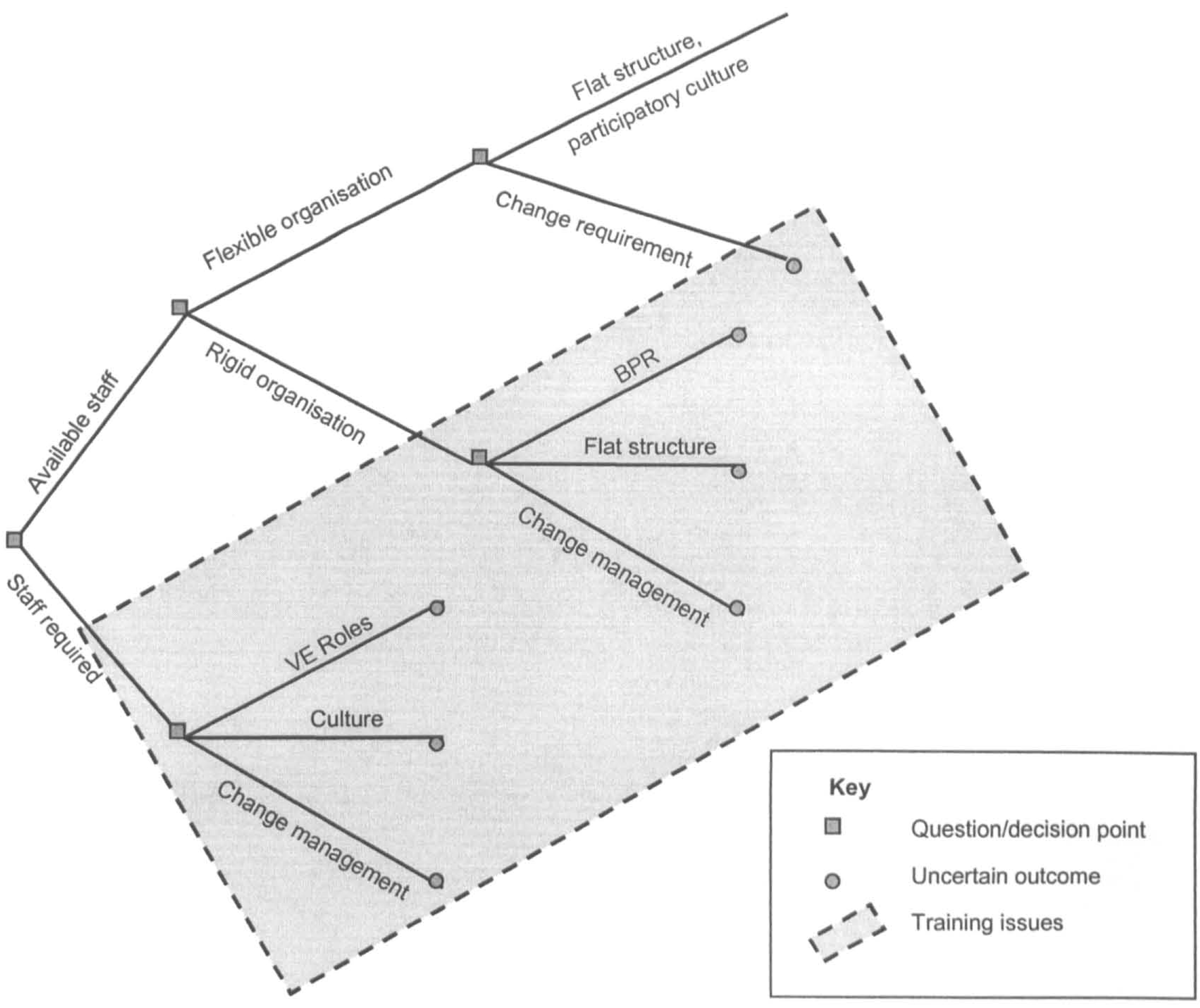


Figure 41: 'Soft' aspects decision map

A key problem in the industry is that of availability of personnel, as shown in the results above. Uptake of the advanced approach to the digitally enabled construction VE proposed in the thesis would inevitably require new skills to be learned. The decision map in Figure 41 takes as a starting point that an organisation intends to adopt the advocated approach (assuming the role of VE Service Provider and/or VE Project Administrator within a VE). The key decisions with respect to the 'soft' issues involved in the migration path begin with questioning whether or not appropriate staff are available to assume the VE roles required. If the answer is negative then clearly staff need to be found. This presents the first risk that the organisation faces: the decision has to be made whether or not the risk of assigning someone to the required role, which is not initially his or her core business, is worth taking. If this decision is taken then there are inevitable training requirements. The person appointed (as, for example, VE Project Administrator) will need to be trained in the overall concepts of the digitally enabled VE approach and specifically the VE roles. Furthermore, a knock-on effect at the organisation level will be to address the culture of the organisation to ensure that all personnel who may be involved in a VE Project have a shared vision and understanding of the reasons for adopting the approach, and plans (which may include provision of further training aspects) will have to be considered with regard to effectively managing the resultant changes. If the decision is made to train the required staff at this point then the decision to the first question is affirmative – staff are (at that point) available.

In the case of an organisation with staff already available, the first consideration is to objectively assess the nature of the organisation. As the thesis has shown, the VE requires a flexible approach to organisation. If the organisation is not flexible then further decisions need to be made considering wide ranging effects in three key areas: potential need for re-engineering business processes (BPR), altering the structure of the organisation (flat structure), and managing the changes. As in the previous case, the key decisions here can all be seen to require training (to a greater or lesser extent), and the result is an uncertain outcome (dependant on whether or not to take these risks).

If an organisation does decide to take on these changes, or can already confidently decide that in assessing the nature of the company it is that of flexible organisation, the next key assessment pertains to the structure and culture inherent in the organisation. Again, as shown within the thesis the VE also relies on a flat organisational structure and a participatory culture (in which a shared common vision and commitment exists). If this is the case, then the decision to adopt the advocated approach is at its lowest risk in terms of human and organisational issues. (This corresponds to following the top branch of the map to its end). If the outcome of this question is negative however, again there is a change requirement that needs to be assessed in terms of the risks involved.

The map indicates that the issues that result from negative responses to the required question points all require a degree of training for an adequate resolution. In terms of training in organisations, particularly regarding technological intervention, as is the case here, the Researcher believes that this research is showing an important need (due to some neglect) for training in 'softer' issues, and not merely in technical discipline. In order to meet the best organisational requirements to take advantage of the digitally enabled VE, key concepts from organisational theory such as organisational flexibility, culture, structure, and BPR should not be ignored from training plans and strategies. Equally, change management strategy should be taken into consideration in planning learning and training.

7.6 Initial exploitation

To complete this discussion chapter, it is worth noting that Granlund has exploited some of the concepts from the research and developments in the OSMOS project in the 'real world'. This section presents this exploitation.

7.6.1 The situation at the beginning of the OSMOS project

When the OSMOS project started at the beginning of 2000, Granlund's Windows-based solution for technical facility management (FM), Ryhti, had a strong position in the Finnish market. There were over 200 installations of the software, mainly in Finland but also in Scandinavia, the UK, Germany and Hungary. Many of the customers were big Finnish building owners with hundreds of buildings, and in some cases in excess of a thousand. Characteristic to these Windows-based installations, were big FM databases with a limited number of users (1-20 people), the software typically being used over a local area network (LAN).

Ongoing trends in technical FM include outsourcing of services to maintenance companies, the use of FM consultants, and an increasing need to distribute FM services to a larger audience. These trends made the use of LAN-based services problematic and Granlund realised that the use of the Internet in combination with the OSMOS concept offered a solution to the problem by allowing new and existing Ryhti customers to set up virtual enterprises for all parts of the FM process.

7.6.2 The current situation

RyhtiWeb is Granlund's implementation of the OSMOS concept and is fully compatible with the existing Ryhti platform. RyhtiWeb is a direct result of Granlund's participation in the OSMOS project and enables customers to set up FM-based virtual enterprises in an intranet/extranet/internet environment. RyhtiWeb has incorporated the central concepts from the OSMOS models, i.e. the ability to register any third party service to the VE and control the access to both data and services through a role-based scheme. RyhtiWeb also enables entities to be linked, i.e. cross-referenced across service boundaries.

By the end of February 2002, Granlund had installed RyhtiWeb to six existing Ryhti customers in Finland and Germany. Granlund also has a partnership with an application service provider offering RyhtiWeb to smaller customers or for a shorter period. The current RyhtiWeb customers are presented in Table 11.

Currently the main interest in the OSMOS concept among customers is its ability to provide role-based, location independent access to FM services and data for a large number of users. The FM Helpdesk service is a typical example of a service that involves interaction between a large number of users holding different roles.

Company	Profile	Project Size
Senaatti Properties	Senaatti Properties is a government owned enterprise responsible for managing and letting the property assets of the Finnish state. The property stock includes university, office research, and cultural and other buildings.	The FM database contains over 2000 buildings in Finland.
Elisa Communications	Elisa Communications is a leading telecommunications company in Finland and employs 8000 people. The company provides fixed network voice, data and internet services for residential and corporate customers. The company's networks host over one million fixed telephone and over 1.3 million mobile subscriptions.	The FM database contains 400 office and telecommunication buildings.
Wärtsilä	Wärtsilä Corporation is the leading global ship power supplier and a major provider of solutions for decentralised power generation and of supporting services. Wärtsilä employs around 10,000 people	Hundreds of thousands m^2 of industrial buildings.
Nokia	Nokia is the world's leading supplier of mobile phones and a leading supplier of mobile, fixed and IP networks. Nokia has 18 production facilities in 10 countries and research and development in 15 countries around the world. Nokia employs around 54,000 people.	Hundreds of thousands m^2 of industrial buildings in Finland, Germany and Hungary.
The Civil Aviation Administration	The Civil Aviation Administration maintains Finland's network of airports and the air navigation system. CAA's airport network consists of 25 airports and the organisation employs 1,872 people.	Hundreds of thousands m^2 of national airport, aviation and office buildings.
Tapiola	The Tapiola Group is the largest mutual insurance group in Finland.	Hundreds of thousands m^2 of office buildings.

Table 11: Granlund's RyhtiWeb customers

While most of the customer companies are using only various FM services through RyhtiWeb, Senaatti Properties is focusing on integrating FM and electronic document management (EDM) services through RyhtiWeb. Senaatti Properties is using a large number of external building consultants to produce maintenance plans and reports of the building mass located all over Finland. Maintenance reports consist of a group of textual and graphical documents related to a specific building describing both short and long-term maintenance activities required. The goal of Senaatti Properties is to utilise RyhtiWeb as an extranet entry point to the FM and EDM services so that the external consultants could store their maintenance plans directly into the system, thus creating a link between buildings and documents. The RyhtiWeb browser would provide a logical view to the building data and the EDMS would act as a document repository. Through a role-based access scheme the data would be accessible both to the organisation's own personnel and to users from external organisations.

7.7 Conclusion

This chapter presented a discussion drawing together all of the various elements dealt with in the preceding chapters. In the first two sections the overall problem addressed by the thesis and the VE concept were reviewed to establish the context of the discussion. In a synthesis of the results from the case study surveys four key themes emerged in relation to the 'soft' aspects of the research. In discussing development of the proposed solution to digitally enable the construction VE, four critical success factors emerged to be tested from the field trials results in order to validate it. These discussions of the research results were then taken into account to reveal potential benefits likely to be achieved through the adoption of the proposed solution, which led to the elaboration of some business recommendations regarding the migration path to adopting this approach to the VE. After assessing the need for training in the construction industry, and taking this into account with the previous sections regarding potential benefits and business recommendations, the chapter presented a decision 'map' to consolidate the business recommendations from the perspective of key human and organisational issues. Finally, the chapter presented a successful exploitation of some of the underlying concepts. It has been demonstrated in this chapter that the eight research objectives of the thesis have been achieved, which enables the research questions to be addressed in the concluding chapter.

Chapter 8
Conclusion

Addressing the research questions; Contribution of the thesis; Limitations of the research; Future research

8.1 Introduction

This chapter concludes the thesis. The first section provides answers to the research questions based on the findings from the study as a whole. In the second section the Researcher's perception of the contribution of the thesis research is addressed. This is followed by an account of the limitations of the research, and the final section offers some thoughts on potential future research that have emerged through the process of completing the current study.

8.2 Addressing the research questions

As described in Chapter 2 (section 3.3) the main research question is supported by three further questions that to some extent aid in scoping it. In addressing the research questions therefore, it is logical to deal with these 'supporting' questions first.

Research question 2:

> *"Is the technology advanced enough to offer adapted solutions to the very characteristics of the construction industry?"*

The subject area of the study originates from the need to digitally enable the construction industry VE. As was initially shown from the literature and subsequently elaborated upon in the efforts required in the central case study, the characteristics of the construction industry indicate that it has been operating in the mode of a VE that is inefficient due to various causes, including inadequate technological support. A technological solution, it has been shown, had to support the central business processes; allow integration of systems and interoperability between disparate applications used in non-collocated teams; the creation, management and operation of the VE, and so on, whilst at the same time take into account the fact that the industry runs on razor thin margins.

The technical solution developed and tested was based on a methodology that combined IDEF0 modelling and UML techniques, producing conceptual models to address these fundamental features. Java was selected as the programming language in which to develop both the underlying functionality and the user interfaces for the solution. From the models a unique API was developed that allowed services to be integrated to the core system of the VE, and interoperability was facilitated by a middleware technology. From the results of the OSMOS field trials it is clear that the technical aims were satisfied adequately, and indeed that the models were robust enough to deal with the requirements, including management of roles, access rights, semantic relationships between information elements, etc. In terms of the middleware, the 'X' layer provided a simple and technologically independent access to the whole OSMOS API. Since the completion of the OSMOS project SOAP technology has advanced enough to be used as a standard for such purposes. It is apparent from the above that the technology is indeed advanced enough to offer the required solutions.

Research question 3:

> *"Is the technology on its own able to provide a solution to the needs and aspirations of construction end-users?"*

Whilst the technology needed to be advanced enough to support the characteristics of the construction industry, the construction end-users' needs and aspirations go beyond what is achievable by automation and digital support. The technical solution developed largely achieved what was expected from the perspective of support. But this raises a point that the Researcher believes cannot be stressed strongly enough in technological development and intervention in the real world: simply that support is the main function of the technology. It is a tool to be used to adequately assist in achieving a purpose. In conceptualising the VE, however, the technology forms only a portion of the elements that define it. It is people that work in teams, on projects, and in organisations, and the purpose for which they do that is a human construct. The approach to modelling the solution in the OSMOS project was firmly grounded on the real world requirements of the construction industry. Systems analysts and software developers quite rightly claim that their designs are human centred because they are there to support real needs in achieving purpose. To allude to a famous cartoon, the Gatling gun is there to be used if only the soldier with his inadequate solution will break off from the task at hand to take a look! But needs and aspirations go beyond what even a sound technological solution can offer – witness the many IT failures over the course of history, and the many excellent technologies that are completed successfully and then never implemented because whilst they work, they are not accepted. It is known for example, that many IT failures occur because the informal methods and processes people *actually* use in their work are not modelled. Even given the apparent success of the OSMOS field trials, there were still some quite marked differences in the responses of the participants, despite the fact that they were testing the same concepts and technology. On reflection it would be somewhat naïve to claim that the technology on its own would be able to provide a response to the real needs of the end-users.

Research question 4:

> *"Given the characteristics of the construction industry, does the industry require a new business model in relation to the purchase of ICT offering an affordable and profitable solution for SME and Clients on projects?"*

The research shows two main strands to the answer for this question. Firstly the results in the thesis have shown that education and learning continue to pose a real problem. The rapid pace of technological change, and indeed organisational change, exacerbates this problem. Furthermore, even in recognising the gap that needs to be bridged between current ICT usage and the potentials best practice can offer, the SME dominance of the industry means that for example, introducing a training strategy or an ICT strategy in one firm is fine, but the same training or ICT strategy will be meaningless to a company employing four people if it was developed for a company employing for example sixty people. But this does not alter the fact that the human and organisational factors of the research still indicate a need for such strategies to be added to the business model.

Secondly, the very nature of the industry in terms of financial margins means that costly research into, and purchase of the 'correct' ICT is not possible for many over-busy, SME actors. What the thesis indicates, however, is that a possible solution in this respect may be made available. By federating services from various non-collocated organisations, and making the tools and services they have to offer available via ubiquitous web browsers, a potential new business model would be that of 'rental' ICT services via a platform designed to support a VE.

Main Research question:

> *"Is the construction industry ready to move from a paper-based approach to collaborating and sharing information on projects, to an innovative model-based approach making use of the latest development in ICT?"*

In the preceding chapter it was shown that in Finland, Granlund have successfully exploited some of the concepts resulting from the research and development in the OSMOS case study. This would suggest an unequivocal affirmative to the above question. However, this is not the complete answer. As the answers to the above questions have shown, the ICT are definitely advanced enough to offer adapted solutions to the industry, but the human and financial elements still prohibit immediate advancement. The very fact that Granlund have successfully interested some very large players to their web based FM tools proves that certainly in those cases the industry is ready to alter its approach with respect to the concepts used. What is not clear, however, is the extent to which the majority of the industry would react to such developments as are proposed in the overall approach to adopting a digital solution to enable the VE, concomitant with the possible process reengineering and potential change management involved. On reflection, therefore, it is too soon to claim that the answer to this question is 'yes'. The Researcher believes that what is required is for an innovative model-based approach such as the solution researched in this thesis to be implemented and adopted in full by a 'prime mover', an entrepreneurial spirit who is prepared to take the early risk. In taking this risk such a prime mover would be recommended to take heed of the types of decisions that should be considered regarding the human and organisational aspects of digitally enabling the construction VE (as mapped in Figure 41).

8.3 Contribution of the thesis

The research contributes to the body of knowledge on three levels: to modelling and technology, to IST research methodology, and to the construction industry in the 'real world'.

In terms of modelling, firstly, as was stated in Chapter 4 (Section 4.2.1), IDEF0 has limitations when used alone for process description. The combination of IDEF0 and UML modelling methodology used however, proved to overcome these shortcomings in a novel way. By using IDEF0 to produce the high-level process diagrams from which the functionality could be modelled using UML in an iterative way, enabled a deep comprehension of the industrial end-user organisations' business processes, which resulted in a robust set of models to underpin the proposed solution. Secondly, the GVEPM developed in OSMOS, on comparison with other VE models in VOSTER, proves to be a well-grounded approach, forming a paradigm for the construction industry. Thirdly, the OSMOS API has been proven as a successful technical development in enabling the construction VE, as evidenced not only by the OSMOS field trials, but also by Granlund's exploitation.

In terms of research methodology (and IST projects in particular), the methodology used in the OSMOS project shows the direct benefit of recognising that technology research is not only about the technology. Whilst most research projects are investigating developments that will be adopted possibly many years in the future, and this can be seen to be the case in OSMOS as well, the iterative and incremental methodology that included many human and organisational aspects often neglected in this type of research, which OSMOS employed, contributed greatly to the fact that one of the partners of the project has exploited some of the concepts developed.

In terms of the construction industry, the open – as opposed to proprietary – solution proposed is well suited to SME on tight margins. Furthermore, if the concept of rental services federated through such a platform is more widely disseminated, this could have a lasting effect on the industry's *modus operandi.*

As the central case studies of the thesis are collaborative in nature, it is worth specifically noting the Researcher's personal contribution to the body of knowledge within and further to the above. Throughout the lifecycle of the central case study (OSMOS), and also on a currently ongoing basis in the supporting case studies (within the ICCI project in particular), whilst the Researcher has been honoured and privileged to work with some of the pre-eminent minds in technical and indeed construction ICT, and VE research, a constant battle has been fought to ensure that human and organisational issues are included in the process. This thesis would not have been possible without the Researcher gaining successful acceptance that such issues are important enough to allow the type of surveys on which the thesis has relied in answering the research questions. Furthermore, the critical field trials carried out to test and validate the advocated approach would not have drawn together the human and organisational with the technical elements without the Researcher's management, leadership, and persistence in approach. The central focus of researching the key human and organisational aspects of advanced ICT research culminates in the thesis with the elaboration (within Chapter 7) of business recommendations, and the unique decision mapping toward the goal of real world implementation of such an approach to digitally enabling the construction VE.

8.4 Limitations of the research

In researching this area, it is clear that many varied but interconnected factors come into play. Even in selecting the areas on which to concentrate for the literature review, the Researcher is aware that the findings may not be sound in some respects because of other topics that may have a direct effect but which had to be overlooked through the limitations of time and scope.

Whilst the Researcher believes the GVEPM to be a sound paradigm that adds to the body of knowledge, it has to be reiterated that it could (and indeed ought to) be extended to the extent that all of the activities are adequately decomposed from the top level through to the dissolution of the VE.

Although some consideration to contractual, legal and IPR considerations have been made throughout the case study, this is a complex area that requires much deeper research than has been possible within the scope of this thesis.

The nature of the VE entails various partners directly sharing information and systems, and exchanging documents. This requires a high degree of security, which has not been addressed deeply in the study. Furthermore, the subject of 'trust' as a cultural issue also deserves attention that was not paid in this thesis.

The Researcher is also very aware that robust economic evaluation was not addressed in the case study, which, for applied research ought to be achieved.

8.5 Future research

As stated in the derivation of the research questions for the thesis, it is inevitable that any considered research effort will ultimately produce more questions than it intends to answer. For the sake of brevity only five themes the Researcher believes should be addressed following this thesis are mentioned here.

As the above section shows there are limitations to the current thesis, which can be recommended for future research. It would be useful to completely model the construction VE from idea to dissolution, and in doing so the research should involve different sized organisations on a 'level playing field'. The industry is still dominated by a handful of large organisations, and many firms are disadvantaged by the leverage the larger firms have. The concept of the digitally enabled VE for the construction industry should be expanded upon, looking at all of the security, legal and contractual, and socio-organisational aspects throughout.

Whilst interconnectivity and information sharing are not new topics, the problem of document structure is still limiting efficiency in the construction industry. It would be beneficial to conduct research into the concept of 'intelligent' documents for the sector, but not only at the technical level. It is the human that requires the document; therefore it is the human's needs that should be directly and explicitly addressed in such research. If the informal processes that real actors use to carry out their daily tasks are fully analysed, it should be possible to model the nature of the documents they require.

Learning and training in the construction industry is a complex topic due in many respects to the SME-dominant nature of the industry. More research is required to study the real needs of the industry, and web-based tools and programs created that can be accessed through a browser to give the learner interactive situation based scenarios.

The concept of rental services for the construction industry should be researched as a serious long-term paradigm shift. The fact that managers still make their choices of technology due to mimetic isomorphism, often due to the fact that they simply do not have the time to spend on researching the most suitable technology for their own situation would be alleviated if they had the availability of rental tools.

Finally, as already alluded to, the Researcher believes that it is only through an initial entrepreneurial spirit taking the necessary risk that the digitally enabled VE can be truly adopted as a construction industry norm. Many revolutions in business are started in such ways, and it is the prime mover in an organisation that differentiates the leaders from the followers. On a completely non-technical note, it would be highly enlightening to study the true role of the prime mover in large organisations, and the extent to which differing organisational cultures suppress the development and retention of such people.

8.6 Closing comments

Due to the nature of the industry, and the economic importance of construction in all developed societies, the research into technology use in the construction industry will undoubtedly continue for many years to come. In researching for this thesis, the Researcher increasingly feels that the importance of the human aspects in technological development are still inadequately addressed in the construction industry, and would like to finish on a very wise caveat from the man regarded as the founder of the UK civil engineering profession:

> *Stone, wood and iron are wrought and put together by mechanical methods, but the greatest work is to keep right the animal part of the machinery.* John Smeaton (1724-92)

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Appendix 1:
OSMOS IT and Construction VE Questionnaire

OSMOS IST-1999-10491
IT AND CONSTRUCTION VIRTUAL ENTERPRISE QUESTIONNAIRE

This questionnaire will be used simultaneously in three European countries: the phrasing of some questions may therefore be slightly unfamiliar to you. You will note that the questionnaire is anonymous, and your answers will be kept strictly confidential.

Where a question refers to **'you'** please answer from your own viewpoint. The terms **'organisation'** and **'company'** are used synonymously. Where a question offers the response **'other'**, please specify.

Section 1: General Information

1.1 Please state the name of your company:

____

1.2 How many employees are there within your company?

- 1-50 ☐
- 51-100 ☐
- 101-150 ☐
- 151+ ☐

1.3 How long have you worked at this company?

____

1.4 What is your job title?

____

____

____

1.5 In which department do you work?

- IT ☐
- Marketing ☐
- Human Resources ☐
- Commercial ☐
- Production ☐
- Design ☐
- Other________________

1.6 What level of market share does your company have?

- 0-10% ☐
- 11-25% ☐
- 26-50% ☐
- 51%+ ☐

1.7 Who are your main competitors?

____

____

____

____

____

____

1.8 Please list the main strengths of your department, and rank them in order of importance.

____

____

____

____

1.9 Please list the main factors you think are critical to the future growth and success of your company and rank them in order of importance.

____

____

____

____

____

____

Section 2: Information Technology

2.1 Do you use computers in your work? *(If 'no' please go to Section 3)*

Yes ☐ No ☐

2.2 How long have you been using computers?

____

2.3 How frequently do you use computers?

Very infrequently 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ Very frequently

2.4 How confident do you feel using computers?

Not at all 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ Very confident

2.5 For what do you mainly use computers?

- Word-processing ☐
- E-mail ☐
- Presentation ☐
- CAD/CAM ☐
- Document Printing ☐
- Spreadsheet ☐
- Database ☐
- Internet ☐
- Project Management ☐
- SAPr3 ☐
- Other ______________________

2.6 Is computer training available to everyone in your company?

Yes ☐ No ☐

2.7 What further training do you feel you need at present (if at all)?

____

____

2.8 Do you perform any work tasks that you feel could be improved by using computers?

Yes ☐ No ☐

2.9 If 'yes', what are they?

____

____

____

____

Section 3: Teamwork

3.1 Do you work as a member of a team (or project group)? *(If 'no' please go to section 4)*

Yes ☐ No ☐

3.2 How frequently do you work in teams?

- Every day ☐
- Once a week ☐
- Once a month ☐
- Very rarely ☐
- Other________________

3.3 How many teams are you participating in?

____

3.4 How many people work in your team(s)?

____

3.5 How would you characterise working in teams in your organisation?

____

3.6 What teamwork problems have you had to deal with?

____

3.7 Does your team use an electronic communication and scheduling system (Groupware)? *(If 'no' please go to Q3.10)*

Yes ☐ No ☐

3.8 If 'yes', what type of application?

____

3.9 How would you rate the effectiveness of Groupware?

Not at all 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ Very effective

3.10 Which of the following methods does your team use for communications within the team?

- Telephone ☐
- E-mail ☐
- Fax ☐
- Groupware ☐
- Informal gatherings ☐
- Voice mail ☐
- Memo ☐
- Notice board ☐
- Scheduled meetings ☐
- Other ________________

3.11 Which of the following methods does your team use for communications with other departments?

Telephone	☐	Voice mail	☐
E-mail	☐	Memo	☐
Fax	☐	Notice board	☐
Groupware	☐	Scheduled meetings	☐
Informal gatherings	☐	Internal post	☐

Other ______________________________

3.12 Does your team work with external companies? *(If 'no' please go to Q3.16)*

Yes ☐ No ☐

3.13 Which of the following categories of information do you share?

CAD drawings	☐	Documents	☐
Spreadsheets	☐	Database tables	☐
Financial	☐	Legal	☐
Project proposals	☐	Contractual	☐
Project planning	☐	Presentations	☐

Other ______________________________

3.14 Which of the following methods does your team use for external communications?

Telephone	☐	Voice mail	☐
E-mail	☐	Memo	☐
Fax	☐	Notice board	☐
Groupware	☐	Scheduled meetings	☐
Informal gatherings	☐	Postal service	☐

Other ______________________________

3.15 What problems do you experience with the information you share?

____

____

____

3.16 If you could change your team's communications practices, what would you change?

____

____

3.17 How do you think that your teamwork methods could be improved in the future?

____

____

Section 4: Business Environment

4.1 How would you describe the culture of your company?

- Bureaucratic ☐
- Participatory ☐
- Autocratic ☐
- Innovative ☐
- Other__________________

4.2 How would you describe the structure of your company?

Flat — Hierarchical

1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐

4.3 How does your company view individual technical ability?

Not at all — Very important

1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐

4.4 What is the most difficult aspect of your job?

____

____

____

4.5 To whom do you go if you need advice?

- Manager ☐
- Team leader ☐
- Colleague ☐
- The team (as a group) ☐
- Other__________________

4.6 Do you generally participate in team/department decisions?

Yes ☐ No ☐

4.7 Please indicate your answer to the statement: "Task assignment in my company is decided by…"

- Consensus ☐
- Centrally ☐
- Senior manager ☐
- Team leader ☐
- Other__________________

4.8 How effective do you feel this method of task assignment (Q. 4.7) to be?

Not at all — Very effective

1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐

4.9 Do you feel that the decision-making process could be improved?

Yes ☐ No ☐

4.10 If 'yes', how?

____

____

____

Section 5: Business processes and Organisational Change

5.1 Are you aware of the business processes[1] related to your job?

Not at all — Very much

1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐

5.2 Are the processes computer based?

Not at all — Completely

1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐

5.3 Do they have supporting documentation?

Not at all — Completely

1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐

5.4 Were you formally trained to carry out these processes?

Not at all — For all of them

1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐

5.5 How important do you feel processes are in your company?

Not at all — Very much

1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐

5.6 Do roles in your company follow procedures?

Never — Always

1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐

5.7 Have there been any major changes within your company in the last 24 months?

Yes ☐ No ☐

5.8 If 'yes' please describe the main one *(If 'no' please go to Q5.12)*:

____

____

5.9 What were the main reasons for the change?

____

____

5.10 What were the main consequences of the change?

____

____

5.11 Was there any resistance to the change?

Not at all — Very much

1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐

5.12 How would you describe your attitude to change?

Negative — Positive

1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐

5.13 How would you describe your company's attitude to change?

Negative — Positive

1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐

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[1] A business process is a set of tasks performed to achieve a defined business outcome (e.g. detail planning)

Section 6: Knowledge Management

6.1 Do you use any of the following in your work?

- Internet ☐
- Intranet ☐
- Extranet ☐
- Electronic Document Management ☐
- Distributed Database ☐

6.2 How do you access company specific information (e.g. code of practice, quality standards)?

____

6.3 How do you access project specific information (e.g. project CAD drawings, project specification document)?

____

6.4 How do you access industry specific information (e.g. regulations)?

____

6.5 Does your organisation store legal documents electronically?

Yes ☐ No ☐ Don't know ☐

6.6 Does your organisation store contracts electronically?

Yes ☐ No ☐ Don't know ☐

6.7 What security measures does your organisation have for such documents that are stored electronically?

____

____

____

6.8 What is the legal position if electronically stored legal documents or contracts are lost due to technical problems?

____

____

____

6.9 How do you feel about the idea of an *internally* shared database of knowledge?

Not at all happy 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ Very happy

6.10 How do you feel about the idea of an *externally* shared database of knowledge?

Not at all happy | | | | | Very happy
1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐

6.11 Someone in your organisation devises an innovative new way of working that is adopted in the workplace. In such a situation, should this method be shared openly with other departments of the organisation?

Yes ☐ No ☐

6.12 If an employee in your organisation has a new idea will this idea be stored electronically on the network for everyone to see?

Yes ☐ No ☐

6.13 If you had a new idea would you be prepared to make it available in a shared database of knowledge?

Yes ☐ No ☐

6.14 If 'no' why not?

____

____

6.15 If an employee brings some specialist knowledge to the organisation, should this knowledge be stored in a shared database of knowledge?

Yes ☐ No ☐

6.16 Would you be prepared to make your own specialist knowledge available in a shared database of knowledge?

Yes ☐ No ☐

6.17 If 'no' why not?

____

____

Thank you for taking the time to complete the questionnaire.

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Appendix 2:
Interview Guide

Interview Guide

Name of Interviewee:
Organisation:
Position:
Date and Location:

1. General Introduction

1.1 Now, first of all can you tell me a little about yourself?
(Nature of work, department, position)

1.2 What can you tell me about the nature of your organisation?
(Aims and objectives, policies, business environment, competitors)

2. Business Environment

2.1 How would you describe the structure of the organisation?
(Structure, communications, culture)

2.2 How would you describe the climate within your organisation?
(Relations between supervisor/subordinate/colleagues, communications, appraisals)

2.3 What is the dominant method of working within the organisation?
(Team work / individuals)

2.4 How does the organisation encourage its personnel?
(Rewards, motivation, team support, training)

2.5 How does the organisation deal with innovation?
(Encourage/discourage, change implications, R & D)

3. Information Technology

3.1 How do you feel about the use of IT in your organisation?

How does the use of IT today compare to the situation 5 years ago?
(Efficiency, usefulness of computers, main purpose, training)

3.2 Are there any areas of the organisation that you think would benefit from the introduction of computers?

If so, what are they?

Why do you feel computerisation would be beneficial?

Are there any plans to introduce this? (Strategy)

3.3 How do you view the future use of computers in the organisation?
(Planned introduction, changes, acceptance of technology)

4. VE Integration Services

4.1 How do people relate different types of information? [E.g. where a part of a CAD drawing relates to a particular section of a Word document.]

If you could be provided with a service that allows you to view all the available information related to another piece of information, is this be something you would find useful?
(Document cross-referencing service)

4.2 How widely is email used within the organisation?

What are the main purposes for which staff use email?

How do you think your email system could be improved?

4.3 How are you currently notified when a document or piece of information you are interested in is updated?

If a system was made available to you that would allow people to be automatically notified by email when specific topics, files, folders, they are interested in are updated, is this something that you would find useful in the organisation?

Would you encourage your staff to use it?

Does the organisation use email archives?

Mailing lists?

What do you think of these tools?
(Email based communication service)

4.4 How do you currently track the progress of your work activities/ processes?

How does the organisation currently decide the order of events in your work activities?

Would you be in favour of a system that would monitor and track work activities?

Would you be in favour of a system that would notify users of specific events?
(Workflow service, describing and defining processes, identification of inefficiencies/bottlenecks)

4.5 Does the organisation face any problems due to the number of different software applications in use?

What are they?

How would you suggest they could be resolved?

Would you be in favour of a tool that would give software applications the ability to request services from other software components, without the need to open another application?
(Application inter-working services)

4.6 What methods do you currently use to schedule meetings?

What do think about the idea of a tool that would allow personnel to view (and possibly update) other people's calendars (where they have specific responsibilities or have been granted permission)?

How would you feel if other employees could access your calendar to reserve your time for meetings/events?

If you were notified automatically and had the right to accept or reject?
(CSCW, Scheduling service)

4.7 How do you normally conduct meetings?

Do you have facilities for video conferencing?

Remote meetings via, for example, electronic message boards/newsgroups?

Shared workspace (e.g. BSCW or for collaborative design)?

Do you think these services would be useful?

Would you encourage your staff to use them? How?
(Conferencing service, CSCW, team working, IT/Business focus)

4.8 Does the organisation have plans in place to introduce any of these facilities?

5. Change

5.1 What major changes have you seen in the organisation?
(IT based? IT/Business driven?)
Why did this/these change(s) occur?

5.2 Who was involved in the change process?
(Only management/management and supervisors/subordinates?)

5.3 How did you feel about the change?
How did others feel about the change?
(Acceptance, resistance, consultation)

5.4 How were the future users involved in the development process?
(Involvement)

5.5 What changes do you envisage for the future of the organisation?
(IT/business based?)

5.6 Why do you see these changes occurring?
(Strategy, competition; are the changes in terms of technology alone? Personnel? Team/working practices?)

Appendix 3:

VE Server Administrator and TPS Provider Evaluation Form

VE Server Administrator and Third Party Service Provider evaluation form for the 3rd iteration OSMOS Field Trials

Please respond by entering a cross in one of the boxes (1–4) for each question.

1. Integration

	Not at all 1	2	3	Very much 4
1. Is it easy to integrate the VE Manager/Web Browser into your existing network architecture?				
2. Is it easy to integrate your own applications (proprietary or otherwise) into the OSMOS architecture?				
3. Do you feel that the system allows other services to be added quickly?				
4. Would this improve availability of these services compared to the current situation?				
5. How efficient is the process for registering VE services?				
6. Does the system allow easy maintenance of TPS?				
7. Does the system allow easy removal of TPS?				
8. Do you feel that implementation of this system will allow greater exposure to the services your company offers?				
9. Overall, do you feel that the software will enable you to efficiently manage the IT support required for a successful Virtual Enterprise?				

2. Training

	1	2	3	4
1. To what extent do you think your company will have to invest in training (a Server Administrator)?				
2. To what extent do you think users will require training in the TPS being provided?				
3. Would the company need to invest in formal training (e.g. a structured training programme)?				

Overall, please indicate which of the following business benefits you think will be gained through the introduction of this system, and rank them in order of importance (using 1 as most important, 2, 3...)

Improved day-to-day operations		Improved project management	
Ability to attract more clients		Improved teamworking	
Positive impact on the final product/service		Increased client satisfaction	
Increased competitiveness		Other (please specify):	

Please add any further comments you would like to make:

Appendix 4:

VE Project Administrator and User Evaluation Form

VE Project Administrator and User evaluation form for the 3rd iteration OSMOS Field Trials

Please respond by entering a cross in one of the boxes (1–4) for each question.

1. Usability	1 (Not at all)	2	3	4 (Very much)
1. Do you feel the system is easy to use?				
2. Are the links and buttons clearly understandable?				
3. How easy is it to learn how the system works?				
4. Is the system easy to navigate?				
5. Is the system easy to exit?				
6. Were you satisfied with the response time of the system?				
7. Do you get sufficient feedback from the system?				
8. Does the system return information quickly enough?				
9. Did you encounter any errors, bugs, or unexpected results when using the software?				
10. Were you able to recover easily from these errors?				
11. Does the system provide the functionality you would expect?				

2. Training	1	2	3	4
1. To what extent do you think your company will have to invest in training (a Project Administrator)?				
2. To what extent do you think users will require training to be able to use the system?				
3. Would the company need to invest in formal training (e.g. a structured training programme)?				

3. Job effectiveness	1	2	3	4
1. Do you think the system could improve your daily work?				
2. Do you think it would improve the speed of your work?				
3. Do you think it would improve the quality of your work?				
4. Overall, do you feel that you would become more efficient in your work with this system?				
5. Would you be prepared to use these tools in your work?				

4. Organisational effectiveness	Not at all 1	2	3	Very much 4
1. Does the system allow project teams to be set-up more rapidly than your current method for this process?				
2. Will the system improve project management in your organisation?				
3. Will the system facilitate better co-operation in the planning and scheduling of resources on projects?				
4. Do you think there will better co-ordination of interactions between individuals and teams using this system?				
5. Does the system give you simpler access to information?				
6. Does the system give you faster access to information?				
7. Does the system provide secure transmission and sharing of information?				
8. Does the system improve information sharing compared to the methods currently used?				
9. How well does the system support communications?				
10. Would communications within your team(s) be improved?				
11. Would communications across the organisation be improved?				
12. Would communications with external project partners be improved?				
13. How effective is the system for managing services on projects?				
14. How well does the system support multiple projects?				
15. Do you have confidence in the security aspects of this system?				
16. Do you think the system would be acceptable to your clients?				
17. Will the use of this system help your company to attract more clients/contracts?				
18. Do you think the use of this system will increase the competitiveness of your company?				
19. Do you think the use of this system will help improve the quality of the project's final product/service?				

Overall, please indicate which of the following business benefits you think will be gained through the introduction of this system, and rank them in order of importance (using 1 as most important, 2, 3...)

Improved day-to-day operations	☐	Improved project management	☐
Ability to attract more clients	☐	Improved teamworking	☐
Positive impact on the final product/service	☐	Increased client satisfaction	☐
Increased competitiveness	☐	Other (please specify): ______________	

Please add any further comments you would like to make:

____

____

____

Appendix 5:

Observer Evaluation Form

Observer evaluation form for the 3rd iteration OSMOS Field Trials

1. **VE Service Provider**

1. If you feel the software could be improved please comment:

2. Please describe any errors, bugs, or unexpected results you may have encountered during the trials:

3. Please comment on the efficiency gains you feel will be made using this process for setting up a construction VE (in terms of the time saved) compared to the method currently used:

4. Do you envisage any issues or problems regarding the handling of contractual information (e.g. Contractual Agreement)? Please comment:

5. Please add any further comments you would like to make:

- **VE Project Administrators / Users**

1. If you feel the software could be improved please comment:

2. Please describe any errors, bugs, or unexpected results you may have encountered during the trials:

3. Please comment on whether or not you think the software will be robust enough to meet a VE manager's requirements when there are large numbers of actors, roles, objects, classes and access rights:

4. Do you expect any issues or problems regarding the security of information? Please comment:

5. Does the system offer advantages/disadvantages in helping to preserve the integrity of data through versioning?

6. How do you feel the system will improve the management of projects within your organisation?

7. What changes to your organisation's current way of working do you think would emerge with the introduction of a system like this?

8. How well do you feel that people will accept these changes?

9. Do you think that the introduction of this system will change the relationship between your organisation and other organisations?

10. Do you think that your clients (e.g. building owners) would accept the use of this system?

11. What business benefits do you feel are introduced through the provision of the Third Party Services made available to you in this test scenario?

12. Please add any further comments you would like to make: