Virtual Reality Systems in the Management of Technology-based Organizations

Allan McLay
MEng. Grad Dip TT&L

A Thesis submitted in fulfilment of the requirements for the degree Doctor of Philosophy

School of Aerospace, Mechanical & Manufacturing Engineering
Science, Engineering & Health Portfolio
RMIT University

August 2011

Declaration

"I certify that except where due acknowledgement has been made, the work is that of the author alone; the work has not been submitted previously, in whole or in part, to qualify for any other academic award; the content of the thesis is the result of work which has been carried out since the official commencement date of the approved research program; and, any editorial work, paid or unpaid, carried out by a third party is acknowledged."

____

Allan McLay

Permission to copy

"I hereby give permission to the staff of the RMIT Library and to the staff and students of the School of Aerospace, Mechanical & Manufacturing Engineering – RMIT University to copy this thesis in whole or in part without reference to me. This permission covers only single copies made for study purposes, subject to normal conditions of acknowledgment."

____

Allan McLay

Acknowledgments

Acknowledgment is made to the following people for their assistance and support:

Professor Bruce Wilson, Director of the European Union Centre at RMIT University; Associate Professor Adela McMurray, Associate Dean Research in the School of Management, RMIT University; Professor John Mo, Discipline Head Manufacturing, and supportive colleagues in the School of Aerospace, Mechanical and Manufacturing Engineering, RMIT University; Mr Norbet Nimmervoll, Past Director, RMIT Interactive Information Institute (I^3) and Mr Ray Denison and technical staff at RMIT I^3; an amazingly patient, tolerant, and loving wife Tricia, and family!

Publications & Presentations

The following publications and presentations have been derived from this research program:

Publications:

McLay, Allan (2002) Applying Visualisation Technologies and Strategies for Effective Knowledge Management and Decision Analysis in Engineering and Technology-based Enterprises, in *Proceedings of 3rd International Conference on Quality and Reliability*, 2002, Edited by A.J. Subic, H.C.Tsang, C.Y.Tang, & G. Netherwood, RMIT University, Melbourne.

McLay, Allan (2003) Virtual Reality – Quality Management Integration, in *Proceedings of QUALCON 2003 International Conference*, Edited by Anthony Pilli, Australian Organization for Quality & RMIT University, Melbourne.

McLay, Allan (2010) Realising Virtual Reality: A Reflection on the Continuing Evolution of New Media, *International Journal for Sociotechnology and Knowledge Development, Vol.2, No.3, July-September, 2010, pp.37-53,* Hershey, PA: IGI-Global.

Invited Presentation:

Invited presentation and paper presented to meeting of researchers in the Centre for Strategy and Performance, Institute for Manufacturing, Department of Engineering, University of Cambridge, UK. Nov. 28 2008

A Taxonomy for Describing Necessary Conditions for the Application of Virtual Reality Systems in the Management of Technology-based Organizations.

Table of Contents

List of Figures

List of Tables

Summary

The introduction of virtual reality media into engineering or technology-based organizations is investigated and a taxonomy for identifying determinants for successful introduction of such media, is developed in the form of a taxonometric planning framework. The research addresses the continuing convergence and integration of digital electronic media, in particular, virtual reality technology and systems, as an exemplary application of new media. This is addressed as a strategic and potentially radical and disruptive innovation.

The proposed taxonomy framework is intended as a means of aiding organizations to determine their preparedness or potential adaptability to meet, manage and use new media technology to optimal affect and to manage effectively the demands and impacts of potentially disruptive, technological change. The thesis itself explores and develops the theme that communicative media entail a specific lexicon or language of use that continually evolves, and to be effective, must be understood, at least within its community of practice. In turn, the cultural impact of using virtual reality technology and systems, and the use of virtual representation and virtual world modelling as reflecting events or behaviours and desired outcomes in the real world, is discussed throughout the thesis from a socio-technical perspective. Overall, the taxonomy represents a 'new way of thinking' about the introduction and implementation of new media and virtual reality based systems.

An adaptation of Checkland & Scholes (1990) Soft-Systems Methodology (SSM) is the core research methodology implemented throughout the research program. Research activity has incorporated use of advanced visualization systems in the Virtual Reality Centre of RMIT University's Interactive Information Institute (I^3), development of a Virtual Reality Users Survey and associated analysis instrument, and a meta-analysis of secondary sources. Collectively, these form the core data collection strategies. The research is characterized by a strongly interdisciplinary approach, exploring the potentialities for and impact of new media and virtual reality systems on the management of technology-based organizations. The taxonomy is a step towards developing a theory of the dynamics of complex technology-based organizations and the various transformations that can occur with the introduction of new and potentially disruptive technology.

It is asserted that effective alignment of strategic information and communications technologies with organizational strategic goals and a range of sociological factors, can lead to successful introduction of potentially disruptive technology (in this case: new media based virtual reality) in engineering and technology management environments. It is argued further that the transformative effect of introducing new media technology such as virtual reality, can be catalytic toward producing and driving paradigmatic transformation within an organization.

Chapter 1 Introduction

1.1 Research Purpose and Background

This research program has developed a taxonometric style strategic planning framework, that describes requisite organizational characteristics for the application of advanced interactive simulation and visualization systems in the management of engineering and technology oriented organizations. It uses Virtual Reality (VR) as an exemplar of such systems. In particular, it develops specific insights into the effective implementation of advanced visualization systems incorporating synthetic or virtual environments, for use as formal decision support tools in the management of engineering and technology based enterprises. It identifies existing and emergent Virtual Reality simulation applications and the approaches used by organizations in introducing technological innovation, with an emphasis on new media virtual reality systems and associated technologies. It has become apparent that there are many issues to be considered when advanced simulation and visualization systems are introduced into an organization. These issues will induce significant adjustments to current management approaches and work practices, specifically in terms of how potential users, and in particular executive management users, approach the introduction and use of new media in their organizations.

The key focus on identifying the necessary conditions for successful introduction of virtual reality visualization technology and associated systems in technology-based organizations is articulated in the form of a taxonomy that can guide strategic planning. Why a taxonomy? Three key aspects are addressed in the proposed taxonomy and planning framework:

1. The new-media virtual reality related products or services being considered for development or application
2. The organization considering the possible application of new-media virtual reality products and services.
3. The mode and application of new media virtual reality systems and technologies and the impact that user organizations experience through such use.

It is the latter two aspects identified above that this research has focussed on primarily.

The proposed taxonomy is not intended as a prescriptive approach to the use of new media virtual reality in decision-making. Rather, it is intended to provide insight into both the theoretical and practical possibilities of such use, and the possible locus of such application within the enterprise. It is also intended to aid management in determining the extent to which the organization is itself ready for and capable of leveraging enhancement to performance, through the introduction and utilisation of such potentially transformative technology.

In order to refine the research questions, a thorough review was undertaken of existing research literature on: organizational theory and practice with a specific emphasis on the management of organizations with a strong orientation towards engineering and technology-based activities; the management of innovation and change in such organizations; the identification, development and management of corporate competencies of significant strategic value; knowledge management; strategic management; and the key relationships between these bodies of knowledge and practice. As such, this meta-analysis approach presents an eclectic and powerful overview of ideas, processes, social environments and behaviours, related to contemporary technology and its associated artefacts. Within this cross-disciplinary context, the research program has also taken account of contemporary developments in cognitive science, particularly in relation to the role of iconic processing, visualization and understandings of how image-based decision support models are constructed and understood. Overall, the research program has determined that there exists a range of opportunities for the integration and application of new media and related emerging technologies and systems in enterprise management and decision-making.

Current and continuing developments in information and communications technology (ICT) and associated technological systems, have been widely investigated by other researchers, academics and information technology specialists, with specific regard to identifying the essential technical conditions required to support advanced visualization systems. However, most such research has focussed on aspects of computer hardware and associated software and systems, with an emphasis on their technical performance and effectiveness in producing acceptable visualization systems. Many hundreds of formal papers and publications have been published that reflect these approaches. Many virtual reality research publications specifically relate to the technical development of 3-D characteristics and immersive 3-D models of synthetic environments and virtual objects, and navigation techniques within virtual worlds. In particular, extensive research has been done on the application of advanced simulation systems and related state-of-the-art visualization technologies in areas such as: art, engineering design (particularly in aerospace and automotive) physics, chemistry, architecture, communications, medical research, mathematics, defence, and education and training.

By comparison, only recently has research focussed on how virtual reality tools may be applied directly to the day-to-day management of organizations. This might include for example, as decision analysis support tools, or as an innovative means of accessing knowledge management resources, such as real-time operational performance management and the Quality Management systems of an industrial manufacturing environment. Whilst decision analysis methodologies have progressively developed over the past 30 years from simplistic deterministic approaches, to quite sophisticated predictive modelling, such as in the formulation and application of influence diagrams, the area of applying advanced visualization systems in knowledge management environments for example is still relatively new, and to a large extent perceived as a case of 'smoke and mirrors'.

The past 25 years has seen a phenomenal global expansion of electronic media and information technology as a ubiquitous and pervasive force that has seen corporate management make considerable, and expanding, use of ICT and associated systems to support decision-making (Turban & Volonino, 2010). With progressive globalisation of business and commerce has also come the need for new techniques for communicating ideas, business constructs, technical design issues, processes and procedures (Silverthorne, 2006). However, it has further become apparent that failure to effectively integrate new media and emerging technologies with organizational processes and strategic positioning strategies, particularly those related to knowledge and information management, can lead to business –

technology segmentation with subsequently ineffective deployment of such technologies (Andriole, 2005; Betz, 2001, 2003).

Rapidly evolving multi-media technology, simulation systems and technologically integrated broad band communications technologies, have provided organizations with a unique opportunity to resolve many of the technical constraints that historically have confounded attempts to improve the use of real-time corporate decision support systems, whether in in-situ locations or between geographically dispersed organisational elements (Stair & Reynolds, 2006). At the same time, rapid growth in computing technology is providing organizations with readily available and affordable access to advanced computing and network-based technology on the desktop. Current developments in such desktop technology, are certainly capable of supporting sophisticated virtual reality simulation and stereoscopic 3-D visualization systems in typical office environments. Congruent with this continuing growth in underlying computer technology, sophisticated human-computer interface technologies and 3-D stereoscopic application software such as is required to support virtual reality, are also being developed and progressively introduced into the marketplace.

The continuing growth and development of image and knowledge processing systems necessarily invokes the further convergence of video, audio, computing, robotics and telecommunications technologies. This in turn places engineering and technology-based firms and organizations in a seemingly constant state of technology transition, in which the ontological status of 'what is', becomes potentially quite unstable, even at times unpredictable beyond relatively short time frames. Managing such instability poses very real concerns and challenges (Creeber & Martin, 2009; Tidd *et al*, 2005; Verburg *et al*, 2006). Consequently, there is a concomitant need to analyse formally the potential influence of such technologies and simulation systems on organizations, particularly in relation to their use in support of day-to-day decision-making and management (Woolgar, 2002). This is a differing focus to the considerable interest shown by many technology based organizations in the application of virtual reality systems at the 'technical design' stage of products and processes, in robotics control systems, and in modelling hazardous or extreme environments.

In 1996 Professor Sherman of the National Centre for Supercomputing Applications at the University of Illinois noted: 'VR is a medium – a means of communication. Like any media, the use or reading of VR has to be learned…. That is, the user becomes literate with the medium. As a new medium, the language of VR is still in its infancy' (Sherman & Craig, 1995, p.37). With the maturation of virtual reality technology and rapid growth in new-media systems over recent years, it is now possible to reflect with rather more certainty on what such systems are capable of supporting and the corporate competencies (Prahalad & Hamel, 1990) and the related range and level of skills and expertise that may be required for organizations to achieve a realizable 'value-chain' from their effective utilization.

In time, it is very likely that virtual reality resources will be utilised actively in a wide range of company activity including: real-time collaboration in product design; production planning and control; supply chain and inventory management; risk and feasibility assessment; and performance appraisal and monitoring (Lister *et al*, 2009). Further development and expansion of digital assets, particularly in engineering and technology based organizations, will progressively make it possible to envisage virtual reality style visual 'fly-through' of an organization's data and operational systems, enabling internal examination of organizational performance parameters, akin to the use of modern CAT-Scan technology in medical and biological visualization systems. Certainly, at present there are numerous organizations with considerable expertise in the use of virtual reality systems and technologies for the design, development and testing of products, for example in the aerospace and automotive industry sectors. Similarly, there are examples of specialised training using virtual reality systems, particularly in the aviation, aerospace, defence, and the mining, oil and gas industries, and a growing number of virtual reality applications in the design of manufacturing and production planning systems, compared with other sectors.

1.2 Thesis Structure & Organization

This chapter has introduced the research program and identified the key focus of the research program as being to: 'identify the necessary conditions for successful introduction of new media with an emphasis on virtual reality style advanced visualization technology and associated systems, and how such systems may be best deployed in the management of technology-based organizations'. The second chapter reviews the research literature on the introduction of new media, advanced visualisation systems and technologies (with a particular emphasis on the evolution of virtual reality systems and their application) and the role of engineering management theory and practice in technology-based organizations. It includes an overview of current theory and practice. The third chapter outlines the formal objectives, purpose and intent of the research program, including the key research questions, and provides details on the evolution and use of adaptive soft systems research methodologies and the specific research methods.

An initial soft systems methodology analysis using Checkland's (1990) SSM structure addressing the real-world issues of virtual reality technologies and their use in organizations is presented in chapter 4. This chapter specifically identifies and addresses issues arising from the content analysis of a wide range of published works relative to: (a) three core areas of: new media; simulation systems and virtual reality; and the management of engineering and technology-based organizations, and (b) review of virtual reality visualization projects as case studies. It constitutes a core formative data collection strategy that feeds directly into both the Soft Systems Methodology (SSM) conceptual analysis and theory-informed taxonomy and strategic planning framework development stages. Chapter 5 conceptualises a taxonomy or framework relating to the application of virtual reality systems and advanced visualization technologies in the management of engineering and technology based organizations. It draws largely on information and data derived from the thematic development and content analysis activity, research projects and case study analyses, to develop system elements, and proposed domains and factor lists.

Chapter 6 then develops the essential structure, components and approaches to visualizing the proposed taxonomy. It takes the many system elements derived in chapter 5 and proposes a structure incorporating four key domains of influence. It also develops an associated Paradigmatic Strategic Planning

Framework for organizations considering the introduction and use of new media virtual reality and associated applications. In chapter 7 the taxonomy is subjected to testing and review processes, including the surveying of organizations either currently committed to using virtual reality or with a demonstrated interest in possible future uses. The analysis and findings of this survey and testing process are documented and discussed. Finally, in chapter 8 the key findings of the research are discussed and future opportunities for the application of the proposed taxonomy and strategic planning framework are outlined.

A detailed 'References' list provides a full listing of all sources of material directly referenced within the body of the thesis text. Similarly, a 'Bibliography' lists published resource materials used throughout the research program but not directly referred to in the body of the thesis text. The Appendix contains the survey materials for and used during the testing stages of the research program. The section on World Wide Web Sites lists a range of Internet based resources used throughout the research program.

Chapter 2.

Literature Review and Thematic Development

2.1 Introduction to the Literature Review and Thematic Development

This literature review chapter addresses the existing body of knowledge, theory and practice, in relation to the introduction and use of advanced new media simulation and visualization technologies and systems and the management of engineering and technology based organizations. It reviews the early developmental stages of the virtual reality concept (1980-1995) and reflects both supportive and otherwise views of technologists, scientists, sociologists and business entrepreneurs, before addressing more contemporary views and developments in new-media (1995-2010). Whilst this research is linked ultimately to engineering and technology management, this chapter has concentrated on the introduction of new visualization and communications technology, with an emphasis on virtual reality technologies and the development of related new work-practices and decision-making processes.

In keeping with a discourse on the use of visualization techniques, images depicting many aspects of virtual reality technology, related systems and actual implementations, are used expressly and liberally throughout the Review. Extensive direct quotation has also been used with the intent of demonstrating and grounding key formative inputs to the thematic development and subsequent conceptual analysis stages (Strauss & Corbin, 1990). Many authors have addressed the general issue of technological change; indeed, the introduction and management of new technology has attracted much attention from academics, technologists, industrialists, journalists and the political sector, since the onset of the industrial revolution. Only a few however, have undertaken direct analysis of the causal and socio-technical influences on the introduction of new technology-based systems, other than to observe the apparent effects and to speculate on possible future developments.

The continuing development and Moore's Law style growth in micro-electronics and related digital technologies (Moore, 1964, as attributed in Swann & Watts, 2002) has led inexorably to the development of specialised human-machine interface systems necessary for the integrated use of such technologies. It is largely this integration of underlying technology and interface systems with continually changing modes of use and user expectations that drives the continuing evolution of contemporary new media. In turn, the continuing introduction of new media based applications continues to influence and in effect transform the way we communicate, work, make decisions, rest and play (Boczkowski & Lievrouw, 2008; Lister *et al*, 2003; Yoffie, 1997).

Given the endemic presence of media hype, marketing-related disinformation and the occasional more outrageous predictions of an over-excited techno-evangelist in the area of new technology and its application, it is sobering to reflect at the outset on the following words attributed to Thomas Edison, circa 1913: 'It is possible to teach every branch of human knowledge with the motion picture. Our school system will be completely changed in ten years' [as attributed to Edison (1913) by Gould & Mason, 1985, p.1]. Clearly, with the advantage of hindsight, a prediction about the role of motion film which failed to appreciate both the real potential and the limitations of film media. Similar statements of expectation are today commonly expressed with regard to the future evolution of contemporary new media.

The literature in relation to the introduction of new technology and electronic media in particular, typically contains discipline specific nomenclature such as abbreviations, acronyms, buzzwords, and uniquely derived expressions. The List of Abbreviations and Glossary of Terms contain some of the most common abbreviations, acronyms and expressions to be found in the literature in relation to research into simulation and virtual reality systems and technologies, as used throughout this document. The definitions used are drawn from the Oxford English Dictionary 2nd Ed., Oxford University Press (1989) unless otherwise stated.

The review is structured around the development of three specific themes.

1. **The continuing evolution of electronic media and meta-media**. In particular, this addresses the early development of auditory and visual media through to their more recent and continuing convergence with digital technology, computing, networking and virtual reality and their further evolution as 'new media' (Lister *et al,* 2003; Manovich, 2001) and the continuing emergence of related global and essentially ubiquitous telematic media.
2. **Simulation systems, virtual worlds and virtual reality**. The development and application of advanced simulation systems, visualization and related technologies such as virtual reality systems and applications, is discussed with an emphasis on their role as 'strategic' and potentially 'disruptive' technologies.
3. **Managing engineering and technology based organizations**. This outlines contemporary approaches to the management of technology-focused organizations, with specific reference and attention to the role of systems thinking, the development of strategic management approaches, and the introduction and management of technological innovation and change.

In presenting these three themes thematic commentary and analysis has been incorporated throughout the review, drawing out the relevance to and development of the overall argument supporting the use of electronic media, advanced simulation and visualization technologies, as potentially strategic toolsets in the management of engineering and technology based organizations.

2.2 The Continuing Evolution of Electronic Media and Meta-media

2.2.1 New media – new language

The construct of what makes or constitutes contemporary new media, is represented by many authors as being based substantively on a continually changing mix of digitally-based technologies and systems with an ever expanding array of applications (Flew, 2005, 2007; Lievrouw & Livingstone, 2008; Lister *et al*, 2009). As such, it reflects a continuing convergence of what was considered previously as disparate media with discontinuous applications, a condition that to a large extent is no longer the case, as technologies and applications seemingly converge, or at least utilize common components and exhibit common characteristics and interdependencies (Lister *et al*, 2009). This raises many questions about process and practice in the use of such still evolving, and potentially very (technologically) powerful, 'new media'.

Lister *et al* (2009) and Manovich (2001) refer to such convergence as a computer media revolution that is affecting all stages of contemporary communication and impacting on all types of communication media, whether text, images, sound, or graphics construction based. Manovich highlights his concerns about the potential impact of such convergence as follows: 'How shall we begin to map out the effects of this fundamental shift? What are the ways in which the use of computers to record, store, create, and distribute media makes it new?' (Manovich, 2001, p. 19-20). Manovich in particular, subsequently developed his argument along the lines of cultural transcoding of new and meta-media, as a form of differential aesthetic wherein both media and the multiple and often divergent social and organizational cultural contexts in which it operates and is operated on, are in a constant state of change and interaction (Charles, 2009; Manovich, 2001; Murphie & Potts, 2003). Just as earlier analogue or time dependent media have progressively converged with digital media to acquire a new form and extended functionality, so also have they acquired a new language and associated culture (Manovich, 2001). In effect, the traditional business construct of a value chain for contemporary new media hinges on new media's capacity to represent and add value to information in a form capable of translation, transformation, and distribution wherever and whenever digital processes and electronic network communication is accessible. Today, this implies virtually any time, anywhere on the globe (Lister *et al*, 2009).

The continuing growth and development of image and knowledge processing systems necessarily invokes the further convergence of video, audio, computing, robotics and communications technologies. Technological examples of such convergence can be seen in: high definition image display systems enabling special visualization effects in computer displays to enable sophisticated data visualization (Turban *et al*, 2008); video and movies integrated with and largely indistinguishable from, actual photographic images; and miniature touch screens and voice, face and gesture recognition as human-computer interface devices.

In large measure then, the technological aspects of new media can be seen as a continually evolving new form and set of technological artefacts, as a consequence of continuing and widespread digitalisation and presumed technological convergence of networkable media and systems (Lister *et al*, 2009). Castells describes this mass diffusion of information and communications technology as being the key element in formulating a new social structure or 'networked society' (Castells, 1996). He further outlined a 'new economy' based on information and communications technology and exhibiting the three core characteristics of 'informational', 'global', and 'networked' [Castells (2000) cited in Flew, 2005]. In a sociological sense this can be interpreted in the case of new media as a continuing growth in connectivity between: purpose (for the introduction of new media); functionality (of new media as an effective communicative medium); role (of new media within a given communication context); place (both at a geographical level and 'logical' positioning within a given community of practice); relationships to contemporary cultural norms [whether within or between organizational contexts or at a broader societal context); and its potency (ostensibly resulting from both technology-technology and business-technology convergence (Andriole, 2005)] as an inherently transformative media. This embedded communicative relationship between the 'users' as a growing, yet diverse community of practice and the inherently 'networked' connectivity of new media is very tightly summarized by Ito *et al* (2008): '…all forms of media are increasingly being contextualised in an online communication ecology where creative production and expression is inseparable from social communication' (Ito *et al*, 2008, p.viii).

The very suggestion of associating the introduction of technology with 'transformation' is itself subject to challenge and the overtones of technological determinism. Such views reflect classic Heideggerian perspectives of technology as a challenge to nature and societal structures, rather than as an aggregate form of knowledge, the use of which may provide a means of 'revealing' nature and the world (Downes, 2005). As such, it is essential that we explore the nature of such potentially transformative media, examine its potential to affect change in society and determine just how, when and where we may utilize to best advantage its strengths whilst mitigating potential demerits (Woolgar, 2002).

However, the very notion of convergence between old and new media forms, the technological platforms on which they are constructed, and the changing patterns of information and knowledge ownership, distribution and use, is now itself a source of argument and re-thinking, from Manovich's 'cultural transcoding' (Manovich, 2001) to Jenkins' 'convergence culture' (Jenkins, 2006) to Storsul and Stuedahl's 'ambivalence towards convergence' (Storsul & Stuedahl, 2007) and Knight and Weedon's 'shifting notions of convergence' (Knight & Weedon, 2009). The complexity and changing face of which, with regard to new media and virtual reality (VR) related media in particular, is further compounded by the non-elemental character of new media as a thriving hybrid of multiple (largely digital) technologies, sociological constructs and with an inherent capability to influence cognitive perceptions and related behaviours (Coyne, 1995) within or external to synthetic or virtual-world environments. It is this 'decoupling of space from place' (Shields, 2003, p.42) to create virtual representations and constructions of real or imagined objects/subjects/environments and associated relationships, that most notably distinguishes new media virtual reality applications from earlier communication media.

The use of new media in its various and continually evolving forms to deploy virtual reality systems as a working 'space' that is no longer constrained by physical 'place' (as was previously the case with mandated requirements of physical access to expensive and technologically complex equipment and communications facilities) reflects in turn the significant and continuing evolution of high performance digital computing systems and their seamless interfacing with high speed digital communication systems, which jointly provides the uniqueness of cyber-space as a 'global' working environment. The continuing expansion of such systems, their reach and potentially universal access, and increasingly wide array of applications, reflects McLuhan's much earlier observation about the context of new evolving media. The rise of 'social media' reinforces the relevance of his comment that: 'Today the environment itself becomes the artefact' [McLuhan (1964) cited in Heim, 1993, p.66].

Flew (2002, 2005, 2007) describes contemporary new media as an outcome of integrating converging digital technologies, the result of which is to enable new 'media' applications and new forms of media 'content' to be developed. In turn, he identifies the following core characteristics of new-media: 'manipulable; networkable; dense', as in capable of producing-storing-using large quanta of data; 'compressible; impartial' as independent of content (Flew, 2002, pp.10-11). In particular, Flew argues that the communities of practice, the users of such technological innovation, have undergone also continuing change in 'political-economic and socio-cultural environment' (Flew, 2007, p.24) with at times dramatic discontinuities, which in turn affect both their expectations of new-media and the role and purpose for which it is used (Flew, 2005, 2007). Just as earlier analogue and specifically time dependent media have progressively converged with digital media to acquire a new form and extended functionality, so did such new media acquire a new language that addresses changes and challenges in the field of mass communication and associated cultural norms of user communities (Marshall, 2004). As with the evolution of any 'language', the language of new media is being formed and reformed, both by the integration of convergent technologies and the global extensions of similar, yet differing, communities of practice with changing needs and expectations and continuing adaptations in perceptions of social reality and context, behaviours and cultural norms (Flew, 2005).

In 1994, Richard Caldine of the Centre for Staff Development at the University of Wollongong extended many of his observations on imaging techniques and message 'structuring' in educational television to what he perceived as the growing areas of commonality between the then new media: Internet and early multi-media based systems: 'An understanding of the language of television will assist those who in the future are faced with other screen-based media as the language of television forms the basis of the lexicon for multimedia' (Caldine, 1994, p.3). Caldine's insight into the concept of needing to understand the language of a particular media is of particular relevance even if television might not offer a transferable media language.

The role of language in the evolution of human culture has been long acknowledged (Dewey (1938). However, its relevance to the language of communication media and its impact on society and culture has been less well understood: 'Language in its widest sense... is the medium in which culture exists and through which it is transmitted… is the record that perpetuates occurrences and rends them amenable to public consideration' [Dewey (1938) as cited in Betz, 2003, p.413]. In the context of considering the understanding of the language of new media, Dewey's observation suggests that such language needs to be understood widely, at least to the extent that user communities of practice are able to both create and interpret messages and by extrapolation to explore new ideas and relationships between them, using the explorative capabilities of new media and the constructs of its related language.

A key to the grammar of media is an understanding of the structure and the manner of communication it supports. From earliest times the dominant forms of human communication have been synchronous in nature; they occurred in real-time, at a defined point in time and between concomitant participants, as in oral communication and touch. The progressive development of alternative means of communication such as drawing and the written word, introduced asynchronous communication, a form of time-displaced communication. This characteristic was further extended with the introduction of the printing press and eventually the development of electronic media. The capacity to record and transport communications over space and time as with telephony, radio and television, the Internet and World-Wide-Web, has added further complexity to the grammar, and by now multiple languages, uses, influences and impacts, of communication media. 'With new media, time does not necessarily adhere to the seemingly 'linear' constraints of either face-to-face conversation or early media… With electronic media, the boundaries of synchronous and asynchronous communication are being stretched and merged in new ways' (Jones, 2003, pp.429-430). This implies a form of incipient stretching of time, space and place in the introduction of new approaches to communication. Similarly then, the effective use of new media, such as virtual reality requires an understanding of the media's particular capabilities, constraints and potentially transforming influences on both its community of practice and surrounding social culture. In effect, it is necessary for media users to become literate in the 'language' of a given media.

Soren Kolstrup (2003) a media researcher with a specific interest in visual communications, addresses visualization from yet another perspective, formulating understandings of the language of visual media such as virtual reality with an emphasis on the use of visual communications as 'Communicative pictures: the production of visual meaning, the transmission of visual meaning and the reception of visual meaning' (Kolstrup, 2003, p.77). His focus is on the representation and transmission of 'meaning' using images and image making techniques. In order to perceive and understand such meanings in visual communications, Kolstrup argues for the development and application of an interactive visual grammar, the construction of which needs to address fundamental issues such as the basis for constructing images and for users being able to understand and interpret meaning from such images. Kolstrup's goals for a visual grammar reflect both theoretical and practical aspects of visualization. He proposed these as addressing insights into: the construction of imaging; the relationships between the construction of an image and its embedded or intended meaning(s); the actualisation of elemental image components to create multiple image constructions; the interplay between image construction and social norms and purposes (Kolstrup, 2003, p.78). In effect, the use of images in this literature review, in Section 2.3.1 Contemporary Virtual Reality Systems, provides an example application of Kolstrup's grammar, where images have been used to illustrate visually and give practical insight in the context of a narrative into the physical implementation and forms of technology and systems being used to implement virtual reality.

Kolstup's grammar of visual language, and in particular his insightful reference to its use in relation to developing visualization as narrative and argumentation, is of particular interest and may well prove a powerful tool in developing a successful role for complex imagery (such as in 3-D virtual reality) in a broadened range of future applications outside of the film, television, engineering design, medical imaging, and architecture contexts. In the context of using new media as a visualization tool, such a grammar may prove a necessity to enable widespread diffusion and use of techniques for effective extraction of meaning from complex three-dimensional images as representations of data. Current two-dimensional image constructions for such would include the ubiquitous bar-graph, pie-chart and vector diagram. Future applications and associated socio-technical analyses for which complex multi-dimensional imagery may prove beneficial, could include: identifying multi-dimensional contextual influences on an object or subject of enquiry; or futurist projections of a complex of influences or sensitivities affecting a community of practice.

The use of 'image' as both representation of influencing factors and as an analysis tool to aid in the extraction and representation of 'meaning' through complex multi-dimensional visual communication, will in turn require a community of practice skilled in the use of such language and grammar (Kolstup, 2003). An example of diffusion of an earlier informal version of a visual 'grammar' through a community of practice can be seen in the rapid evolution and diffusion of computer-gaming techniques, typically requiring rapid cognition processing and eye-hand coordination based on recognition of visual cues connected in turn to interpretation of cues implicit in the 'story-line' and constructed grammar of the game (Squire, 2008). The extensive use of high resolution and high-speed computer graphics in computer gaming has enabled the evolution of a mix of visual representation approaches used to present powerful images that can construct expectation and viewpoint on the part of the viewer/user.

How then should visualization of systems, organizations, strategies, products and services, be constructed? This in turn raises multiple areas of enquiry… What could or should they tell? How? In what mode? For what purpose? Through what modality of thought processes: introspective; extraverted; directed; contemplative; predictive; reflective? When different people from varying backgrounds and cultures and with varying purposes in mind, view a given visualization, what do they each see? How does it differ? What effect does this have on their viewpoint or their subsequent actions or reactions? The perspectives of viewpoint and responses to the above questions may indeed vary widely with both background experience and exposure to the subject matter, and the expectations of the viewer (Lofts, 2002).

Manovich (2001) addresses these issues through considering the evolution of image-based media in the context of a shift in the relationship between the two constructs of virtual and physical space. In the earliest forms of image making, the representation was in a fixed form, paintings on walls, ceilings, fixed in space. Progressively, as new forms of image making evolved, on parchment, canvas, photographic plates, film, electronic storage media, the construct of physical space began to change leading progressively to the construction of more virtual forms of representation. For example, in the case of synthesis and simulation both the 'arrow of time' (Coveney & Highfield, 1990) and physical attributes of space and place are in effect manipulated.

This exploration of new ideas and relationships between them is an area of engagement that new forms of communications media can help address (Boellstorff, 2008) and may be seen in the new forms of media representations such as Twitter and Facebook. The use of virtual world constructs, whether on-line or within closed environments (such as virtual reality centres, CAVEs or desktop workstation systems, and open or closed network environments) has facilitated new ways of thinking about the way we communicate complex messages and information, with a particular focus on the evolution of new (virtual) social structures (such as on-line communities) that in turn facilitate acquisition of collective knowledge and shared meaning across both established and new communities of practice (Papargyris & Poulymenakou, 2008).

McLuhan (1964, 1967, 1968) Sherman & Craig (1995) Flew (2002, 2005, 2007) Castells (2004) Jenkins (2006, 2008) and others variously argue that the effective introduction of a new form of communications media requires an understanding of the media's particular capabilities, constraints and potentially transforming influences on both its community of practice and surrounding political, economic and social culture (Flew, 2007). There are however, severe discontinuities between many of these views and perspectives. McLuhan for example, was arguing at a time prior to the development of the Internet and the related array of new digital technologies and communication systems that today form the nexus of contemporary new media. There is a degree of specificity about many of these earlier viewpoints about particular electronic media that does not relate well to contemporary media and related systems, as represented for example by differing perspectives on time, place and space relative to media, content and culturation of communities of practice. Accordingly, the transitioning between media in terms of its form, function and practice, is influenced largely through understandings of, and growing literacy in, the evolving 'language' of the media and its conjunction or otherwise with previously established media (Flew, 2007; Jenkins, 2006; Lievrouw & Livingstone, 2008; Marshall, 2004). By further extrapolation, the presence, role and use of new media is a growing reality particularly with regard to 'their ubiquity and societal reach' [Boczkowski & Lievrouw (2008) in Hackett *et al*, 2008, p.949]. This is evidenced strongly in a world in which communication is structured increasingly around the acquisition and distribution (usually through the medium of digital media) of information and its analysis. The subsequent interpretation and networked communication and translation of meaning to interested communities of practice and their active interaction and engagement with it (Castells, 2004; Flew, 2005, 2007) occurs almost regardless of its current specific technological form (Boczkowski & Lievrouw, 2008; Marshall, 2004). Today, by comparison with the time of McLuhan, media 'in transition' is virtually the norm, placing significant demands on system viability through compatibility across technology platforms, upgradeability particularly in relation to the introduction of new capabilities, and capacity to maintain and ensure message coherence.

Marshal McLuhan, creator of the aphoristic expressions: 'the medium is the message' (McLuhan, 1964, p.7) 'radio: the tribal drum' (McLuhan, 1964, p.297) and 'the global village' (McLuhan & Fiore, 1968, title) was particularly concerned about electronic media and its impact on society and our understandings of communication. He used various mechanisms to categorize communication media (not just electronic media). One such stratagem was to allocate the appellation of being either 'hot' or 'cold' media based on considering the intensity of information involved, engagement of the user, and the required commitment and participation of the user, especially as this related to the engagement of multiple senses (sensory perception) in order to effectively interpret message content (Boczkowski & Lievrouw, 2008; Flew, 2005; McLuhan, 1964). Thus, McLuhan ascribes the status of 'hot' to photographic media, as photographic imaging generally has a high data content 'that extends one single sense in high definition' (McLuhan, 1964, p.22). The telephone and general auditory speech he describes as being 'cool' media of low definition where 'cool media are high in participation or completion by the audience. Naturally, therefore, a hot medium like radio has very different effects on the user from a cool medium like the telephone' (McLuhan, 1964, pp.22-23).

McLuhan also proposed a tetrad of four laws or effects of media. These in turn highlight the complexities of endeavouring to uncover and understand the meanings and language of specific 'media'. He posed four questions to be asked of any medium: 'What does it enhance or <u>amplify</u> in the culture? What does it <u>obsolesce</u> or push out of prominence? What does it <u>retrieve</u> from the past, from the previously obsolesced?' (and here the tetrad projects into the future) – 'What does the medium <u>reverse</u> or flip into when it reaches the limits of its potential?' [McLuhan & McLuhan (1988) as cited in Levinson, 2001, p.16] For McLuhan, radio was an example of an enhancement to communications that extended oral forms of communication, in the terms of McLuhan's tetrad, it enhanced or amplified oral communications. Similarly, radio obsolesced the newspaper as a significant medium for written communication, retrieved something of the earlier 'prominence of oral communication from pre-literate times…' [McLuhan & McLuhan (1988) as cited in Levinson, 2001, p.16] but with the further passage of time it in effect reversed into the medium of television with its more graphic use of combined sound and moving images (Sui & Goodchild, 2003). McLuhan's idiomatic approach and aphoristic language may be difficult to follow with its implicit technological determinism style focus on media as a primary causal influence on society and contemporary culture. However, his insights into the place and role of electronic media in society are still of considerable significance when looking to the new media of the twenty first century, forty plus years after McLuhan first published 'Understanding Media: The Extensions of Man' and enigmatically titled the first chapter: 'The Medium is the Message' (Levinson, 2001; McLuhan, 1964, p.7; Murphie & Potts, 2003). Such may well have also been the message had McLuhan been witness to the phenomenon of the iPhone-iPod-iPad continuing 'media in transition' experience.

With the continuing growth in communications media and associated supporting technologies, systems and services, has come a concomitant development in electronic media complexity, capability, applications, reach and pervasiveness to the point of ubiquitousness. With this has also come a growth in perceptions of the language and functionalities of such media, although some would argue not necessarily in understanding. Marshall McLuhan's earlier definitions of hot and cool media, established some 20 years prior to the introduction of multimedia and 30 years prior to the first effective large scale commercial virtual reality systems and technology (SGI Virtual Reality Centre circa 1994) and the age of digital convergence (Turban *et al*, 2008; Yoffie, 1997) prove problematic when applied to contemporary new media and virtual reality in particular. They would appear to classify virtual reality media as both hot and cool, depending on the design focus of the application. For example: High in participation and immersive engagement by the user = cool; High definition as in: 'well filled with data' (McLuhan, 1964, p.22) and extends (multiple) senses in high definition = hot. Here can be seen the complexity of VR media and new media in general, with its capacity for concurrent intensive exposure to both high definition data and high level interaction through the immersive experience of tele-presence, exemplifying McLuhan's hot and cool media parameters in a unique form of duality.

By comparison with the electronic media of McLuhan's time, the new media communication technologies of today, such as the internet and world-wide-web, are virtually unconstrained by geographic reach (Lister *et al*, 2009) and certainly not by local or even regional cultural norms (despite attempts by some government's agencies to censor or constrain their populace's access to some content). They also reflect, in common with earlier electronic media, typical characteristics of successful innovation diffusion. These include demonstrably improved performance over alternative media in a key area, or multiple key areas of interest (for example, including but not limited to global mass communications, speed of delivery, widespread access, potential for secure asynchronous and synchronous communication and interaction) with decreasing unit costs, multiple (competitive/non-monopolistic) providers of required technology and services, and increasing reliability, collectively resulting in widespread acceptance (Rogers, 2003). Such changes have also seen continuing departures from traditional forms of communication and media use, as in the expanding use of online immersive virtual world cultural environments such as 'Second Life' and the wide variety of semi-immersive virtual world gaming systems (Boellstorff, 2008; Jenkins, 2006; Lister *et al*, 2003; Manovich, 2001).

This focus on considering the impact of new media on society through observing and evaluating its influence on and effective replacement of incumbent or old media, is strongly reflected in McLuhan's view that we may best understand new media by using it in effect as 'a rear-view-mirror' [McLuhan & Fiore (1967) as cited in Levinson, 2001, p.173]. This appears at the very least during the transition era from the old to the new and progressively as it evolves, enhances and in turn is subsequently obsolesced and displaced (Jones, 2003; Theall, 1971). In turn, McLuhan is credited with having influenced the thinking of many media researchers and developers, particularly during resurgence of interest in his writings through the 1990's (Levinson, 2001; Murphie & Potts, 2003). His construct of 'language' and 'grammar' of a media has been a significant driver of media research over the past 40 years, encompassing many different approaches to the use of media and the way that its very presence influences the way we engage in daily life and business, 'one implication of McLuhan's analysis was that the impact of the communication media on sensory perception influences not only what we think but how we think' [McPhail and McPhail (1990) as cited in Flew, 2005, p.32].

Whilst the purveyors of new media technologies may endeavour to induce the image of a common 'global' culture of new-media applications, there are significant arguments that suggest that 'variance' in cultural acceptance of role, function, use and interpretation of embedded meanings in new media applications, is more the norm (Flew, 2007; Marshall, 2004). Cultural diversity and its influence on both the development, acceptance and diffusion of new technology (Rogers, 2003) is a key area of argument in attempting to identify and annunciate a new media language and implied culture that has relevance across widespread and changing user cultures and communities of practice (Papargyris & Poulymenakou, 2008). Or, as Marshall (2004) expresses it: '…emerging cultures of new media. These cultures, in their dynamic relationship with products, networks, hardware, software and practices, are constantly changing in sometimes profound and sometimes banal ways' (Marshall, 2004, p.viii).

The continuing growth in complexity and dynamic capabilities of new media and the concomitant convergence of digital media (Yoffie, 1997; Pagani, 2003) will thus continue to challenge our concepts of the language and role of new media (Manovich, 2001). This applies to the applications for such new media, particularly in the context of contemporary business – technology convergence (Andriole, 2005) and will see a growing diversity both within and between communities of practice associated with new media virtual reality and new media *per se*. Such diversity of interest can be seen in existing communities of practice with interests as diverse as: interactive scientific visualization for data analysis; visualization as sketch-pad for multi-dimensional computer-aided design; visualization as immersive exploration and testing of new ideas, constructs and system level relationships; and creative visualization as dynamic virtual art form. In turn, the effective outcomes of such media convergence go well beyond introducing a simple technological shift, rather, fundamental relationships between existing technologies and between such technologies and its users and communities of practice are altered (Jenkins, 2006). Similarly, it challenges our perceptions of how access to information via interaction with new media, adds value to our lives and enhances work performance, particularly in the context of contemporary business–technology convergence (Andriole, 2005).

This reflection on the continuing conceptual evolution of virtual reality and new media and its potential role in the exploration of new ideas and relationships between them is an area of engagement that is essentially new and challenging for technology focussed managers in engineering and technology-based enterprises.

2.2.2 New media technology evolution

The actual underlying technology bases and technological artefacts of electronic and digital media have also undergone constant, if at times rather erratic and even spectacular, innovation and change and associated technological convergence. In relation to new media, this means that 'older media are constantly mutating into new media' (attributed to McLuhan in Murphie & Potts, 2003, p.85). Underpinning the rapid growth in digital media technology capability has been the inexorable growth in computer processing capability through associated miniaturisation of digital technology, as per the predictions of Moore's Law [Moore (1964) as attributed in Swann & Watts, 2002]. Related improvements in visualization display technologies (Gutiérrez *et al*, 2008) and global growth in telecommunications networking and interconnectivity (Stair & Reynolds, 2006) have in turn extended the technological capabilities of new media enabling the development and distribution of and engagement with, new or extended forms of media content as is demonstrated in virtual reality applications (Flew, 2007; Sobel Lojeski & Reilly, 2008). This continuing state of integration and convergence of multiple technologies (Andriole, 2005; Turban *et al*, 2008) and transition from one level of technology and resultant media capability to the next (Flew, 2005, 2007; Lievrouw & Livingstone, 2008; Murphy & Potts, 2003) has in turn produced differing strategies and techniques for 'structuring' the introduction, diffusion and widespread use of such media.

Expanded functionalities in 'user' telecommunications media over the past two decades provide a particularly glaring example of media convergence and the potential for media language conflict: the fixed/wired telephone versus the mobile telephone with built in still and video camera; iPod/iPad portable media player with wi-fi text messaging/email and internet access; mobile Global Positioning System (GPS) with built-in maps, location finding and travel directions. Each device exhibits its own specific enhancements to communications, yet each also carries inherent constraints and restrictions, collectively representing further convergence in both the telecommunications and information technology bases, and the characteristics of contemporary communications media and their associated communities of practice (Bell, 2007; Jenkins, 2006; Sobel Lojeski & Reilly, 2008).

A wide array of integrated technologies can be utilised to form virtual reality systems (Turban, 2008; Woolgar, 2002). At the high-end of the scale these can involve supercomputer-based immersive systems supporting multiple overhead image projection onto surrounding curved screens with multi-directional surround sound, or semi-enclosed multi-wall projection environments called CAVEs (Cruz-Neira, *et al*, 1992; Kjeldskov & Stage, 2003). These are used with stereo-vision shutter glasses and hand-held haptic control devices to provide interactive full surround/immersive three-dimensional imaging. Alternatively, flat screen technologies either wall or table based, or desk-top computers with broadband communications access to the internet can enable interactive applications such as Second Life (Boellstorff, 2008) to run on the office desk-top, alongside notebook or even hand-held 'touch' screen devices incorporating wireless connection to either internet or local intranet applications.

The subsequent continuing convergence of contemporary computing and communications technologies also poses both challenge and opportunity for paradigmatic revolution. This can be seen for example, in the case of the rapidly expanding use of the cyber-world of the Internet and the world-wide-web, interactive multi-user computer gaming and the exploration of on-line virtual worlds (Boellstorff, 2008). Just as the introduction of the printing press introduced a revolution in the form of widespread access to print-based information, the introduction of word-processing began a revolution in text processing that inexorably led to the development of desk-top publishing and the demise of the previously unique role of physical lead-block type-setting, so now the addition of global communications and sophisticated search-engines are fundamentally changing concepts of accessibility to knowledge and ownership of information (Handzic, 2004, Henczel, 2001).

Similarly, the evolution of electronic communications systems over the past 170+ years since the introduction of the telegraph (circa 1840) may be interpreted as having diffused over time to its current representations in the global telecommunication systems and networks, the internet and world-wide-web, and the wide array of new media devices and applications. Clearly, in the above examples there have been many technology developments and innovations and the necessity of complex technology transfer mechanisms to facilitate global diffusion (Rogers, 2003) not of one particular product, but of multiple systems and products, which are the embodiment of a particular concept. The history of technology transfer and its diffusion illustrates that it is an inherently complex set of processes (Rogers, 2003). Seemingly simple or obvious developments fail, whilst others succeed (Swann & Watts, 2002).

Many authors have referred to new media technology in its various and convergent forms as being potentially ‘new thinking tools’, with their own form of media language and unique representational structures, symbolisms and participatory culture. They could be a form of communication through which new culture or cultural variance is constructed (Boellstorff, 2008; Flew, 2005; Jenkins, 2006; Pimental & Teixeira, 1993; Manovich, 2001). For example, Jenkins (2006) refers to the significant influences that the introduction of new media has had on the mass media enterprises, where ‘rather than talking about media producers and consumers as occupying separate roles, we might now see them as participants who interact with each other according to a new set of rules that none of us fully understand’ (Jenkins, 2006, p.13).

Virtual reality systems provide a complex means of visualizing new representations of real-world objects or even more abstract concepts, through synthesis and simulation. Yet still the question remains: for what purpose? ‘Visualization is all about giving shape to a vision; about giving ideas a concrete form’ (Christensen & Lamm, 2003, p.257). Whilst artists, engineers and scientists have long used visual tools (pencil and paper for example) the development and application of computer imaging technologies, particularly through the 1970’s-1990’s, and again even more rapidly over the past decade with growth in economically available computing power, has led to imaging capabilities that were simply not available at any cost to artists, engineers or scientists alike, in previous generations (Friedhoff & Peercy, 2000). By 1987 the computer graphics community was an established reality, with growing application areas acknowledged in computer-aided design, film and video production, and the rapidly evolving computer games industry which in itself placed, and continues to place, significant demand for high speed graphics processing (McCormick *et al*, 1987).

In this light, the following rhetorical questions arise from the work of Professor Allucquere Rosanne Stone on proposing her taxonomy, or epochs of communal virtuality: Virtual Reality, an oxymoron or a natural progression in Communal Virtuality? VR as an exemplar Epoch of Communal Virtuality? (Stone, 1992). Stone's 'Epochs of Communal Virtuality' evolved from her interest in the way human communication has been mediated increasingly by the application of technology. Her work proposed a set of epochs through which can be seen the development of virtual communities. In a sense, each of the epochs continues to this day and beyond. However, each also identifies the transition from one form of technological evolution/revolution to another, in effect, constituting a progressive process towards phenomenal media. Each of Stone's Epochs effectively extends the level of immersion within the virtual environment: The Story Teller; Textual Media; Auditory Media; Visual Media; Phenomenal Media (Stone, 1992).

The structure of the above taxonomy of communal virtuality is clear. For many tens of thousands of years mankind has explored meaning in the world through story telling. The power of a great storyteller, playwright, actor, to hold captive an audience, or the community of listeners, is altogether timeless and as real today as it ever was. Yet, it is by its very nature (in its original format) constrained in time and place, the storyteller and his audience being of necessity in close proximity. However, the very essence of story telling, the use of imagination, the structuring and painting of word images through oral language, remain as powerful entities in contemporary communications media. The development of recordable and reproducible sound provided a clear transition in the taxonomy of communal virtuality. It was no longer necessary for the listener, or community of listeners, to be present to hear the voice or sounds of the speaker or performer. Today, contemporary sound systems are more than capable of presenting with exceptional clarity the auditory illusion of 'being there'.

Many forms of imaging appear in history dating back to an early description of the 'Camera Obscura' (A darkened box with a hole in one side, allowing an inverted image to appear on the opposite wall of the box) by the Arabian mathematician and physicist Alhazen, circa 1000AD (Friedhoff & Peercy, 2000). From the first public demonstration of motion film in Paris by Louis and Auguste Lumiere on 28th December 1895 (Prentice Hall, 1992) it was another 30 years (mid 1920's) to the experimental development of television and another 10+ years (mid-late 1930's) to irregular transmission by television broadcasting and then another 30+ years (mid 1960's) to the early generation of computer graphics imaging, followed by yet another 30+ years of further and continuing development to the realisation of today's sophisticated 3-D digital photo-realistic imaging systems.

The evolution of the concept of phenomenal media is clearly entwined with the development of all of Stone's Epochs of Communal Virtuality, particularly Text; Auditory; and Visual media (Stone, 1992). It goes further to encapsulate also the integration of kinesthetics, prosthetics, robotics, telecommunications, computing systems, and a wide range of supporting mechanical and electronics devices and inter-related systems, an assemblage of technologies, which when integrated in a new media or virtual reality system, is capable of supporting and enhancing the illusion of reality in a virtual or synthetic world (Loeffler & Anderson, 1994; Stair & Reynolds, 2006).

New technologies, as per the current amalgam instituted as new media, is both a result of and a changing response to our growing and shifting knowledge base and a reflection of our capacity to extend knowledge through imaginative creativity (Heim, 1993) and to challenge what is known and what is, and the possible positions of these within the construct of using illusion, constructing virtual objects and relationships and in the context of this research: managing an organization and operating a business using virtual reality and virtual world systems and technologies. Chen (2006) extends these insights through a focus on the emergent field of knowledge domain visualization. In this form, information visualization tools, including virtual reality systems, are used to access and interpret meaning from enterprise data or knowledge-banks such as documents, databases, network records, and operations data. In moving visualization methods into the field of knowledge management, Chen (2006) acknowledges the need for detailed insights into and a clear understanding of the characteristics that construct a given area of knowledge. Empirical studies into the application of advanced visualization tools in knowledge management are as yet very few, however, there is considerable potential for future application of information visualization systems such as virtual reality in the context of technology based organizations and related industry sectors.

Directly and deliberately using virtual reality visualization and image making tools to create images that stimulate our thinking through creating 'short-cuts' to established ideas, or known associations of events or practices or phenomenon, may well be seen as creating a new puzzle-solving or intuitive framework for developing new knowledge and experience (Hanrahan, 2000). The construct of using virtual reality image making as a means of accessing a 'short-cut' to a higher level of cognition and perception presents a significant challenge to executive decision makers, media managers and producers of image making techniques/technologies/systems, as well as to the education community as developers of management skills and expertise in future leaders and executive managers, for whom such iconographic techniques (Lacy, 2009; O'Shaughnessy & Stadler, 2002) in using visual computing as a thinking tool in decision making, will undoubtedly become *fete accompli* in their future real world (if not already the case, such as in some areas of technology design).

Explorations of new forms of relations with and between cyber-world entities, now raises the prospect of even more challenging demands than ever before being placed on systems modelling approaches and their use in the management of new innovative and potentially disruptive technology. Virtual reality and virtual world modelling and simulation systems have for example been explored extensively for their inherent capacity for advanced training, particularly through advanced simulation (for example, high level immersion for fighter pilot training and military tank battle-simulators) and their capacity as 'phenomenal' media to use high levels of sensory stimulation, for example in surgical technique training (Stair & Reynolds, 2006). Clearly in these instances, examples of virtual reality and virtual world systems modelling directly related to real world entities and behaviours. The most significant feature of virtual reality systems as identified by Friedhoff and Peercy (2000) is that of the visual dimension, that is, modelling in virtual reality and virtual worlds will primarily engage the visual senses. In turn it will be a cognition task to relate image to purpose and intent, apparent effect to presumed cause and vice versa.

2.3 Simulation Systems, Virtual Worlds and Virtual Reality.

The notion of virtual reality is older than science fiction. Indeed, the art of reality manipulation stems from prehistoric campfire enactments, Greek theatre, and a host of ancient performance rituals intended to heighten human experience via dramatic, multi-sensory stimulation (Barnatt, 1997, p.Preface, ix).

2.3.1 Contemporary Virtual Reality Systems

Initial virtual reality systems, as introduced through the late 1980's and early 1990's, were mainly predicated on the use of either head-mounted displays or boom-type stereovision viewers and as such assumed a highly individual user workstation environment. An important step forward in the evolution of virtual reality technologies and systems came with the development of the multi-user immersive CAVE (Cave Automatic Virtual Environment) six-sided projected display system, developed by researchers from the University of Illinois at Chicago and the National Centre for Supercomputing Applications (Durlach & Mavor, 1995; Cruz-Neira, 1992, 2002). This facility has lead to the development of a wide range of educational, research and industrial design applications where immersion without the necessary use of constricting head-mounted displays is desirable. In particular, the CAVE system has proven to be particularly valuable in engineering and manufacturing design environments. Its immersive visualization techniques have enabled effective virtual prototyping of products and systems through supporting interactive team-based design, analysis and evaluation prior to physical prototyping and testing. Its use of surround 3D visualization in effect enables designers to step into their developing designs and manipulate their design data in ways not feasible or possible in the real world (Gutiérrez *et al*, 2008; Kjeldskov & Stage, 2003).

Educational applications include scientific visualization and non-Euclidean geometry, physics, chemistry, architecture, engineering systems, aerospace, automotive, medical science and many others. In addition to a range of university research facilities CAVE facilities have also been installed in many engineering design establishments including: the automotive and aerospace industries, oil and gas exploration industries, and in defence simulation facilities (Durlach & Mavor, 1995; Cruz-Neira, 2002). The following pages contain a collection of images describing a range of current virtual reality systems and technologies, mainly derived from various company-marketing materials. Figure 1 provides an external view of a typical stand-alone CAVE installation and environment, with external image projectors, mirrors, and the translucent walls and ceiling of the CAVE onto which images are projected.

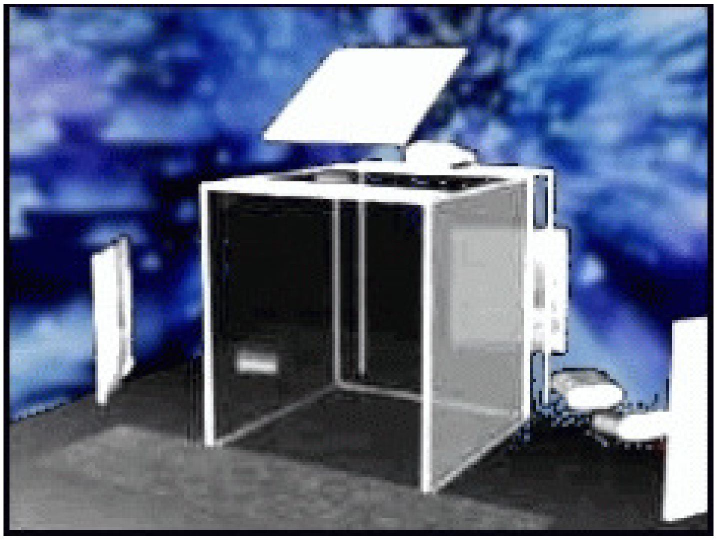


Figure 1. Typical Structure of Projection CAVE Facility (Courtesy SGI: www.sgi.com , 2003)

Figure 2 illustrates in this instance, three people wearing shutter glasses for stereovision effect inside a CAVE, with 3 walls and the floor being illuminated with graphic imaging. Whilst this represents a typical CAVE installation, other versions may include all four walls, floor, and ceiling being illuminated with graphics or video sourced imaging. (BARCO, 2000)

Figure 2. Virtual Reality CAVE Facility (Courtesy BARCO: www.barco.com , 2000)

The Virtual Reality Centre projected display concept was developed by researchers at Silicon Graphics Inc. in 1994. This display system utilises a large semi-circular display screen with at least three projectors and has been widely adopted for group virtual reality environments. Display systems used with the Reality Centre concept may be either forward or rear projected with screens that are: flat, curved or cylindrical, and may vary in size from 3 metres up to 30 metres wide. They also are capable of running stereo viewing (www.sgi.com/realitycenter/display_configs.html, 2004). The following Figures provide views of various Virtual Reality Centres, including that at the RMIT University Interactive Information Institute (RMIT I^3).

Figure 3. RMIT University I^3 Virtual Reality Centre
(Courtesy RMIT I^3, 2003)

In figures 3, 4, 5, 6, there are triple overhead projectors and various audio speaker system configurations.

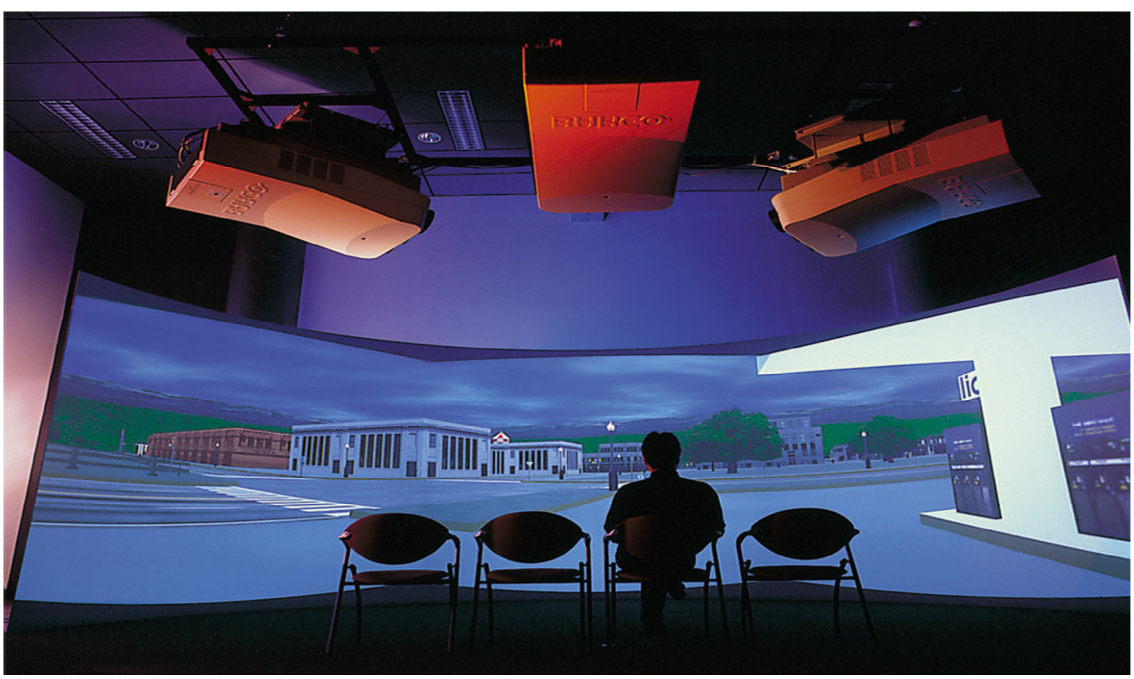


Figure 4. Typical Virtual Reality Centre with Projection Display Technology (Courtesy BARCO, 2000)

Figure 5. Exemplar Group Engagement in Reality Centre Environment
(Courtesy: Northrop Grumman/Newport News Shipbuilding/Panoram Technologies,
www.panoramtech.com/resource/pr_images/ , 1999)

Figure 6. Semi-circular Wall Display at Scripps Institute of Oceanography, La Jolla, California. (Courtesy: Scripps Institute & Panoram Technologies. www.panoramtech.com/resource/pr_images/ , 2003)

Various arrangements for group activity in a Virtual Reality Centre environment are demonstrated above, particularly in Figures 5 and 6. In Figure 5 participants are grouped around a presenter or discussion leader with the greater portion of the wrap around screen being used to display relevant imaging (in 2-D format in this case, but could also be in 3-D with users wearing either shutter glasses or polarised lens glasses) whilst data sets/menus are clustered at the outer edges of the screen (www. panoramtech.com/resource/pr_images/, 2003). Figure 6 illustrates a Virtual Reality Centre facility installation in the Scripps Institute of Oceanography at La Jolla, California, structured as a large boardroom or meeting-room style environment for group activity. In this instance, a semi-circular front projected screen is located at one end of the meeting room (www. panoramtech.com/resource/pr_images/, 2003).

The first commercially accessible installation of a Virtual Reality Centre was in Silicon Graphic Inc. UK offices at Reading in 1994. By year 2000 some 200 such installations were in place globally with 580 by September 2002. By July 2004, 670 such facilities had been commissioned in a wide range of application environments, varying from: defence simulations; automotive and aerospace design; university education and training; oil and gas exploration (with 120+ VR centres in use by 40 oil companies and seismic contractors). The rapid rate of growth in take-up of such technologies can be seen in figure 7.

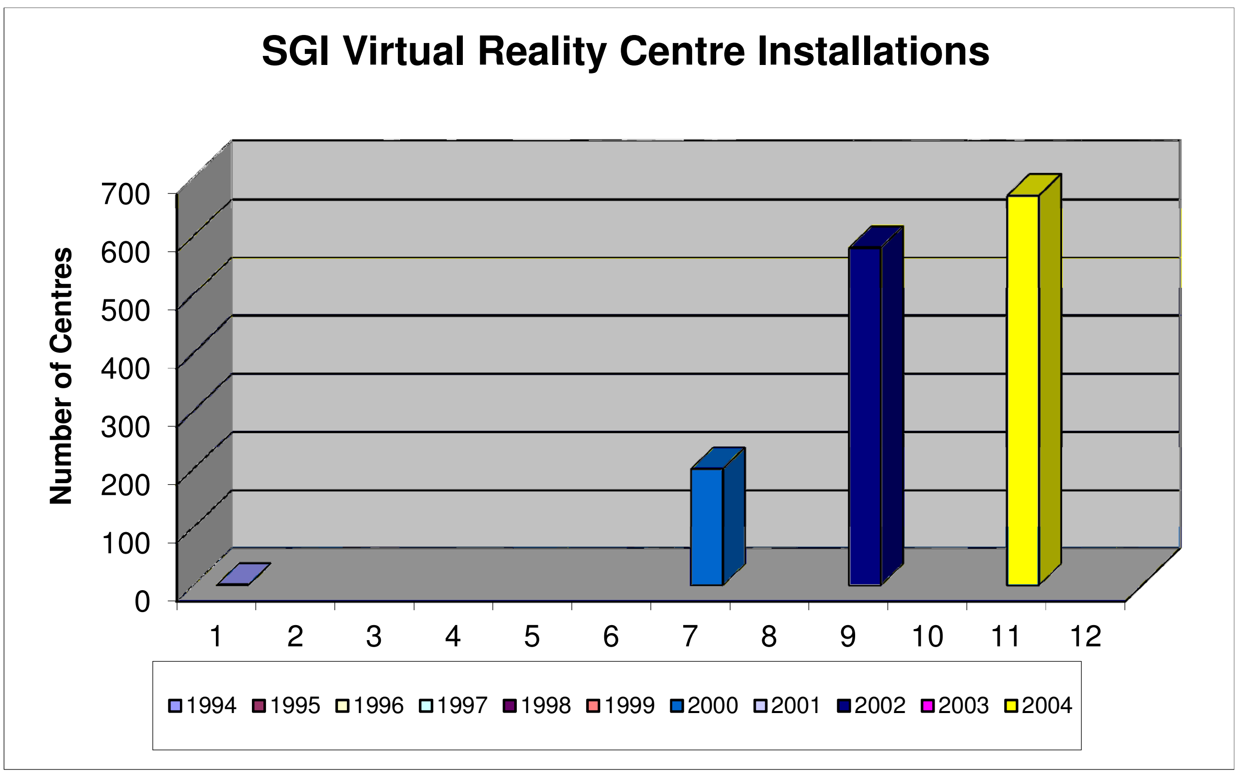


Figure 7. Introduction of Virtual Reality Centres (1994-2004)

Data Derived from:

(www.sgi.com/newsroom/press_releases/2002/september/ford.html , 19-4-2004)

(www.sgi.com/newsroom/press_releases/2002/march/australia_state_rail.html , 12-12-2002)

(www.sgi.com/products/visualization/realitycenter/energy.html , 2005)

(www.sgi.com/company_info/newsroom/press_releases/2004/july/rc_anniversary.html , 2005)

Other projection systems have followed. For example, various sized Hemispheres and globes in a range of sizes from 3-12 metres diameter, enabling sizable groups of people to be together within a semi or full wrap-around screen, whilst smaller versions cater for a single user. See Figures 8 and 9.

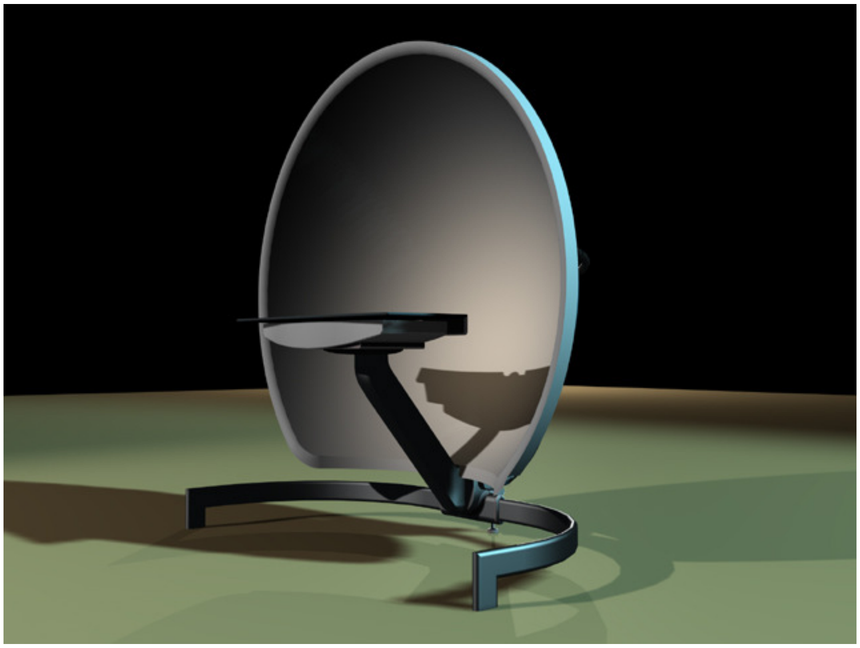


Figure 8. Small Single User Hemisphere
(Courtesy Elumens: www.elumens.com , 2002)

Figure 9. Medium Sized Hemisphere
(Courtesy iCinema: www.icinema.unsw.edu.au , 2007)

Figure 9 is of a medium sized (~3m diameter) hemisphere vertically mounted flush in a wall. In this particular instance as an experimental demonstrator installation in the Powerhouse Museum, Sydney, NSW and based on the iDome platform developed by the iCinema Centre, University of New South Wales. Flat-screen display formats have also found a range of applications using various stand-alone VR workstations such as image walls, graphics workstations and flat benches using 3-D shutter glasses and various haptic interface devices to enable interaction, examples of these are shown in Figures 10. and 11. (Note the use of 'shutter' glasses for stereoscopic/3D imaging and hand controller (3D equivalent to a point and click mouse).

Figure 10. Design Type 'Immersa' Desk (Courtesy SGI/Immersa Desk: www.sgi.com , 2000)

Large vertical flat screen display versions have also been utilised where such displays may be built-in to a room or facility such as a company boardroom, lecture theatre, or operations control room. Sizes vary from that equivalent to a small whiteboard to larger examples as shown in Figure 11 an early rear-projection version display normally built into a wall rather than stand-alone as illustrated here, see Figure 20 for another example of a large flat wall projection type display.

Figure 11. Virtual Reality 'Flat Wall' Display (Courtesy SGI: www.sgi.com , 2000)

Another variation on the multi-screen, stereo viewing, projection system called 'The Wedge', was developed in 1996-7 at the Australian National University, Canberra, in collaboration between the ANU's Plasma Research Laboratory, the Research School of Physical Sciences and Engineering, and the ANU Supercomputer Facility's Visualization Laboratory. The system uses rear projection techniques and shutter glasses. A larger version with screen sizes of 4 metres by 2.2 metres was installed in 1998. This display 'theatre' (see Figure 12) can accommodate some 20 users.

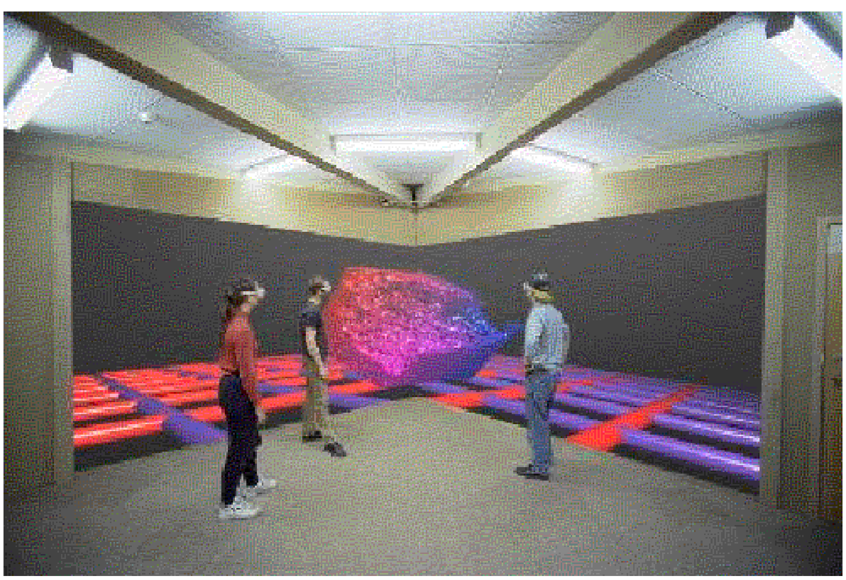


Figure 12. Wide Angle WEDGE Theatre, Australian National University
(Courtesy ANU: http://wedge.anu.edu.au , 2004)

In addition to the use of large display systems, such as used in virtual reality centers, there are also head-mounted individual display technology with or without 3-D, integrated with haptic manipulation and pointing devices and head/body position detection technology (see Figure 13). Figure 14 illustrates more contemporary near-to-the-eye LCD display technology. Figures 15 and 16 illustrate typical multi-screen display systems for desktop workstation environments.

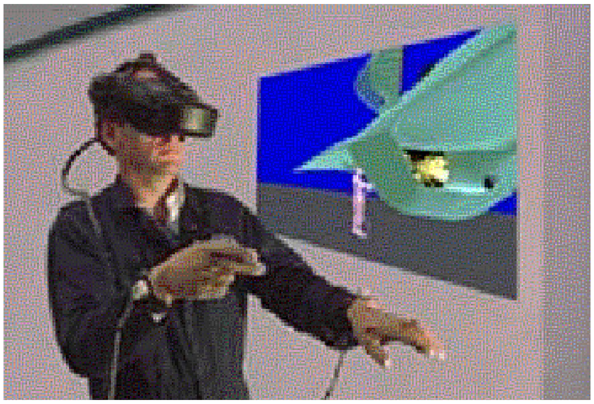


Figure 13. Early Head mounted Display & Haptic Data Gloves
(Courtesy Boeing & SGI: (www.sgi.com/industries/manufacturingf/aerospace/index.html , 2002)

Figure 14. Typical Contemporary Lightweight LCD Video Eyewear
(Courtesy: Vuzix Corporation, www.vuzix.com , 2007)

Figure 15. Individual/desktop 'Office' Workstations with Wrap-around Screens

(Courtesy: Panoram Technologies, www.paroramtech.com/products/desktop.html , 2007)

Figure 16 Multi Screen Desktop Display System

(Courtesy: Samsung,

www.http://www.samsung.com/au/consumer/pc-peripherals/monitor/lcd-monitor/LS23MURHB/XP/index.idx?pagetype=prd_detail&pid=au_monitortype_keyvisual1_md230x6_20100701 , 2011

As an exemplar of a virtual reality application operative on an individual or desktop workstation and accessed via the Internet, the format of the 3-D virtual world application 'Second Life Grid' implemented by Linden Lab, provides an interesting analogue for considering virtual reality implementation in a large dynamic organization. The metaphors of property, services and community as developed in the Second Life synthetic world directly reflect their real-world equivalents and communities of practice in the real-physical world. A range of users (including government agencies, educational institutions, and commercial organizations) have engaged with this particular internet based/delivered virtual world application system with mixed reactions, although most tend to be supportive, at least in principle (Boellstorff, 2008). Typical examples for how organizations can use such virtual world constructions may include: person to person and business to business meetings for both design and business collaboration discussions involving or requiring access to complex datasets, or negotiations over development of new products or services, or specialised immersive staff training activities (Linden Lab, 2009).

The continuing evolution of this very powerful combination of advanced computing hardware and software, visualization tools and telecommunications systems, has already raised many complex issues for telecommunications engineers, hardware designers, software developers and again educators. As an example, the technical, operational and potential market ramifications arising from such complex interactions between a wide range of concurrently rapidly evolving systems were perhaps first enunciated by Scott and Biggar of the Telecom Research Laboratories (Clayton, Melbourne) in mid 1992, in their early developmental research associated with the introduction of broadband services into the Australian telecommunications network of broadband services: 'VR offers real promise as a significant means of communicating, learning and experiencing remotely, across a city, a country or the world' (Scott & Biggar, 1992, pp.23-24).

Scott and Biggar specifically cited interactive virtual reality as a significant application on future broadband networks, with global ramifications. The continuing convergence of information technology in its many forms with communications media, particularly widespread broadband access, mobile networks, and smart terminal equipment, has in time seen their observations and projections converge with reality. Whilst accepting the impact of continuous improvement and growth in processing power in computing systems and telecommunications network switching and support for multiparty and multipoint services, they also identified the need for more visionary approaches to the design of telecommunications networks and associated systems development if the full potential of such new applications was to be actualized. They also specifically identified tele-virtuality as the most likely form of interactive virtual reality experience to be implemented in support of education and training services (Scott & Biggar, 1992). But then, eight years later, Frank McQuillan of Silicon Graphics Inc. incorporated into his presentation to the Pan Pacific VR Summit conference held in RMIT University in 2000, concerns that few organizations were making actual use of the potential for collaborative applications using virtual reality systems and technology: 'Lots of talk, not enough action: Customers are clearly articulating a need for remote collaboration using Reality Centres… People are coming up with ingenious gizmos, but... People are not coming up with ingenious ways to interact with 3D data or manage a 3D display space' (McQuillan, 2000, PowerPoint slide set, slides 16-17).

In approaching virtual reality as a complex, leading-edge technology, the US National Research Council's Research Committee on VR Research and Development, chaired through the mid 1990's by Nathaniel Durlach, established a framework for their investigations which in turn directly relates to this research program. They established a division of four categories of technology relevant to virtual reality systems: Human-machine interfaces; Computer generation of virtual environments; Tele-robotics; Networks.

Specifically in relation to the role of networks, they noted that advanced communications networks have the potential to provide geographically distributed access to virtual environments: 'Communication networks have the potential to transform virtual environments into shared worlds in which individuals, objects, and processes interact without regard to their location' (Durlach & Mavor, 1995, pp.6-7). Today, these observations/predictions on network-based applications have in some considerable measure come to pass (as epitomized by the online 3D/immersive system 'Second Life'): 'Our scientific partners and collaborators will virtually join us in our immersive worlds while located at inter-networked, geographically disperse sites' [Rhyne (2000) in IEEE Computer Graphics & Applications Jan/Feb 2000, p.20].

Concerns over the fidelity of visual experience and that of the other senses in virtual environments is of significant concern for those seeking to further develop the capacity to generate a sense of presence through virtual reality technology and systems (Gutiérrez *et al*, 2008). In these instances, the extent of fidelity of the illusion of 'being there' is critical and generally involves multiple sensory stimulation to enhance the illusion of virtual reality or presence: 'The illusion of presence is a form of tele-presence, the experience of presence in a mediated environment, as opposed to the experience of presence in an immediate physical environment' (Jones, 2003, p.472). Here again can be seen the complexity of virtual reality media and new media in general, with its capacity for concurrent intensive exposure to both high definition data and high level interaction through the immersive experience of tele-presence, exemplifying McLuhan's hot and cool media parameters in a unique form of duality.

2.3.2 Virtual reality: definitions

The history of contemporary Virtual Reality technology dates to the early 1960's with the publishing of Ivan Sutherland's paper 'The Ultimate Display' in 1965 (Sutherland, 1965) and his subsequent research and development activities through the early 1970's at Harvard University and the University of Utah. The actual term 'virtual reality' first appears in 1986 and is attributed to Jaron Lanier, early virtual reality entrepreneur (Gutiérrez *et al*, 2008; Heim, 1998). Subsequent research and development produced working models of the various elements required to construct usable virtual reality visual display systems (Rheingold, 1991; Sherman & Judkins, 1993) with commercial products entering the marketplace by the early 1990's. By year 2000, virtual reality systems were available globally and in use in virtually all areas of industrial design, computer gaming/entertainment, defence strategy development and training, real-time military battlespace planning and management, medical research and training, nuclear research, and a growing array of real-time control systems and robotics (Gutiérrez *et al*, 2008).

There would appear to be almost as many definitions of virtual reality as there are interested users of the technology and its associated systems, each user in turn bringing his or her own perceptions, interests and ownerships, to bear on their particular use and application of virtual worlds and virtual reality. These vary from the simplistic and pragmatic to the highly sophisticated and abstract. The following examples reflect the insights and expectations of various researchers and users.

Pimental and Teixeira (1995) focus on and emphasize the role of illusion and virtuality in the use of virtual reality systems, whilst reflecting on the potential for using such tools to introduce new ideas in ways that challenge both traditional and contemporary methods of thinking. Their construct of 'getting inside information' is of particular relevance to the future application of virtual reality systems and new media in decision making and has been a common view held by many researchers: 'Virtual reality is all about illusion... experiencing some event that doesn't physically exist in front of you… a new media for getting your hands on information, getting inside information, and representing ideas in ways not previously possible' (Pimental & Teixeira, 1995, p.7).

Sherman and Judkins' (1993) viewpoint provides a shift in position away from the use of illusion, focussing as it does on establishing the use of virtual reality as a means for representing 'real-world' practical issues and by default, real-world opportunities through utilising the incipient power of computing technology. Implicit in this view is the proposition that advanced visualization systems can provide a means of accessing and realizing information embedded in real-world computable data, grounding the use of virtual style tools in the realities and demands of the real world: 'Although it sounds like the subject of some sort of medieval disputation or a metaphysical concept, VR is very practical. It transforms the computer from its traditional role as a processor of data (numbers and words) into a machine which generates a different, visual reality. And reality is the crux of this technique' (Barrie Sherman & Phil Judkins, technology observers/critics, London, attributed in Sherman & Judkins, 1993, p.24).

Heim (1998) again shifts the emphasis, this time to reflect on characteristics of virtual reality and what they offer the user, with a particular focus on positioning the user within the virtual world, able to engage with and experience a range of interaction opportunities with data and the processing of information far beyond the normal limitations of human physical capabilities in the real world. His use of the construct of 'information intensity' provides a particularly insightful perspective into the possible future direction of applications. Heim envisages the use of virtual world entities to explore, interact with and make practical (real-world) use of the growing quanta of available computable data and information: 'Virtual reality… defining characteristics boil down to the 'three I's' of VR: immersion, interactivity, and information intensity' (Michael Heim, Art Center College of Design, Pasadena, in Heim, 1998, p.67).

Shields' (2003) definition also focuses on the immersive capabilities of virtual reality and its capability to enable users to experience a sense of presence and engagement in an interactive role within a computer generated virtual world. His 'dramatis personae' reflects the range of possible interactions and communications techniques possible within such synthetic world environments, whether with automated software agents or (in the language of sociology) representations of real-world human actors: 'Virtual environments (VEs) are digital stage sets and the available dramatis personae, whether they be cartooned avatars, stylised bodies, Jurassic Park-style animations or talking flowerpots, (are the players) in VR' (Rob Shields, Carleton University, in Shields, 2003, p.54).

McCloy and Stone's (2001) definition emphasises the role of user interaction with data-sets and virtual objects within a virtual world, but also adds the critical characteristics of interaction in real-time and in a manner that engages the user's real-world physical and cognitive senses and capabilities. Virtual reality technology should enable users to engage with and 'interact efficiently with 3D computerised databases in real time using their natural senses and skills… The key strength of virtual reality, be it in design or training, is that it supports and enhances real time interaction on the part of the user' (Rory McCloy, Manchester Royal Infirmary, and Robert Stone, visiting Professor of Virtual Reality in Surgery, University of Manchester, in McCloy & Stone, 2001, p.912).

Friedhoff and Peercy (2000) in their study of Visual Computing provide a range of further insights and bring additional meaning into the consideration of what is meant by inducing and using sophisticated visual experience, or virtual reality, through the use of advanced computing and visualization technologies. Their viewpoint extends the potential role and function of virtual reality, whilst placing significant demands on the performance and actualisation of such technologies and associated systems. They note the dichotomy of increasing processing power and speed of advanced computing systems and the limitations inherent in human – computer interface mechanisms: 'high-speed processors can perform trillions of calculations per second. Human beings cannot, however, process the output of such computations directly. The computations must be first converted… More and more scientists are finding that the best way to do this is to convert data into shapes, colours, and textures, which are rich stimuli' (Friedhoff & Peercy, 2000, p.112-113).

Friedhoff and Peercy's position is further supported by Gutiérrez *et al* (2008): 'The main goal of VR is to create in the user the illusion of being in an environment that can be perceived as a believable place with enough interactivity to perform specific tasks in an efficient and comfortable way' (Gutiérrez, *et al*, 2008, p.2). More importantly, Friedhoff and Peercy (2000) and Gutiérrez, *et al* (2008) have captured the essence of the core issue in virtual reality systems and applications, namely, the complexity and potential of the human - computer interface to enable realisable immersion and presence in virtual environments. Virtual reality technology is perceived as a component in a complex system of integrated processes, human and technology related, that must work together to form an effective interface. The expectation is that such an interface could provide the user with access to computable information in a manner previously unachievable. The potential for using new media/virtual reality systems to help develop new ways of expressing and communicating complex and abstract ideas has attracted the attention of contemporary educators, strategic thinkers, and cognitive scientists alike (Boellstorff, 2008).

Among the many issues arising from the interaction-related characteristics, so strongly identified in the foregoing example definitions, is that of concern about human factors and the need to place the health and safety of human users as a priority in the design of effective virtual reality systems (Woolgar, 2002). This has already been recognised with industry representatives acknowledging the need for further research in Human Factors and compliance with established policy and practice, as represented for example by the International Standards Organization in its promulgation of the ISO standard ISO13407 'Human Centred Design for Interactive Systems' (McCloy & Stone, 2001).

The positioning of virtual reality systems and technologies as providing the necessary technical conditions and technological capabilities to affect realistic illusion, to act as 'Phenomenal Media', can be seen in the following summary listing of phenomenal media characteristics as derived from the work of Pimental & Teixeira: Iconic processing; Visualization; Tactile translation; Physical Experience; Auditory stimulation; Immersion; Engagement (Pimental & Teixeira, 1993, 1995). The appellation of 'Phenomenal' media can be interpreted as: 'Known or perceived by the senses rather than the mind. Relating to: A thing as it appears and is interpreted in perception and reflection, as distinguished from its real nature as a thing in itself' (Attributed to Kant, in the Collins English Dictionary 4th Ed., 1998, p.1163). Add to these the capability for interactivity, particularly through engagement of the haptic sensory perceptions, that is tactile and force feedback perceptions (tactile feedback represents the forces acting on the skin, while force feedback represents the forces acting on the muscles, joints and tendons) and VR may clearly be categorized as phenomenal media (Pimentel & Teixeira, 1995). An example of the application of such phenomenal media characteristics can be seen in the continuing medical and human factors research over the past 10 years that has investigated the use of virtual reality systems and haptic technologies in the development of full kinaesthetic prostheses and haptic devices which generate auditory, visual and tactile feedback (Cao & Rogers, 2004; Cavusoglu *et al*, 2002; Rizun, 2005).

Although much of the early development work on virtual reality was in NASA-funded research laboratories, the advent of powerful super-computers, high-end workstations and low-cost fast microcomputers with multi Giga-bytes of memory and Tera-byte data storage capacity has now made this advanced simulation technology, or at least the results of its application, more widely available. Jaron Lanier, the founder of VPL Research and an early advocate of virtual reality systems perceived something of the potential for virtual reality systems beyond the highly complex engineering and science oriented environment of NASA, and later computer gaming environments. He saw virtual reality as being a technique for creating simulated experience in a range of environments (Stair & Reynolds, 2006). In elaborating on this, Ken Pimental and Kevin Teixeira, early researchers at Intel, endeavoured to connect this work to the role of virtual reality in education and the potential power of virtual reality in communicating ideas and developing new ways to think about and analyse data and information (Pimental & Teixeira, 1995).

The key industry organizations engaged in the evolution of and continuing developments in virtual reality systems have been from the high-end computer manufacturers, systems and software development companies, specialised electronics and microelectronics product development companies, robotics manufacturers, and significantly the defence industries. Virtual reality systems and software are close to, if not at the top of, the list of technologies that require more computer processing power, more complex, larger and higher resolution display systems, and access to more telecommunication bandwidth (Stair & Reynolds, 2006). As such, the sustained growth and development of both hardware and software for virtual reality systems typifies the continuing digital convergence between multiple technology and application sectors, with significant ramifications for the strategic positioning of companies and organizations capable of implementing virtual reality products and systems (Silverthorne, 2006; Yoffie, 1997). Similarly, given the strongly embedded relationship between contemporary new media and visualisation systems, the use of 'image' as both representation of influencing factors and as an analysis tool to aid in the extraction and representation of 'meaning' through complex multi-dimensional visual communication will in turn require a community of practice skilled in the use of such language and grammar (Kolstup, 2003).

This research will contribute specific insights into how engineering and technology-based organizations can prepare themselves to undertake the introduction of such innovative and potentially disruptive technology as a management tool. In doing so, each of the above perspectives on virtual reality is deemed relevant, yet none totally convincing, compelling, or complete. However, each in turn informs and helps to identify the theoretical and applied context for the application of virtual reality in organizational management. Given the broad range of applications and situations that virtual reality systems have been used in, it is difficult to find a single statement that adequately or satisfactorily meets all conditions. For the purposes of this research, the foregoing definitions, particularly those of Heim (1998) Freidhoff & Peercy (2000) and McCloy & Stone (2001) collectively provide a range of insights into the use of immersive imaging techniques and interaction with data and information sources, that provide a starting point for considering virtual reality in management applications.

2.3.3 Simulation Systems, Design & Virtual Reality

The development and application of sophisticated simulation systems and related visualization technologies in support of design experimentation, testing and validation has been particularly evident in the areas of defence, and the aerospace and automotive industries, emphasizing their potential role as strategic technologies. Design applications have been a significant virtual reality activity right from the earliest introduction of commercial virtual reality systems. The automotive and aerospace industries have been significant users of visualization and virtual reality systems for the past 20 years, in a wide range of design stages using imaging of both internal and external appearances of new products. Progressively these approaches have led to more integrated applications, where design engineers could test ideas for technical systems, physical layout, production planning, technical training and running complex simulations of engineering entities, such as suspension systems, engines, braking systems, structural assemblies, and air-flow analyses (Gutiérrez *et al*, 2008; Vince, 2004).

In recent years entire design projects have been implemented utilising integrated advanced simulation and visualization systems, for example: Airbus and a wide range of automotive vehicles. These fully integrated virtual reality projects have involved extensive 3-D photo-realism visualization, using CAVE technology, headset technology, desktop workstations and/or large screen Reality Centre installations, integrated with haptic point and touch technologies (Gutiérrez *et al*, 2008; Silicon Graphics Inc, 2004; Vince, 2004). Automotive, aerospace, oil and gas exploration, and electronics manufacturing companies now use and rely on high performance computing and visualization technologies to enable integrated design and production (Silicon Graphics Inc, 2004). The use of simulation tools and systems provides engineers and engineering managers with the means of experimenting with alternative scenarios, within prescribed or experimentally developed models of behaviour. This is particularly relevant when endeavouring to determine issues affecting risk assessment. Whilst there are several approaches to analysing risk, Ragsdale (2007) identifies three in particular as the most common: '...best-case/worst-case analysis, what-if analysis, and simulation. Of these methods, simulation is the most powerful' (Ragsdale, 2007, p.560).

Given the construction and implementation of products derived from complex simulations and subsequent improvements in modelling and simulation technologies, designers and engineering managers are now able to take simulation practices further into for example non-destructive testing using simulation and visualization for associated risk and reliability studies (Robinson, 2002). Essentially, the difference and advantage of simulation approaches is the potential to develop and observe the distribution and characteristics of performance measures derived from multiple results taken over a range of conditions. Given the increasing complexity of engineering and technology-based environments and emerging new technologies, simulation systems can provide powerful tool-sets for insight into potential or virtual problem areas, long before they are apparent in the real world (Blanchard & Fabrycky, 2006). The case for developing effective simulation systems and their use in business environments in particular, is made by Lofts (2002) by reference to the practical difficulty of experiencing business processes before they have actually been introduced. Whereas, in simulation we get the opportunity to test and validate whether a given design or set of criteria will work or influence functionality as expected: 'The primary use of simulation in systems engineering is to explore the effects of alternative system characteristics on system performance without actually producing and testing each candidate system' (Blanchard & Fabrycky, 2006, p.168). Bringing the combined computational power of contemporary computer processing and visualization systems together in the role of design, simulation, testing and validation, and planning, constitutes a smart approach to solving potentially complex problems before they occur. See Figure 17.

However, the very nature of sophisticated contemporary information technology raises its own complexities and challenges when faced with the need to collect, collate, and analyse extensive quanta of data. Armitage (2003) characterises twenty first century business and industry data as: 'new, it's big, it's multi-media, and it's often real-time. Successfully ingesting, processing and archiving terabytes of streaming data per day requires a low-latency high bandwidth approach… Bringing real-time visual modelling and simulation to…wherever the team members may be located, is the ultimate competitive weapon for driving innovation and discovery' (Armitage, 2003, www.siaa.asn.au/simtect/2003/simprog.html). The Defence sector has been particularly active in the evolution and continuing development of virtual reality systems and technologies. Its prime applications have been in the areas of specialised training, planning, equipment design, logistics modelling, and developing real-time battlespace visualization strategies. Again, this raises significant complexities (Defence Modelling & Simulation Office (US), 2002; Defence Science and Technology Organization (Aust.), 2002; Stair & Reynolds, 2006).

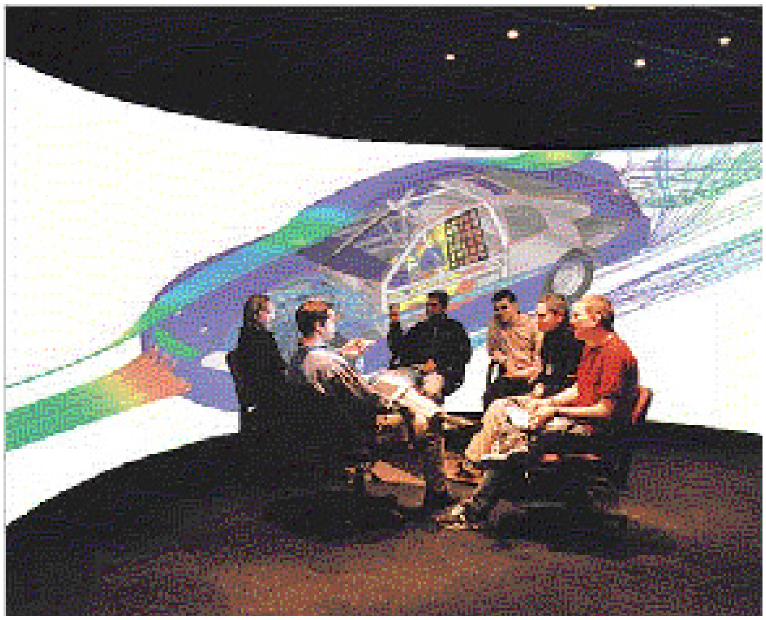


Figure 17. Small Group Meeting in Virtual reality Centre, showing Simulation of 'Airflow' Profiles on Screen. (Courtesy SGI: www.sgi.com/features/2003/apr/onyx350/ , 2004)

A wide range of simulation projects involving virtual reality systems and technologies are currently underway within defence circles. In the defence environment, simulation systems have for many years played a significant role in the areas of skills training, improving planning and logistics support, and equipment design and testing (see Figure 18). Training Defence staff has been a significant application for virtual reality systems. Whilst staff from a wide range of duties may be involved at various times, it is in the high risk high resource areas that virtual reality has been found to be both cost effective and viable. For example, virtual reality simulations have been utilized in military weapons development and training environments where the use of virtual weapons '…allow users to be immersed in a simulated battlefield using hardware that is still in the concept development stage' (Vince, 2004, p.124). In such instances the use of virtual reality goes well beyond the role of an effective product development and training mechanism to being an effective 'risk' mitigation strategy and Defence systems planning tool.

Aerospace design for defence is a high risk high resource area with multiple mission critical components and functions embodied in the design. This is so not only for actual design for systems performance in the field, but also design for ready maintenance. Developing and testing maintainability as well as training defence maintenance engineers has for some years been seen as a viable use of virtual reality systems: 'In the new Boeing virtual reality lab in Seattle, Joint Strike Fighter designers and maintainers can don a head-mounted display and gloves to physically immerse themselves in a virtual environment and simulate a maintenance task' (Attributed to Boeing in Silicon Graphics Inc, 2002, www.sgi.com/industries/manufacturing/aerospace/index.html)

Figure 18. Defence Pilot Training Module with Projection Environment
(Courtesy SGI: www.sgi.com/realitycenter/gov_solutions.html , 2004)

The aerospace and aviation industry as a whole has made extensive use of and has been actively involved in the application of simulation systems in aircraft design and in the planning stages for aircraft maintenance and servicing as well as in pilot training and concept testing (Turban *et al*, 2008). See Figures 18, 19 and 20.

Figure 19. Boeing Concept Presentation
(Courtesy: Boeing and SGI www.sgi.com/ , 2004)

Figure 20. Wall Display System in use during Boeing C130 Modernization Program at Long Beach, California
Courtesy: Boeing & Panoram Technologies: (www.panoramtech.com/resource/pr_images , 2003)

Figure 20 illustrates the use of a large-scale rear-projection flat-wall display system in a large-group or auditorium type environment. The control desk in the foreground illustrates how in fact the large projected image is constructed from three separate channels of data, merged in the display system and overlaid with menu items. Figure 21 illustrates the use of nine overhead mounted projectors to achieve a full 360^0 out-of-the-window-view of the airport traffic control tower environment at Roissy, Aeroport de Paris France, using a circular screen of 10 metres diameter and height of 2.56 metres. Here, the trainees/users are surrounded by the virtual world created in the simulation, but a virtual world that as accurately as possible visually reflects the real world of their would-be normal operating environment (Boeing & Panoram Technologies, 2003).

In developing new rapid planning and logistics management strategies, the US Defence Forces have made particular use of virtual reality systems with large-scale high-resolution 3-D displays. These systems now also form a substantial component in what has become known as battlespace management platforms. These systems use information rich visualizations as a means to provide military commanders with: 'a three-dimensional graphically rich battlespace, with clear discernable friendly air defence assets and enemy ballistic missiles, land attack weapons, and air fighters (the) technology displays objects in the theatre as they really are' (Attributed to US Navy sources in Silicon Graphics Inc www.sgi.com/newsroom/img_library/, 2002). Figure 22 illustrates an early form of such a system.

Figure 21. 360^0 Air Traffic Control Tower Simulation, Roissy, France

(Courtesy: BARCO: www.barco.com/VirtualReality/en/references/references.asp?ref=2361 , 2005)

Figure 22. The Area Air Defense Commander System with Wall Display

(Courtesy US Navy & SGI: www.sgi.com/newsroom/img_library/ , 2002)

2.3.4 Virtual Worlds

The concept of virtual world and virtual world building has a history as long as the recording of human endeavour. Recorded history itself constitutes a form of virtual world building, with the historian or storyteller describing the conditions prevailing at the time of certain events, very often in vivid terms. Indeed the power of an expert storyteller to take the listener or reader, beyond their physical presence and into another imaginary world, has been long acknowledged (Pimentel & Teixeira, 1993). The use of argument and discourse involving the use of virtual situations and events and the interplay between the virtual and the real has had a turbulent history. With regard to the use of contemporary virtual reality systems there has been concern over the validity of using virtual environments to address real world issues and the potential risks associated with extending such use beyond acceptable boundaries: 'The long-term problem with VR might not be the question of "what can we do with it?" but rather that we can do too much with it and become seduced by the engaging dynamics of interactive reality. It's important to never forget that these are computer-generated models' (Pimentel & Teixeira, 1993, p.193).

There are multiple issues here, including the potential for the abuse of virtual world building, in particular through the manipulation of imagery. For example, some historical perspectives: During the period of the rise of Nazism in Germany, particularly through the 1930's and early 1940's, the Nazi regime developed/encouraged the evolution of particular art forms that developed the imagery of the pure Arian form and the strength and power associated (supposedly) with Nazi ideals. Similarly the Russian Communist Party from the 1920's (certainly from 1928 onwards) developed the propaganda models of art that showed a peasantry replete with tools of trade and eyes shining and looking to the future, 'Building a Nation' (Hinz, 1979; Steinweis, 1993). In the fullness of time it has now become clear that such imagery was essentially false, based on false pretexts, unstable ideologies, false expectations, and unverifiable facts. The virtual world developed through the imagery was itself deliberately grossly misleading, a particular form of deliberate disinformation: 'The painting of German fascism no longer reflected reality but presented it in such a way that it paralysed consciousness' (Hinz, 1979, p.75).

The deliberate use of factual material and/or a known or recognizable context, combined with explicitly false information to create a false impression or unachievable expectation, has long been perceived as unethical, or propaganda when used in political environments. Grau (2003) describes visual propaganda as occurring through the use of idealistic aberration or conscious falsification. He further describes this transition from the real, through the virtual, to a deliberately biased message content as following the schematic of: 'Authenticity + illusionistic effect + idealized composition = propaganda' (Grau, 2003, p.98). Contemporary advertising, particularly that using sophisticated digital imaging technology, similarly may also be seen to use falsified imagery to present a distorted view of the world. Distorted that is, to give a bias towards the product being marketed (Lester, 2006). Clearly this raises multiple issues of concern many of which interplay with particularised forms of new media as well as virtual reality applications: 'There is an 'ethics of trading' that prohibits the use of false or deceptive claims and tricks... Virtually all aspects of marketing – from the development of new products to pricing, promotion, and sales – raise ethical questions that do not always have an easy answer..' (Boatright, 2003, p.5; p.275; p.284). Roberts and Webber (1999) along with many other concerned scholars have addressed the issue of ethical practices in imaging and visualization. Their proposal for a protocol for digital imaging ethics succinctly outlines the issues of concern: 'The ease of image manipulation in the digital age requires the establishment of an ethical protocol for the guidance of practitioners and consumers... Modern computerised photographic techniques allow, as well, the quick synthesis of artificial images which are not based on reality' (Roberts & Webber, 1999, p.2).

There are different forms of ‘virtual world’ modelling. In the case of designing new products, for example automotive vehicles, and their testing in virtual world environments, the simulation of conditions as in the real world is of paramount importance. This entails not only the appearance but the behaviours of objects within the virtual world and in turn the influence of the virtual world on the objects. It is expected that this should replicate as closely as possible the effects of such influences and behaviours as in the real world. To a large extent, such virtual world configurations are tightly predicated on a detailed knowledge and experience of the relevant influences, actual conditions and detailed measurement parameters of such influences as existing in the real world.

Alternatively, there is another form of virtual world building where correlation with the real world is not in the appearance or apparent physical behaviours of objects, but rather is embedded in the logical response of models to influences introduced and impacting on them from the surrounding (virtual) world (Lofts, 2002; Vince, 2004). This could be illustrated as an interactive visualization for a theoretical ‘supply chain’ in an ‘economic’ virtual world where conditions of supply and demand, cost and availability of resources, time, contractual agreements, Quality parameters for acceptance of supply, local and international regulatory Statutes and formal Trade Agreements, and economic models are key variables. In complex manufacturing organizations it is not uncommon for such supply chains to involve large numbers of suppliers covering a wide range of products and components sourced from a global marketplace. In such complex contexts, the configuration and management of supply chain issues is of critical importance.

2.4 Managing Engineering & Technology-based Organizations

2.4.1 The Technology-based Organization

Engineering and technology-based enterprises/organizations take many different forms. They may be large or small, develop products and/or deliver technical services, be structured differently, populated by people with widely differing skills and expertise, serve widely differing purposes, produce different products, services and outcomes, have different life expectancies, different levels of efficiency and effectiveness, indeed may differ in as many ways as it is possible to think of different combinations of people and purposes for association. However, generally engineering and technology-based organizations are characterised by a strong focus or reliance on either the development or essential use of technology in their production processes or other services related activities (Thamhain, 1992). Katzy (2006) in turn designates technology-based organizations as being focussed on performance enhancement through the effective utilisation of technologically based resources: 'Technological firms are about technology – the trend towards resources that make the difference' (Katzy, 2006, p.28). In the context of engineering and technology focussed organizations, Katzy's inference here is that such organizations are directly and inextricably linked to the deployment of significant technological resources relative to their primary organizational role, function and activities. This can be demonstrated for a civil engineering consultancy as follows: role – commercial engineering works consulting and advisory services; function – engineering design of significant bridge, dam and road-works to a high level of exactitude and compliance with industry and government technical planning and approvals processes; activities – extensive use of survey technology, earth and rock core sample technologies, and computing resources for access to information sources such as geodetic data-bases, computational tasks, and computer aided draughting and graphics (as used in all of the above).

Theorists focussed on the organization and coordination of work and the manner in which it is assembled into an effectively functioning organization have been many and varied, with widely conflicting views, particularly so in western thought throughout the twentieth century. Taylor's 'Principles of Scientific Management' (Taylor, 1911) with its empirical focus on organizing and managing work, largely set the scene for much of the subsequent studies and research on the efficient organization of work. The construct of 'foreman' or today's 'production manager' is a direct outcome of Taylor's initial work focussed on improving organizational and work efficiency in the first two decades of the twentieth Century (Wren, 1994). Subsequent researchers [Fayol (1916), Davis (1928, 1951) Weber (1947)] further developed our understandings of the classical theorist formal theoretical perspectives on the construct of organization, laying down organizational principles or the functions that a manager should perform, the formalised construct of bureaucracy built on the metaphor of organization as a machine, and the rational-planning perspective (Morgan, 2006; Tosi, 2009; Wren, 1994). Whilst classical management theory and the metaphor of organization as machine continues to be acted out in many engineering and technology based organizations, the 1930's through 1960's saw many significant changes incorporating the role of humanistic themes and human relations in the management of formalised organizations (Nankervis *et al*, 2005, 2008, 2011).

The evolution of engineering and technology management can be seen as a continuing integration of the profession of engineering with the various schools of thought in the 'art and science of management' (Babcock and Morse, 2002, p.xii). Babock's view was that the impact of Taylorism in the early decades of the twentieth century produced an inevitable and formal intertwining of the two previously separate professions, each with its own history and purpose although in reality each strongly aligned with the other. The highly structured quantitative approaches of Taylor and earlier researchers into the world of work organization and management certainly identified opportunities for major improvements in the arrangement and organization of work and the use of technology. However, their research also raised many questions that were not easily addressed nor understood: 'Here were three engineers – Taylor, Gantt, and Gilbreth – struggling to realize the wider implications of their technique, in travail with a 'mental revolution', their great danger that they might not appreciate the difference between applying scientific thinking to material things and to human beings' (Urwick, 1952, cited in Babcock & Morse, 2002, p.33). Taylor's principles of scientific management (1911) may have laid the foundation for subsequent development in engineering management over the past 100 years, but his original mechanistic view of 'work' and the management of work has seen serious challenge and change, especially over the past 40 years. However, the interface between the engineering and technology base that underpins production and the management of the productive enterprise is, in today's highly technologically literate world, now more integrated than ever before.

Tschirky (2004) provides a succinct but insightful statement of how engineering and technology management sits with regard to general notions of management and the role of 'engineering' expertise and knowledge. His fundamental position is that the technological base and specialist engineering and technology expertise of an organization should reflect its strategic intentions and that the investments apparent in the technological capabilities of the organization should expressly support the realization of such (Tschirky, 2004, in Probert *et al*, 2004, p.13).

Figure 23 provides a simple illustration that reflects something of Babcock and Morse and Tschirky's arguments. However, it should be noted that what appears to be a simple overlapping of mutual interests in the context of engineering and technology management is an extremely complex relationship. It requires an holistic perspective in order to appreciate its inherent complexity and the potential benefits that can be derived from strategically positioning and effectively deploying technological capability in an organization (Babcock & Morse, 2002; Betz, 2003; Tidd & Bessant, 2009; Tschirsky, 2004).

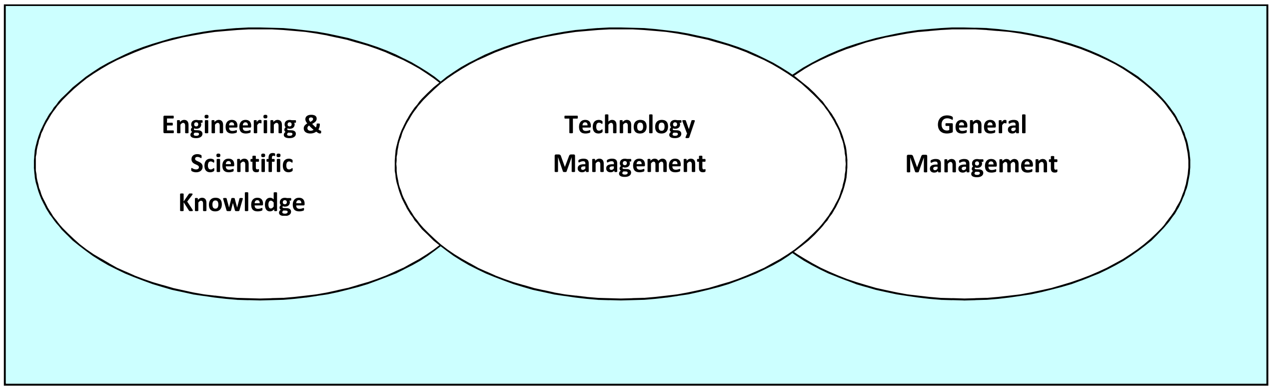


Figure 23. Technology Management as Linkage

(Derived from Tschirky (2004) in Probert *et al*, 2004, and Babcock & Morse, 2002)

The American Society of Mechanical Engineers (ASME) in their 'Guide to the Engineering Management Body of Knowledge' have endeavoured to address this complexity through identifying eight key 'domains of knowledge' which in turn incorporate some 46 knowledge areas and a further 210 sub-knowledge areas (ASME, 2010). The many potential linkages between the three seemingly discreet areas illustrated in Figure 23 can be appreciated by considering the implications of the eight ASME key domains of knowledge in their 'Engineering Management Body of Knowledge' as summarised below. An appraisal of these many areas of interest quickly identifies that most can be identified as being of equal importance to both professional areas of engagement, whether general management focussed or engineering and technology based:

- *Market Research, Assessment and Forecasting:* Strongly focussed on analysis of market information and environmental scanning to address: benchmarking, business forecasting, risk analysis, trend analysis and technology assessment;
- *Strategic Planning and Change Management:* Focussed on methods for planning and implementing new technologies, involving tools and techniques in systems design, comparative analysis, strategic management models and change management techniques;
- *Product, Service and Process Development:* Addresses interpretation of research findings and manufacturability of proposed new products, product feasibility analyses, assembly and disassembly procedures, Quality Management processes, and life-cycle engineering;
- *Engineering Projects and Process Management:* Determining resource requirements, financial projections, budget and performance monitoring, project management techniques, scheduling practices, and assessment of legal liabilities;
- *Financial Resource Management:* Addresses procurement and contract processes, project funding and proposals, economic analysis techniques, inventory control and supply chain management;
- *Marketing, Sales and Communications Management:* Focussed on marketing and branding practices local and global, customer satisfaction and competition;
- *Leadership and Organizational Management:* Addresses management style and organizational structures, management systems, internal and external business environments, human resource management issues;
- *Professional Responsibility, Ethics and Legal Issues:* Addresses regulatory requirements, codes and practices, intellectual property protection, and the application of a professional code of ethics.

(Derived from: ASME, 2010, pp.13-16).

The notion of having a defined structure that characterises a given organization and its approach to engaging in its intended business raises many questions and issues, some of which are resolved through the choice of structure, some of which remain and in effect challenge the choice of structure. In particular, hierarchical authority and control mechanisms, levels of accountability and responsibility, leadership, reporting relationships and interaction mechanics between organizational elements, strongly influence and in turn are influenced by choice of organizational structure (Robbins & Barnwell, 2006; Robbins & Judge, 2010). Mintzberg (1983) for example, argued strongly for an organizational framework of five basic elements: the operating core; the strategic apex; the middle line; the technostructure; and the support staff. Within this formalism, any one element may dominate the organization for a time, possibly consistently, with control passing from one sector to another under differing conditions or situations (Robbins & Barnwell, 2006). Robbins & Barnwell (2006) consider organizational structures to be characterised by three particular formalisms: Complexity; Formalisation; Centralisation. Whilst Tosi (1990) develops the theme that there are three core internal cultural elements to the notion of organization and thus the determinants for constructing models of organizational behaviour: Individual members of the organization; Groups of individuals clustered according to the structure of the organization; The organization itself, positioned within its specific societal / economic / technological environment.

In general, the structuring of an organization in turn invokes the creation of groups of people who now work together for a particular purpose, or to achieve a particular organizationally set goal, or to produce defined outputs, according to their place in the organizational structure. This is typically evidenced in engineering and technology based organizations in the design and planning of technological production systems where highly specific tasks, typically involving classical work specialization, are designed and are required to be sequenced in highly structured ways (Robbins & Judge, 2010; Tosi, 2009). To these can be added an array of additional parameters that influence behaviours within the organization and affect its apparent organizational behaviour, including: leadership mechanisms and style; locus of power; mechanisms for influence and accountability; group size; group cohesiveness; goal setting; task characterisation (Katzy, 2006; Robbins & Judge, 2010; Worchel *et al*, 1991). Or, as Drucker so succinctly stated: 'a given organization structure fits certain tasks in certain conditions and at certain times' (Drucker, 1999, p.11).

Further external elements that can also affect an organization's behaviours and that of its constituent parts, its people/personnel, include: the locus of the organization within an external supply chain involving customers and suppliers; its competitors; the organization's legal and regulatory environment; and both its surrounding and internal economic environment (Child, 2005; Robbins & Barnwell, 2002, 2006). In turn, the very presence of technology in an organization (an endemic characteristic of engineering and technology based organizations) directly or indirectly impacts on the choice of internal organizational structures, processes and performance characteristics of the organization, and indeed further influences the 'way-of-life' or perceived 'organizational culture' in vogue within the organization (Winner, 2004). The development of organizational planning strategies and the setting of organisational structure to achieve organizationally set goals and objectives has in turn been the subject of formalised theory and debate among organizational theorists for an extended period of time and continues to attract argument and rigorous debate. Overall, theoretical perspectives on a wide range of perspectives on organizations varied widely throughout the twentieth century and indeed continue to be the source of debate and discourse.

The management of engineering, and specifically technology based organizations, evolved as a set of practices focussed on extracting the optimal benefit from technological resources during the industrial revolution in England, Europe and North America in the early-mid 1700s. It also foreshadowed the continuing displacement of the human workforce in favour of machines and greater productivity, with subsequent disruption to social structures and the devaluing of traditional craftsman skills and expertise: 'factory owners and their engineers realized that the efficient operation of their new machines ultimately required major changes in the design and control of work' (Morgan, 1997, p.21). In contemporary enterprises we see the continuing emergence of new technologies as requiring concomitant shifts and changes in the skills, expertise and roles of the workforce, with fewer numbers of low-skilled workers, growing numbers of higher-skilled employees and shifting emphases on relationships between employees and an organization's technology base (Nankervis *et al*, 2011). Increasingly employees are expected, indeed required, to have advanced levels of skills in the day-to-day use of information technology and related software and computing applications and communications systems (Nankervis *et al*, 2008). Indeed, the technology worker, let alone the engineering and technology manager, must now reflect the tenet that 'the emergence of knowledge as the economy's key resource' (Drucker, 1999, p.xi) is already strongly in position an a key criterion for building competitive advantage through an effective, productive and knowledgeable workforce of the twenty first century (Härtel & Fujimoto, 2010).

The foundations of modern engineering management and technology management were first laid down in the 1930's and 1940's and built on through the 1950's, 1960's, 1970's. By the early 1980's, researchers investigating the behaviour of industrial management systems were also identifying the impact on organizations of increasing frequency in technological innovations and a growing imperative for effective technology management at the level of the individual enterprise (Alford, 1940; Alford & Beatty, 1951; Antill & Farmer, 1991; Babcock, 1991). Betz (1993, 2001) develops much of his argument for strategically positioning and explicitly managing technology on the premise that there can be no clear permanent technology advantage for any firm. Rather, he considers that there can at best only be temporary lead times, which makes managing strategic technologies a necessity for long-term survival. The complexities inherent in the management of technology and technology-based environments is further summarised by Gaynor (1996) and involves the engagement of all and across the whole of an organization. It involves: '…taking a systems approach. It requires including more than the activities of scientists and engineers. MOT (Management of Technology) involves the complete organization' (Gaynor, 1996, p.1.31).

Thamhain (1992, 2005) provides an insightful summary of the need to explicitly address the management of engineering and technology-oriented environments: 'To get results, R&D and engineering managers must… understand the cultural and value system of the organization for which they work. The days of the managers who get by with only technical expertise or pure administrative skills are gone' (Thamhain, 1992, Preface p.v). In particular, over his years of research and subsequent writings he has identified strategies for linking contemporary engineering management practices with modern administrative techniques, determining appropriate organizational structures and processes, and building effective human resource management strategies and communication processes targeted at improving the performance of engineering and technology based organizations.

In introducing his concept of Strategic Technology Management in firms and organizations primarily involved in or oriented towards the development or use of engineering and technology systems, Betz asserts that the effective implementation of technology to achieve organizational objectives and enhance competitiveness is a seriously challenging task facing management: 'Although technology is widely recognised to be essential to competitiveness, it has been one of the most difficult activities with which management has to deal' (Betz, 1993, Preface p.xv). Betz's subsequent arguments provide an intertwining of the two key facets of method and process. Just as it is essential to have established procedures and recognised management practices in place and working within the technology-based organization, so also Betz argues, it is essential to have in place a clearly defined and enunciated methodological approach to the application and use of technology within the organization. Clarity of organizational intent and technological purpose (as a means of achieving that intent) are seen as being essential requirements for effective technology management: 'Both general management principles and an understanding of the specific business to be managed were (are) both necessary for good management... For good management, the general principles of management must be adapted and refined to the special conditions of the process being managed (which here is technological change)' (Betz, 1993, Preface p.xvi).

The need for explicit management techniques relative to the need to manage technological environments, became increasingly apparent with the onset of rapid technological change post world war 2 and the evolution of modern electronics, computing systems, and the rapid expansion of the automotive, aviation and aerospace industries. 'Effective technology management and, more specifically, the effective management of the new technology and innovation process is now recognised as crucially important' (Martin, 1994, Preface p.vi). In particular this period saw the development of Operations Research and Management Science as empirically based quantitative disciplines focussed on the management of technological environments (Keys, 1991; Thamhain, 1992). Whilst highly successful in production and manufacturing environments, these strongly mechanistic methodologies fall short in the context of the complex 'organic' organization of the twenty first century (Morgan, 2006; Robbins & Judge, 2010).

Where earlier technology management strategies could have extended timelines to develop, test, introduce and maintain, today's engineering and technology manager may be dealing with significant technological change that comes in time frames of months or even weeks, indeed in the software industry sometimes a matter of days! Whilst production and manufacturing environments, telecommunications systems and networks, transport systems and urban utilities systems (electricity/gas/sewerage/water) still largely require efficient quantitative methods for effective management and control, there is a much wider range of technology application across all areas of industry and commerce that requires management that reflects: 'special technical skills and the ability to innovate and deal with complexities, risks, uncertainties, and integration… its functions stretch across the whole spectrum of management and all of its subsystems and social interfaces' (Thamhain, 2005, p.25). The critical nature of the 'social' interface, or role of management in the process of leading and directing the energies and competencies of the engineering and technology based organization (or any other organization for that matter) is effectively summed up by Drucker's alternative to Taylor's scientific management assumptions about people and work: 'One does not 'manage' people. The task is to lead people. And the goal is to make productive the specific strengths and knowledge of each individual' (Drucker, 1999, p23).

Thus, it is essential that the culturally aware enterprise take account of the determinants of its internal culture and the value and potentially critical role of its competitive advantage embodied in the organization's intellectual capital, as represented by and embodied in its participant members and communities of practice: *The business case must be defined in order to justify necessary investment strategies in the human and social (i.e., intellectual) capital of the firm* (Amidon, 2003, p.342). Identifying and harnessing organizational culture and the skills and capabilities that collectively make up an organization's intellectual capital, are essential components in meeting the challenge of achieving competitive advantage that can be sustained over any length of time: *The probability of developing a sustainable competitive advantage increases when firms use their own unique resources, capabilities, and core competencies to implement their strategies* (Hitt *et al*, 2005, p.72). Addressing such an array of issues and developing such a culture and focus in engineering and technology-oriented organizations, is very much a growing and significant challenge for contemporary engineering and technology management practitioners, particularly as they address the potential impacts of introducing disruptive technology and systems such as virtual reality, virtual worlds and new media as strategic tools and related competencies capable of leveraging strategic positioning of the enterprise.

In the specific context of this research program (the use of synthetic or virtual environments to enhance management decision making) it is essential that such 'rules of engagement' with the technology, are clearly defined and understood. Effective decision making requires facts not fallacy, thus, virtual environments and their contents must respond and behave in consistent fashion, and genuinely reflect the parameters that are being used to generate them. However, in the context of using virtual worlds to support decision-making, a virtual world may or may not provide a direct visual correspondence with the real world. Rather, it must provide representations of those parameters or characteristics that in the real world have or result in real and identifiable effects. The actual construction of the virtual world simulation may involve the use of shapes, colour, position, mobility, and other controllable or attributable characteristics. The core purpose being to enable visualization of information, conditions, status, variables, in such a way that managers can effectively perceive and extract meaning from data so represented (Chen, 2003).

2.4.2 Innovation and Technological Change Management

> *It is not an exaggeration to assert that the successful economic performance of an enterprise is now largely dependent on the quality of its technology and innovation management* (Probert *et al*, 2004, p.3)

Technological innovation and the introduction of new technologies, products and services, the associated management of technological change and the capacity to effectively mobilise knowledge and technological skills, is fundamental to sustaining competitiveness in technology oriented firms and organizations (Tidd *et al*, 2005). This is particularly so for technology based organizations in the current context of an emergent knowledge economy and organizations for whom new skills and technological expertise are the basis of their core corporate competencies and provide the potential to attain competitive advantage in the broader marketplace (Ahmed & Shepherd, 2010; Prahalad & Hamel, 1990; Tidd *et al*, 2005).

An issue often raised in relation to the introduction of new technologies is the perceived prevalence of a technology 'push' syndrome. In this mind-set, all things are viewed possible as long as we follow the technological leader and work co-operatively to push back the barriers to technological change and acceptance of new ways of doing things. An interesting alternative view and more pragmatic approach is the concept of Technology-Push-Market-Pull. This is discussed by Martin (1984) in the context of technological strategies for companies engaged in developing innovative new products and processes: 'A revolutionary innovation, such as radio and the computer, can be viewed as a technology-push-market-pull synergy because it seeks to satisfy an un-manifested but nevertheless latent user need. Often, as with radio and the computer, the innovations are both technologically and socially revolutionary' (Martin, 1984, p.57). Certainly, in today's world of continuous development and convergence of electronically based digital media there can occasionally be seen examples of break-through technology that breaks through previous barriers of feasibility.

One of the most significant virtual reality related projects ever to be undertaken is titled: 'DiFac: Digital Factory for Human-Oriented Production System'. In 2006 the European Commission undertook to fund new research into the application of virtual environments and related human factors issues in the development of collaborative manufacturing environments (CMEs) across multiple industry sectors in the European Union (EU). Initially funded for the three year period 2006-2009 (initial project development funding ~$5M) this major project is one of three such projects addressing the most significant industry level challenges facing the European Union over the next 10 years and has thus far involved organizations in the United Kingdom, France, Hungary, Spain, Romania, Sweden, Italy, Germany and Belgium (Constantinescu *et al*, 2007; Lawson, 2006; Pentenrieder *et al*, 2007; Sacco, 2006; DiFac, www.difac.net 2009). The Human Factors Research Group and Virtual Reality Applications Research Team at the University of Nottingham were directly involved in this major EU project.

In many cases the emphasis of such projects is no longer on the actual development and deployment of new virtual reality technologies themselves. Rather, we see a growing focus on the use of such technologies to help resolve complex problems or to provide a pathway to better understanding of the nature of identified problem areas, and, as in the above EU funded project, to extend or create opportunities for industry-wide collaboration as a major innovation and change strategy (Constantinescu *et al*, 2007; Lawson, 2006; Pentenrieder *et al*, 2007; Sacco, 2006).

In this regard we now see a potential ‘technology-pull’ (or conversely, user/application ‘push’) process in operation relative to the introduction and use of virtual reality, taking over from the earlier ‘technology-push’ syndrome that so often typifies the early days of a new technology introduction (Betz, 1993; Ettlie, 2000, 2006; Hagel *et al*, 2009). This in turn indicates the growing maturity of virtual reality as innovation, and a broadening understanding in the wider marketplace of its potential role and diffusion of applications. To some extent at least, virtual reality was an innovation or innovative concept that evolved almost four decades before it’s time. It is only now, in the 21st century, that the actual technology to widely implement such systems is likely to be readily available, affordable, technically understood and commercially viable.

Virtual reality systems would seem to be a particularly apt exemplar of Martin’s earlier construct of ‘revolutionary technological innovation’ (Martin, 1984, p.30). Martin’s subsequent interpretation of his concept is in turn quite radical in its wide-ranging scope and has particular relevance to the introduction of virtual reality as both a technological innovation in itself and as an innovative application of converging new technologies:

> *These may be based upon major inventions which create a new industry. They may also be associated with a creative symbiosis of previously unrelated technologies. They constitute revolutionary discontinuities in the technological evolution since they invoke new paradigmatic frameworks for technological puzzle-solving expressed in the dominant design or technological guidepost* (Martin, 1994, p.39).

Much has happened in the world of technology since Martin’s observations, and yet his insights into revolutionary discontinuities and their potential impact is highly relevant to the world of new media, virtual worlds and the potential use of virtual reality as a management tool. The state of hyper-competition (D’Aveni, 1994) in the ITC industry can be seen in the many competing products and softwares available. This is particularly so in relation to the array of new media products and systems continually entering the marketplace, with each new product introducing new features and capabilities each potentially extending the effects of disruption and change. Selecting and evaluating such products and their potential to meet organizational objectives and needs requires a rigorous and unbiased approach

2.4.3 Virtual Reality in Organizational Contexts

Collectively, there has been much speculation and enthusiasm about virtual reality technology and its future. This has stretched from: bizarre reflections on Gibson’s ‘Neuromancer’ (Gibson, 1986); its widespread use in the computer gaming industry to provide illusion of engagement in 3-dimensional virtual worlds; its application in the film and video industry for special effects generation; to the practical, and by comparison almost mundane, engagement as an effective design tool for everything from automobiles to spacecraft. However, little has been done to develop formal theoretical perspectives on the development of virtual world building technology and its potential use to provide clarity of insight into complex management problems, or of its place in formal business systems or decision-making environments (Turban *et al*, 2008). Whilst Thierhauf (1995) when Professor of Information Systems at Xavier University, certainly foresaw the potential for virtual realty systems in business contexts, most subsequent business applications have been focused on its role in design and demonstration, such as fly-through demonstrations in new architectural plans, or industrial design contexts such as building new oil-rigs, or developing new automotive and aerospace designs.

The use of visualization applications is wide spread in the engineering and related technology design fields, where complex technical models can be created from established knowledge and practical experience with the design elements and their behaviour under given conditions. The creation of a virtual world that can enable a design to be exposed to simulated conditions of the real world, in a virtual world simulation, has been a valued as a means of dealing with the complexities of testing and validating new engineering designs and the use of new materials and new technology. However, applying virtual world simulation and visualization to the operation and management of the enterprise itself has seen limited attention. Early attempts were focused largely on financial modelling and marketing simulations, whilst more recently, production planning engineers have utilised virtual reality tools to create virtual world simulations of manufacturing factory environments to enable the design and testing of new production platforms (European Commission, 2010). The success of these new approaches is largely contingent on the coherence and compliance of the virtual world simulation to the conditions applying or likely to apply in the real world environment (Manovich, 2001, p.112) just as traditional modelling and simulation techniques focussed on the mechanistic modelling of known and measurable parameters and observable conditions. However, by contrast with traditional simulation, virtual reality simulation systems and virtual environments may also be used for exploration of new ideas and concepts not necessarily with a direct or physical analogue in the real world (Pimental & Teixeira, 1995). In these conditions, correlation with the real world may at best be arbitrary or uncertain. Yet, it is in these areas of visualizing 'information' to facilitate the extraction of 'meaning' that virtual reality systems may show greatest potential in organizational management contexts.

The evolution and use of virtual entities also raises serious questions about the veracity or otherwise of our basic assumptions of the nature of the social world and our interaction and engagement with it. Burrell and Morgan (1979) writing as social scientists a decade before the globalisation of the internet and the onset of commercial virtual reality tools and systems, expressed their assumptions about ontological aspects of research into social phenomena in the form of a set of questions relative to: 'whether the reality to be investigated is external to the individual – imposing itself on individual consciousness from without – or the product of individual consciousness; whether reality is of an objective nature, or the product of individual cognition; whether reality is a given out there in the world, or the product of one's mind' [Burrell & Morgan (1979) as cited in Tosi, 2009, p.19].

There has been and continues to be, considerable debate among scholars on issues raised from the above and in considering the relationship(s) if any, between reality and perception. The whole argument of using technology to develop and present images or virtual representations derived from or representative of objects or events in the real world, as a valid process for furthering understandings of real objects or events, raises many issues. For example, the translation from a virtual construct premised on ideas, concepts and relationships expressed only in a synthetic environment, to a realizable construct or form or knowledge-based representation in the real-world can be uncertain.

In considering the epistemological issues associated with the introduction of virtual reality systems and new media, it is notable from the outset that computer-based systems and associated technologies have commonly attracted the misnomer of being Information Technologies (IT), largely due to their having been widely used to collate, store, distribute or provide access to information data-bases. Subsequently this led to the further misnomer of being knowledge systems, essentially due to their growing use in knowledge management, associated decision analysis and related approaches, and continuing application in artificial intelligence systems (Henczel, 2001; Ward & Peppard, 2002). More accurately, information and communications technologies and in particular digital computing technologies and systems, provide a technology platform that can be used to enhance the effective management of information and knowledge creation, collection, collation and distribution and across an organization (Handzic, 2004).

In an organizational context, Mackinlay (2000) notes the potential for integrating visualization strategies with user applications such that users, whether managers or otherwise, can engage more effectively as information workers through accessing visualization strategies and systems and their effective integration into the world of work and the prospect of improving our capacity to make more effective use of the ever growing volume of data available to business and industry. The necessity of systemically integrating visualization techniques into new information systems of the future is reflected in Mackinlay's three-step process describing the potential role for future information workers: 'foraging for data; thinking about data; and acting on data' (Mackinlay, 2000, pp.22-23). For Mackinlay, this is largely about making the contents of databases visible and accessible and bringing them into a workspace wherein data can be explored and potentially integrated into operational applications and decision-making support systems. A similar viewpoint on the use of visualization strategies for data visualization and its pragmatic application in the identification and resolution of complex problems, is expressed by Turban *et al* (2008) 'By using visual analysis technologies, people may spot problems that have existed for years, undetected by standard analysis methods' (Turban *et al*, 2008, p. 448).

Taking virtual world and virtual reality systems into the 'boardroom' of an enterprise entails significant shifts in both the human-computer interface and the required levels of understanding on the part of executive 'users' as to just what the modelling/simulation/visualization is capable of illustrating and the forms of 'meaning' that can be induced from such. Lofts (2002) illustrates well the potential for incorporating into the boardroom context the use of advanced visualization systems:

> *What if you could see how the people, processes, and technologies all work together in your business? What if you had a clear vision of how information, products and services, physical equipment, and money all flow through the processes and systems that define your business operations? If you could see what your people do and how technology supports them today, would it give you a better understanding of the need to change and improve your business practices and supporting technologies? Instead of imagining the possibilities offered by emerging technologies, what if you could see their impact on your business before you start to implement them?* (Lofts, 2002, p.5).

His series of probing questions and the implications behind them, raise significant challenges not only for executive users, but also the organization's information and knowledge management team, engineering, design, production and administration teams, IT systems providers, and a wide array of support and service providers both internal and external. Whilst the principle of being able to effectively visualise corporate data in order to extract relevant meaning in order to improve the quality and effectiveness of decision-making is not new, Lofts' questions imply the added characteristic of real-time analysis and visualization of current operational data and the conditions effecting them.

Whilst historically, the introduction and use of such systems would have required access to significant IT resources, support systems and highly skilled data analysis personnel, the implication for boardroom use is that the interface and operation of such systems must be in the hands of the user, which in turn raises multiple issues, not the least of which is the potential construct of the 'virtual boardroom' (Fraser & Dutta, 2008). Where data in a digital form is largely readily available about most aspects of a company's activities and performance, there is significant potential for the application of computer generated visualization systems to assist in the exploration of large volumes of data and in supporting simulation systems and decision analysis techniques. These potentials are perhaps best summarised by Friedhoff and Peercy (2000): 'A common feature of visualizations from many scientific, engineering, medical, and design disciplines is the manner in which imagery engages perceptual processes to form a close coupling between the human thinker and the prodigious computational power of machines' (Friedhoff & Peercy, 2000, p.95).

Historically, engineers have long been users of visualization tools and strategies as a means for developing virtual models of proposed and/or real-world structures. Virtual world modelling for simulating the behaviours and potential performance of new engineering designs is a current and continuing reality across a wide range of engineering disciplines (Stair & Reynolds, 2006). Engineering designers and production managers experienced in working with and making decisions about engineering design and implementation issues are regularly using virtual design techniques to explore and test new designs in simulated test-bed conditions (Vince, 2004). One of the challenges this research addresses is that of taking skilled and experienced engineering managers out of their comfort zone of interrogation and interpretation of empirical data sets and related simulations with direct real-world correlations (Chen, 2006) to also engage with the explicit use of potentially illusionary mechanisms, using stochastic, inference and perception techniques to explore new ideas and new ways of representing, interacting with, extracting meaning from, and interpreting data (Boellstorff, 2008; Friedhoff & Peercy, 2000; Lofts, 2002; Turban *et al*, 2008).

2.4.4 Virtual Reality in Industrial Training Environments

Virtual reality systems have been used in industry training and related science and technical education from the early days of its inception. Industry managers responsible for the provision of technically competent staff and associated skills training services saw the potential for significant change in the way ideas and concepts for specialised training could be developed and tested without the need for costly real-life models or risky experiments. The potential for providing technical training within simulated environments had long since been demonstrated and in active use, for example using the early 'Link Trainers' for training pilots in situ, dating back to circa 1928, through a wide range of paper-based training tools and actual equipments. NASA has been widely credited with the first successful training implementations of modern virtual reality technology, commencing with training for astronauts (Loeffler & Anderson, 1994).

However, the new virtual reality technologies have changed several factors and made possible potentialities not previously achievable. For example: the potential for photo-realism and greatly improved fidelity in imagery; the potential to change simulation parameters and conditions quickly without major changes in technology, resources, or facilities; the potential for almost life-like interactivity; the potential for highly immersive environments; the potential to engage in manipulation of data, and rapid visualisation of the affects of such manipulation, in ways never before realistically possible; the potential to bring together in simulation the use/stimulation of the three key senses: sight, sound, and touch. Educationalists have been attracted to the potentialities of this new media, particularly as it offers opportunity to explore new territories of concept building and representation, particularly through expanded use of information visualisation: 'Like the inventions of writing ... and movies, virtual reality will make possible the expression and construction of ideas never before dreamed possible' (Pimentel & Teixeira, 1993, p.17).

In many cases, the educational use of virtual reality is in the form of a design tool. Architectural students, industrial design students, construction students, engineering students, all have a need for sophisticated design tools. An increasing number of faculties in these discipline areas now make use of virtual reality systems as fundamental design tools in the teaching of their respective disciplines. Many educational institutions and commercial organizations are also actively engaged in research and development involving the use of scientific visualization using virtual reality systems and technologies (www.iii.rmit.edu.au, 2004). Recent implementations involving a combination of education and entertainment protocols has seen the development and installation of a growing number of Digital Theatres, based on the use of Virtual Reality Centre technology.

Numerous Virtual Reality Centres based on a range of technologies and visualization systems have been established in universities around the globe, particularly in the USA and the UK and are engaged in a range of research and development activities with many demonstrating an active presence in both the theoretical discourse about designing virtual-world environments and the subsequent innovative/practical application of related new-technology in both educational teaching and research contexts. Many have also been directly involved with applying virtual reality systems and technologies to real-world industrial and commercial situations.

Like so many other new media before it, virtual reality as a phenomenal media again opens opportunities for educational technologists to explore new ways of presenting complex ideas and relationships through both enhanced information visualization and interaction and engagement. Among the most successful examples of educational application of virtual reality systems has been the use of visual simulators developed to enhance training through student interaction with simulation models of complex industrial equipment, or training for engagement with equipment in potentially dangerous real-life situations [Crison *et al* (2005) in Frohlich *et al*, 2005]. As an example of this, figure 24 illustrates the use of a Reality Centre style environment for mining industry training at iCinema facilities at the University of New South Wales.

Figure 24. Mining Staff Training in iCinema Advanced Visualization and Interaction Environment. (Courtesy iCinema: www.icinema.unsw.edu.au , 2007)

2.4.5 McLuhan's Tetrad Applied to Organizational Use of Virtual Reality

The following provides a further extrapolation of McLuhan's earlier tetrad (outlined in Chapter 2.2.1) as applied to contemporary virtual reality media as an exemplar new media:

1. Virtual reality amplifies sensory perception through stimulating the use of multiple senses (visual, auditory, tactile, and associated enhanced cognition factors)
2. It obsolesces 2D and constrained 3D graphics-image based simulation by providing opportunity to access a whole-of-world view (the Weltanschauung of systems thinking) through creation of multiple systems of systems in synthetic environments, or virtual worlds.
3. It retrieves the artisan hands-on experiential mode of exploratory learning and skills development whilst reducing inherent risk and enhancing potential quality of outcomes.
4. It reverses (potentially) into a closer understanding of the reality of the world around us and prepares the way for even more sophisticated visual media capable of providing connectivity for manipulating real world entities from within virtual world environments.

In the first instance, amplifying sensory perception, there is widespread acceptance that the multi-sensory nature of new media, particularly those capable of creating conditions of user immersion, does provide enhancement in perception and potentially in performance, although it is still difficult to find actual measures of the latter (Friedhoff & Peercy, 2000; Lister *et al*, 2009; Stair & Reynolds, 2006; Turban *et al*, 2002). Such measures should not be confused, as they often are, with measures of system performance, where virtual reality simulations can achieve design and testing results faster than traditional techniques (Stair & Reynolds, 2006). Whilst virtual reality new media systems may well utilize multiple sensory stimulation, it is primarily the use of visualization that epitomizes virtual reality tools. More particularly, interactive information visualization wherein 'the use of interactive techniques… can transform data, information, and knowledge into a form from which the human visual system can easily perceive its meaning' [Attributed to Robertson *et al*. (1993) in Chen, 2006, p.156].

The impact on designers and project stakeholders alike of visualizing how a final product or structure might appear in the real world invokes a complex interaction of the perceptual, affective and cognitive domains of intellectual behaviour (Jones, 1996). This is particularly 'amplified' when the capability for real-time interaction with a visualization is applied, as Ware (2004) explains: 'A good visualization is something that allows us to drill down and find more data about anything that seems important… in reality we are just as likely to see an interesting detail, zoom out to get an overview, find some related information in a lateral segue, and then zoom in again to get the details of the original object of interest' (Ware, 2004, p.317). The use of immersive visualization may then further amplify sensory (albeit primarily visual) perception through direct engagement with virtual world objects and their affective relationships. In the context of using virtual worlds to support decision-making, a virtual world may or may not provide a direct visual correspondence with the real world. Rather, it must provide virtual representations of those parameters or characteristics that in the real world have or result in real and identifiable effects (Hunsinger, 2008). The actual construction of the virtual world may involve the use of shapes, colour, position, mobility, and other controllable or attributable characteristics. The core purpose is to enable visualization of information, conditions, status, and variables, in such a way that managers can effectively perceive, extract and interpret meaning from data so represented (Chen, 2006).

The second characteristic, obsolescence, can be seen in the progressive replacement of earlier two-dimensional (2-D) and constrained three-dimensional (3-D) graphics by interactive multi-dimensional imaging as a fundamental design tool in a wide range of engineering and production planning processes. The introduction of 'six degrees of freedom' in design and planning imaging (the capability to visually move forward-backward-left-right-up-down, all with 'zoom in and out') plus real-time coherent interconnection to multiple congruent design stages, provides 'interactive 3-D spatial visualization' (Vince, 2004, p.124-125) with significant flexibility and enhanced performance over earlier constrained design imaging techniques.

The third characteristic, retrieval, is more subtle in nature. In management terms, it is akin to the classic concept of 'management by walking around', enabling the manager to see, hear, feel what is actually happening in the organization in real-time. Its potential connectivity to Quality Management approaches is also particularly relevant. Another factor that potentially illustrates this third characteristic is the growing acknowledgement of Knowledge Management as a twenty first century motif for implementing effective executive decision support systems (Blecker, 2005). To be able to more effectively access the intellectual capital and corporate memory of the organization is a serious strategic challenge for many organizations. Connectivity between an organization's collective data, information and knowledge collection and storage systems and a new media visualization tool such as virtual reality, may well be a significant means of creating strategic advantage, through leveraging off the organization's unique knowledge, competence and skills base as strategic capabilities (Johnson *et al*, 2008).

It is perhaps in the fourth characteristic, reversal, that we see the most dramatic indicators of the future strategic potentialities for virtual reality technology and systems. Using sophisticated visualization strategies to facilitate comprehension, understanding, and extract meaning embodied in the process of looking back at what was, reviewing the present for what is, and developing simulation and synthesis strategies to prepare for what might be, demands new approaches, new skills and new insights. However, the first three characteristics are clearly all implicit in contemporary virtual reality systems. Strategic positioning of such new media in contemporary organizations may well be seen as focusing on optimising the effects of these three characteristics.

Positioning virtual reality visualization technology and systems as a core strategic capability is another way of thinking about positioning virtual reality as a strategic technology. In this regard it is about the internal development of specialised skills and expertise as a paradigmatic community of practice (Malhotra, 2001) with an overall capability (in the strategically critical use of virtual reality technology and systems) that can give the company a unique competitive advantage in its external environment [Tschirky (2004) in Probert *et al*, 2004]. 'Companies have to find ways of growing and building advantages rather than just eliminating disadvantages' [Porter (1996) in Gibson, 1998, p.49]

2.5 Literature Review Summary

This chapter has largely focused on determining the key features that have characterised the evolution of 'new media', the development and application of simulation systems utilising visualization technology, virtual worlds and virtual reality applications and systems, and key issues affecting the management of engineering and technology based organizations. In identifying and analysing the works of a wide range of researchers, analysts and practitioners it has placed this research program within appropriate academic and applications contexts and brought together insights into the relevant existing body of knowledge, theory and practice relative to the communities of practice using or interested in using new media; virtual reality systems and related visualization technologies and systems.

A significant feature of contemporary new media that clearly arises from the review of literature and previous research is the continuing convergence of electronic and computer-based media and the subsequent potentials for integration of such media, specifically in the context of contemporary business-technology convergence. The growing ubiquitous nature of digital media and related technology throughout both industrial and commercial environments has largely set in place the initial, or essential, pre-conditions for establishing digital virtual world modelling, consisting of an effective digital media presence and the coordinated collection and digitization of data and information at the organizational/enterprise level.

The continuing convergence in digital technology and simulation environments has the potential to impact on virtually all aspects of organizational culture, products, services, systems, processes, communications, and enterprise level performance. In turn, there is a need for significant adjustments to our understandings of such media, in terms of determining the direction of its continuing development and incipient use of leading-edge new technology, our comprehension of its capabilities, both in terms of its limitations and potentials, and the evolving 'language' of such media. The earlier work of McLuhan (1964, 1968) and that of more contemporary researchers has highlighted the changing nature of media over time and with it the need to appreciate the shifting potentials of a continuously changing media landscape.

Innovation, subsequent technological change, and technology transfer and diffusion, all impinge on the growth of new media as a rapidly evolving 'revolutionary-radical technological innovation' (an appellation that may well be ascribed to 'new media'). Whilst the development of virtual reality systems (as an exemplar of new media) has been in gestation for some 20 years, the underlying technology requirements for its effective widespread implementation as an immersive phenomenal media are only now becoming more widely available, technically feasible and affordable in the workplace environment.

A wide range of visualization 'presentation' technology is available for virtual reality applications, from large screen theatre style environments, various sized hemispheres, small and large flat-wall displays, design-desks, desk-top displays, through to individual stereoscopic eye wear. With a growing range of such presentation technology, and certainly substantially reducing costs over recent times, the selection of appropriate presentation technology is largely dependent on the actual application and work environment rather than earlier restrictions of overbearing cost inhibition. Appendix 4 contains a further tabulated summary of VR technology and associated systems, display methods, number of users, and exemplar areas of application.

Continuing growth of interest in simulation, both for design and management purposes, provides an appropriate avenue for inducing paradigmatic change through the application of virtual world building in organizations. Design teams throughout the aerospace and automotive industry sectors in particular have clearly demonstrated the power of advanced simulation, including virtual reality, in helping to solve complex problems before they occur in the real world. Extrapolating these technical simulation skills from the world of design to that of organizational structures, relationships and processes, whilst unlikely to be a technical (computing technology skills) difficulty, may well induce considerable stress with regard to formulating 'cyber-strategies' for identifying and modelling organizational cognition, perception and organizational logics. This transition (from an engineering/technical logics environment to that of organizational logics) will certainly require substantially new skills in terms of knowledge and understandings of the characteristics of the new virtual-world environment of an adaptable complex organization. Just as anomalies or inaccuracies in data in a design environment can induce serious problems in design implementation, so also may anomalies in virtual-world design of an organization distort or fail to reflect actual organizational behaviours or responses, particularly when under stress or challenge.

This research program has specifically addressed the introduction of virtual reality new media into engineering and technology based organizations. Such organizations are characterised by:

- Specialist engineering and technology expertise that reflects the strategic intentions and technological capabilities of the organization
- A strong focus and reliance upon the deployment of technological resources relative to the organization's primary role, function and activities, resulting in a significant presence of technology in the organization as an endemic characteristic of engineering and technology based organizations.
- Technology management practices that reflect the critical linkage between engineering and technological knowledge and expertise and the demands of general management and business practice.
- A commonly held positive orientation toward technological innovation
- The capacity to effectively mobilise knowledge and technological skills to sustain competitiveness and to attain competitive advantage in the broader marketplace

It is acknowledged that many organizations in the broader scope of commerce and the service industries also reflect many of the above characteristics and may similarly benefit from the introduction and use of virtual reality systems and new media. However, this research program has focussed on engineering and technology based organizations in particular.

There has also been extensive engagement in the application of simulation and visualization systems throughout the education sector over many years. Educational technologists in particular are attracted to the potentialities of virtual reality and virtual-world building as tools for further enhancing teaching and learning environments. This is particularly the case in relation to exploring new ways of presenting complex ideas and relationships using advanced visualization and interactive engagement. Virtual reality style simulation in particular has been actively used for some time in specialised industry training for skills in using specialized equipment, or operating in severe environments. Both medical and military applications have been developed both for specialized training as well as for more complex simulations such as real-time battlespace management and research into the human body.

Collectively, the review has outlined the development of new media and identified relevant key features, attributes, characteristics and areas of current and projected application. Significant areas of concern are identified including a need for specialized skills and expertise in order to effectively utilize new media, particularly in the fields of virtual world building and interactive virtual reality applications. Issues are also identified in the areas of continuing developments in human-computer interface systems and rapidly improving visualization presentation technology capable of bringing low-cost high definition imaging into office environments, as well as continuing developments in computer hardware, software and systems with associated concerns of obsolescence of the old and predicting (realistic) capabilities of the new.

Chapter 3 Methodology

3.1 Research Objectives

This research program addresses the following major research questions:

- Can new media virtual reality technology, systems and applications be used to enhance management practice in engineering and technology based organizations?
- If so, can a classification tool or taxonomy be developed to identify the core characteristics of organizations that are virtual reality capable, or have the potential to make effective use of virtual reality style new media technology, systems and applications?

In addressing these questions and the related issues raised by them, the following are the significant enabling questions that have been used through the research to provide directed focus on key issues and to help inform understandings:

- How may advanced visualization and simulation systems be best deployed in the management and operation of engineering and technology-oriented organizations?
- What organizational mechanisms (structures, relationships, formalisms, and ownerships) affect the introduction of visualization and simulation systems into an organization (whether for product design, production monitoring, or broader management processes and applications)?
- What adjustments to current management and work practices will be required when visualization and simulation systems are introduced into an organization, with an emphasis on how potential users approach new media and virtual reality technology?

Thus, the research is particularly focussed on gaining new knowledge about the introduction and use of virtual reality in engineering and technology-based organizations, and the potential to integrate and utilise within their organizations advanced visualization and simulation systems and the continually changing and developing technology bases associated with them. The new knowledge generated by the research program is presented in a theory-informed taxonomy and planning framework for prospective VR-user organizations, to provide a defined structure within which to classify organizational need, strategies, approaches, products, and systems, and to assist understandings of relationships relevant to successful introduction of virtual reality systems. Given that strategic positioning of advanced simulation and decision support technology and systems may well be among the most significant ‘management information systems’ (MIS) decisions that such organizations will make in the early years of this new millennium (Stair & Reynolds, 2006) it is anticipated that the proposed taxonomy has potential for application in a wide range of engineering and technology based industrial sectors.

3.2 Approach Outline

The research approach begins with an extensive review and content analysis of publications, research reports and conference papers that address new media and virtual reality technology, systems and applications, and the management of technology-oriented organizations. Significant parameters affecting the introduction and use of new media virtual reality systems are identified and assembled as formative inputs to subsequent analysis stages.

The subsequent concept development adopts an 'adaptive' soft-systems methodology (SSM) approach (Checkland & Scholes, 1990; Jackson, 2003) to analyse relevant systems elements and relationships largely identified through content analysis of the reviewed publications, using a Category/Priority Matrix and Analytic Hierarchy Analysis, a form of 'axial' coding, relating concepts and categories to each other in binary pairs (Corbin & Strauss, 2008; Saaty, 2006).

3.3 Philosophical Position and Methodological Processes & Reasoning

The research program has utilised a combination of: grounded thematic analysis and soft-systems methodologies to develop the proposed classification schema. This combination of disparate approaches or research paradigms from the social and technical arenas to form a holistic socio-technical approach has in turn enabled a broader view than either paradigm could offer on its own (Coakes, 2003; Coakes *et al*, 2002). In this regard, there is the formulation of propositions (albeit through qualitative approaches and concurrent analysis) to formulate proposed systems elements for the intended classification schema and then their testing against reality, through analysis of results of a complex survey instrument designed to identify any alignment between theoretical expectations and established practice (Blaikie, 1993).

The research also draws on aspects of Professor Sir Karl Popper's work and philosophical arguments, in particular his defence of Descartes' earlier thesis that mind and body share causal relationships, that is, although utterly distinct in nature, nevertheless they interact causally (Popper & Eccles, 1977; Papineau, 2004). This construct or argument, about the potential for ascribing causal relationships to a presumed connection between abstract and physical entities, is applied to the current research context as follows: As the mind may be related to the body through causal relationships (according to Popper and Eccles, 1977) so also may the ideas or concepts of virtuality and virtual-reality be causally related to the material representation of virtual reality in the form of VR technology and its associated systems and applications.

This being the case, then the following philosophical question arises: could an investigation into such causal relationships form a conceptual basis for the development of a meaningful taxonomy or classification framework for the application of virtual reality technology and related systems? The nature of this question is not necessarily about whether such a derived taxonomy or framework could definitively predict, describe or explain the characteristics, behaviours or actual performance of virtual reality systems and applications in particular circumstances, but rather addresses whether or not it is a feasible form of enquiry. In effect, the nature of this question has also been addressed by Popper in an address at Harvard University in 1963 when he argued that enquiry, whether in the natural sciences or social sciences, is always premised on addressing a 'problem' or issue about which there is the opportunity to gain further or new knowledge, regardless of which direction it may take us in, or how disparate the answers may appear to be: 'Thus we can look upon any particular item of knowledge, and especially upon any scientific theory, as a tentative solution to some problem or other, and as giving rise to new problems' [Popper (1963) in Popper, 1994, pp.154-156].

The apparent difficulties of correlating the established position of scientific and philosophical thought and argument with the potential use of synthetic or virtual objects, processes, and relationships in virtual world incarnations, may well be the kind of 'Bold Idea' that Popper valued as an important component of valuable science (Papineau, 2004). Popper argued that our life experience and observations of the world around us may only be at best the outer layer of a many layered reality. It is thus the scientist's task 'daringly to conjecture what these inner realities are like' (Popper (1974) in Warburton, 1999, p.278) and then to go further, to explore and test such ideas, or in Popperian terms: bold scientific conjectures. Whilst Popper's life experience essentially preceded contemporary virtual reality systems and new media technology, the veracity of his arguments remain and exhort us to actively explore 'layer by layer' our world and the many (and at times volatile) artefacts that science and technology have introduced into the complex of our life experience.

Popper's construct of bold scientific conjectures (Popper, 1974), the observations of contemporary philosopher Thomas Kuhn in his paper addressing anomaly, the emergence of scientific discoveries and the institution of paradigm change (Kuhn, 1996) and Christensen's constructs of discontinuous and disruptive technological innovations (Christensen, 1997) would appear to sit readily with the potential for advanced simulation and virtual reality technology and systems to institute, or at least be a pre-cursor of, paradigmatic change (Swann & Watts, 2002) in the way we explore, examine, visualise, consider and make determinations about our world and its workings:

> *But there is… the boldness of predicting aspects of the world of appearance which so far have been over-looked but which it must possess if the conjectured reality is (more or less) right, if the explanatory hypotheses are (approximately) true. It is this more special kind of boldness which I have usually in mind when I speak of bold scientific conjectures. It is the boldness of a conjecture which takes a real risk – the risk of being tested, and refuted; the risk of clashing with reality* [Popper (1974) Ch. 31 in Warburton, 1999, pp.278-279].

The potential for such change may be seen in the way we approach new information and knowledge-management technology, its application in the structures, processes and dynamics of contemporary commerce, its role in addressing the complexities of relationships in the world around us, and in the character and nature of personal and corporate competencies that we require in an increasingly information rich world and the techniques and mechanisms we use to interact with such information (Johnson *et al*, 2008).

Allowing then that such an approach is philosophically possible, the research program inquires as to whether or not such causal connections may exist. It further enquires as to whether or not they describe potentially necessary conditions, processes or practices (including for example organizational policy and practices) for successful implementation of a synthetic environment application, such as virtual reality using VR enabling technology and associated systems and products.

Putting aside the complex computer software and imaging technology involved in virtual reality systems, the essential virtual reality constructs of highly visual and multi-sensory stimulatory media presents strong attractions to educational researchers as providing new ways of thinking about and representing data, information, and ideas. Dr William Bricken of the Human Interface Technologies Lab (circa 1993) originally took this even further and put it thus: 'The primary defining characteristic of VR is inclusion; being surrounded by an environment. VR places the participant inside information' (Attributed to Bricken in Pimental & Teixeira, 1993, p. 9).

The research methodology being applied throughout the program invokes two technically different levels of engagement:

1. Operating at the abstract level of dealing with concepts and developing propositions that may explain potential relationships between either established or new concepts, with the view of developing and asserting a new construct, the proposed taxonomy. This stage of enquiry is strongly focussed on the concurrent use of a concept development and thematic analysis approach throughout the analysis of published literature and relevant research.

2. Engagement at the empirical level through objective observation and experiential engagement with virtual reality technologies and systems, commercial virtual reality product and service providers, user organizations, and interviews and surveying of individual 'users' of virtual reality systems.

In addressing the major research questions and enabling research questions the research methodology appears to be essentially inductive in its nature and approach. This is also in accord with the qualitative approach largely being used to address these questions and form of enquiry (Blaikie, 1993; Ezzy, 2002, p. 12; Strauss & Corbin, 1990, p. 23). This is evidenced in the use of empirical observation of the 'particular' (either through direct, experiential techniques and engagement by the researcher in various virtual reality research projects and industry based case studies, or via analysis of previously published observations by other researchers) through to the development of a taxonomy or framework theory for application in 'general'.

In addressing the survey based testing of the proposed taxonomy, the research methodology is essentially deductive in nature. It addresses a range of issues in industrial organizations by taking the newly formed generalist taxonomy or framework theory and comparing it to the particular performance found in exemplar organizational contexts. Then once tested, again reverting to the inductive model of presenting the proposed taxonomy with explanatory notes, describing in generalist form a 'paradigmatic planning framework' to assist management to identify key areas to be addressed in the task of introducing and implementing new visualization-technology based decision support strategies. This form of 'mixed-methodology' through a use of a combination of inductive and deductive reasoning throughout the research program is in itself quite a challenge: how to sustain coherence in argument and form whilst using alternate cognitive styles of reasoning and associated research strategies. There is also the curiosity factor of using the essentially realist ontology of inductive reasoning when dealing with such an oxymoron as 'virtual' reality and its implicit use of illusion and fooling the senses, as per Baudrillard's (1990) simulacra. Blaikie's discussion of the Inductive Research Strategy highlights this apparent anomaly best, as follows: 'The Inductive strategy embodies the realist ontology which assumes that there is a reality 'out there' with regularities that can be described and explained, and it adopts the epistemological principle that the task of observing this reality is essentially unproblematic as long as the researcher adopts objective procedures' (Blaikie, 1993, pp. 137-138).

As a consequence of these apparent risks of methodological anomalies and associated constructionist versus reductionist arguments, great care has been taken throughout the research program to ensure coherence of approach in the collection, collation and analysis of data, and development of argument and findings.

3.4 Application of Grounded Theory Method in Content Analysis

The integrative mixed-mode approach (Nichols *et al*, 2001; Bergman, 2008) outlined above, endeavours to use the methodological approaches of Grounded Theory Method to investigate literature relevant to the introduction, application and strategic positioning of new media and virtual reality as technological innovation in engineering and technology based organizations. It utilises content analysis techniques to identify relevant aspects of existing theory and practice, determine its current relevance and identify any new aspects not incorporated or explained by current theory and practice (Clarke & Star, 2008; Strauss & Corbin, 1990; Locke, 2001; Goulding, 2002). Using Grounded Theory Method in this manner across existing documentation on the experiences of a wide ranging group of researchers, authors and existing communities of practice, has the potential to provide both new insights into and add to the existing body of knowledge (Goulding, 2002, p.42).

This approach is based on a combined regimen of Discourse and Interpretative Analysis as described by Neuendorf (2002) whereby the 'connection of words to theme analysis and the establishment of central terms' (Neuendorf, 2002, p.5) is in turn used to identify: 'analytical categories; cumulative, comparative analyses; and the formulation of types of conceptual categories' (Neuendorf, 2002, p.6). As such, this approach to content analysis 'is consistent with the nomothetic approach to scientific investigations, ie. seeking to generate generalizable conclusions' (Neuendorf, 2002, p.15) which in this case is represented in the formulation of systems elements in the Soft Systems Methodology stage and the subsequent development of the proposed taxonomy and paradigmatic planning framework.

Dey (2007) provides a further insight into the methodological variance that researchers using Grounded Theory Method as a core qualitative research paradigm have in turn induced: 'There are elements in grounded theory which point in different directions: a focus on process, an emphasis on theoretical sensitivity, and the centrality of a storyline around which analysis can coalesce' [Dey (2007) in Bryant & Charmaz, 2007, p.167]. In further reflecting on the original work of Glaser and Strauss (1967) Dey moves on to summarise his perspective of their intent to shift theory evolution away from the mechanisms of developing (in effect *a priori*) hypotheses and their empirical testing, to a more flexible approach based on exploring what data can express or meanings that may be embedded in data: 'A grounded theory was not speculative, since it derived directly from empirical observation, and was always substantive, even if it provided a basis for generating more formal and abstract theories. In this context, the grounding of theory refers to the use of data obtained through social research to generate ideas' [Dey (2007) in Bryant & Charmaz, 2007, p.172-173]. This inherent capacity in Grounded Theory Method approaches to 'generate new ideas' is particularly well expressed by the insightful and challenging observation by Charmaz (2006) that it: 'involves taking comparisons from data and reaching up to construct abstractions and then down to tie these abstractions to data… then exploring their links to larger issues or creating larger unrecognised issues in entirety' (Charmaz, 2006, p181).

In this research program, a Grounded Theory Method approach is used for content analysis of extant literature to identify existing new media virtual reality technology, systems, practice and relevant theoretical perspectives, as expressed by a range of authors from multiple communities of practice with a common thread of interest in one or more areas associated with: new-media; virtual reality; technological innovation and change; and the management of technology based organizations. This enables the assembly of data and extraction of meaning through the use of a 'constant comparative method' (attributed to Glaser & Strauss, in Blaikie, 1993, p.191) in which conceptual analysis and subsequent theoretical perspectives 'not only come from the data, but are systematically worked out in relation to the data during the course of the research' (attributed to Glaser & Strauss in Blaikie, 1993, p.191). Accordingly, the identification and assembly of relevant categories of experiential and theoretical considerations are themselves derived from the body of data as it is collected and progressively collated and assembled as formative outputs, a real-time and congruent 'integrated process of data collection, coding and analysis' (Blaikie, 1993, p.193). The formulation and development of such conceptual categories as a form of interpretative analysis (Neuendorf, 2002, p.6) is subsequently taken up in the following Soft Systems Methodology stage to formulate the key 'systems elements' that in turn are used in the formulation of the final taxonomy, as in effect, a substantively 'grounded theory'.

3.5 Systems & Systems Thinking

Systems Thinking is an approach that entails addressing issues, problems and opportunities in the real world from a broadly based viewpoint and taking a holistic perspective with regard to identifying possible solutions or strategies. In effect, it is a way of organising our thoughts about the real world using 'the notion of system as an organising concept' (Flood & Jackson, 1991, p.2). As an alternative to mechanistic thinking (as per classical scientific method approaches to problem solving) systems thinking processes enable a more satisfactory and holistic approach, not only with regard to systems engineering problems but also to addressing social world phenomena. In a problem solving world premised on mechanistic thinking and the analytics of reductionism, the machine metaphor or 'closed' system view applies. In this approach the internal components of a system or collection of related parts is tightly defined and restricted to its specified function. In effect, such a system consisting of an assemblage of independently defined parts and performance categorization 'is an aggregate of parts in which the whole is equal to the sum of the parts' (Flood & Jackson, 1991, p.4). This approach is typified in the organisational mechanics of bureaucracy (Weber, 1947) and the stringent operational strategies of scientific management (Taylor, 1911).

Systems thinking approaches shift the emphasis from the closed view of the machine metaphor and mechanistic thinking to a more 'open' system view of a world imbued with multiple influencing factors, changing conditions, and complex entities. Thus, a systems thinking approach views systems and systems components as inextricably linked, wherein the properties and behaviours of the many components or elements constituting the system both influence and in turn are influenced by each other (Blanchard & Fabryky, 2006). It is in this context of systems as complex 'wholes', in which 'the whole is greater than the sum of its parts' (Flood & Jackson, 1991, p.4) that systems thinking far exceeds the facility of mechanistic thinking to genuinely address the complex nature of organizations and the social interactions that both surround them and are engaged in within them.

There are many working variations on what constitutes a formal 'system' or 'systems approach' to considering the workings of organizations or approaches to addressing issues and solving problems. For example, Blanchard (2004) cites the definition provided by the International Council on Systems Engineering (INCOSE):

- *A system is a construct or collection of different elements that together produce results not obtainable by the elements alone. The elements, or parts, can include people, hardware, software, facilities, policies and documents, that is, all things required to produce system-level results…* (INCOSE definition cited by Blanchard, 2004, p.8).

Nicholas (1990) in turn sees Systems Thinking as in effect a way of building an holistic perspective of both the internal and external world relative to a particular issue or problem situation:

- *Systems thinking means being able to perceive the 'system' in a situation. It is the ability to take a confused, chaotic situation and perceive some degree of order and interrelationship.*
  (Nicholas, 1990, p.52)

Flood and Jackson (1991) provide a more detailed elaboration in relation to considering systems and systems thinking in the context of endeavouring to understand organizations and in particular business environments, as complex social systems that require more abstract thinking approaches in order to gain an effective understanding of social influences and behaviours in organizations (Flood & Jackson, 1991, p.4).

The continuing evolution of systems thinking as an effective approach to problem solving and the process of developing new ideas, has led to its increasing acceptance within the education sector and the social sciences as well as areas such as information technology and the more ‘hard’ science oriented areas such as in engineering. Systems Thinking approaches are seen as providing an effective alternative approach to traditional rational-analytical approaches and in many cases providing better and more effective tools for problem definition, particularly in areas of great complexity (Maani & Cavana, 2000) although issues associated with using a systems approach in areas of great complexity, are also highlighted by Clayton and Radcliffe (1996). They expressed concern over being able to identify and track the many influences and interactions occurring in complex systems, particularly large highly distributed systems such as can be found in large engineering organizations, or indeed in the external world of commerce and government. They particularly express concern about determining the starting point and influencing factors in complex systems, especially when considering large distributed and potentially global complex systems *such as socio economic and environmental systems* (Clayton & Radcliffe, 1996, p.13).

In addition to the earlier quoted INCOSE definition we have the following alternatives:

- *A system is a set of interrelated components working together toward some common objective or purpose.* (Blanchard & Fabrycky, 2006, p.4)
- *System: An open set of complementary, interacting parts with: properties, capabilities, and behaviours emerging both from the parts and from their interactions.* (Hitchins, 2000, www.hitchins.co.uk/SysMods.html)
- *Systems thinking focuses on identifying the relationships between the parts of a system. When managers use systems thinking, they gain insight into how changing these relationships may affect behaviour and performance of a system…* (Cavaleri & Obloj, 1993, p.6)

Defining what makes an effective Systems Approach is a continuing challenge. In effect, it implies being cognizant of all the requirements for a given activity or project and ensuring that any design for implementation incorporates processes that address all of the requirements. Using an effective and adaptable systems approach to address problems or issues of concern can enhance the likelihood of success.

Nicholas (1990) summarises the application of systems approaches in management as being about recognising complexity in problems and being able to identify the key elements, inputs and outputs, and influences from both internal and external environments. This involves keeping in mind the specific objectives and mechanisms required to measure performance against such objectives; the overall environment within which the system is to operate; the resources available to support operations; the various system elements and their specific attributes; and the means by which the system as a whole is managed (Nicholas, 1990). Many writers have addressed the development of Systems Thinking, although few in specific reference to the development of meta-media such as virtual reality, turn many new-technology projects investigated over the past decade reflect the use of informal systems thinking in their developmental stages and demonstrable systematic approaches to implementation.

3.6 Soft Systems Methodology

Applying Systems Thinking approaches expressly to the management of people and organizations is the particular purview of Soft Systems Methodologies (SSM) approaches. SSM has been widely used to address issues involving for example: time variant situations of high complexity; ill-defined problems; and particularly problems involving human and organizational problem solving and decision-making (Godau, 2001; Maani & Cavana, 2000). In developing systems approaches to solving problems, the potential for incorporating virtual reality based management systems into companies using or interested in using Soft Systems Methodologies is particularly interesting. Cavaleri and Obloj (1993) ascribe to SSM approaches the notation of being: 'A New Way of Thinking in Organizations' (Cavaleri & Obloj, 1993, p.132). In particular, they argue that soft systems thinking develops organizational improvement through the use and development of continuous learning and improvement strategies. They see such use as developing the problem solving capacity of an organization through being able to gain insight into the many mechanisms and interactions at work within an organization, thus reducing levels of uncertainty.

Checkland and Scholes (1990) and Checkland (1993) specifically argue for the application of SSM to the management of complex situations where time variant interactions, the introduction of new ideas and approaches, and shifting goals and purpose are commonplace. They see these as the normal conditions that face organizations and indeed society as a whole, where constant change is the norm requiring adaptation and flexibility in approach to problem solving. Schoderbek *et al* (1990) perhaps encapsulate best the essence of applying systems approaches to the management of organizations and related areas, in outlining their view of the relationship between systems science, and the non-science disciplines, such as the humanities. Whilst they argue for a differentiation on the basis that the sciences are largely about determining and explaining similarities between things or objects or phenomena that appear to be different, while the non-sciences are largely about identifying and describing differences between things, objects, or phenomena that at first sight appear to be the same, they also take the view that both approaches are necessary for effective problem solving in complex systems.

In part, the origins of Soft Systems Methodology (SSM) can be attributed to the influences of the work of Churchman and Ackoff on organizational cultures and the potential role of 'soft' systems thinking in improving organizational performance through 'interactive planning' and developing new understandings of 'objectivity' in the construction and setting of systems approaches (Flood & Jackson, 1991). Their work as early pioneers in the social systems sciences in the 1950s and 1960s influenced the subsequent foundational development work on SSM by Checkland at Lancaster University through the 1970's and 1980s (Checkland, 1993; Flood & Jackson, 1991). Underpinning much of Checkland's initial work on applying systems thinking and systems engineering approaches to the purportedly ill-structured and 'messy' area of management decision-making, is that of the inherent metaphor of organization as a 'culture', as per Churchman's approach (Flood & Jackson, 1991, p.39). Checkland's own words about his initial approach to using systems thinking and systems engineering techniques in management contexts express this best:

> *Our initial question was: could this approach perhaps also be applied to management problem situations? In the event, the pattern of activity found in Systems Engineering – namely, precisely define a need and then engineer a system to meet that need using various techniques – was simply not rich enough … Given this, the Lancaster research saw the emergence of a radical alternative to Systems Engineering, namely the new approach which became known as SSM .*
>
> (Checkland & Poulter, 2006, p.xi-xii)

In effect, the earlier Popperian/positivist notions that so strongly underpinned the 'hard systems' approaches, needed to change, 'SSM had to develop new ways of thinking about the complexity of real-life situations' (Checkland & Poulter, 2006, p.xiii). Checkland initially proposed a formal seven-stage model for implementing SSM (see Figure 25). His graphical model is in itself a form of 'rich picture' (Flood & Jackson, 1991, p.172) or expressive representation of a methodology for addressing 'soft' or organizationally focussed problems or concerns that typically entail social and culture related issues (Checkland & Poulter, 2006).

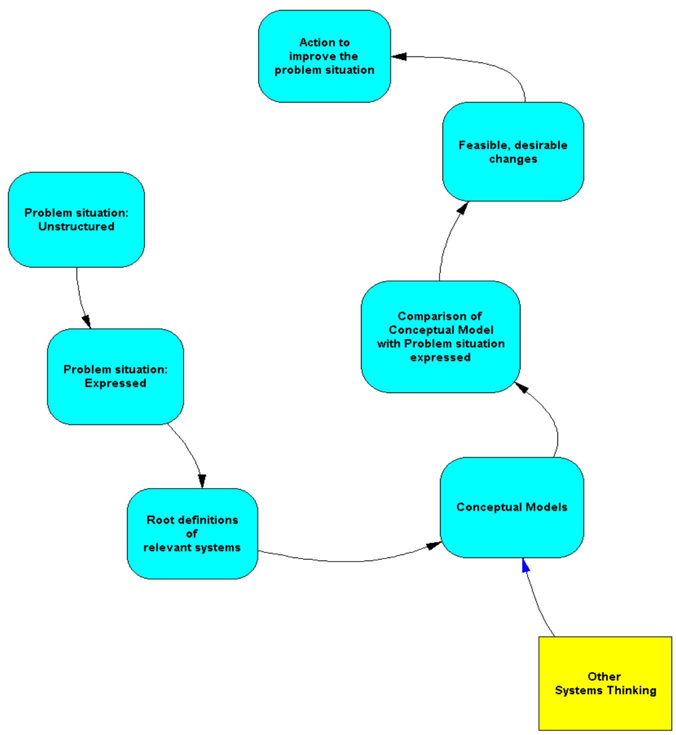


Figure 25. Checkland's Initial Seven-Stage SSM Approach: Mode I

(Derived from: Checkland & Scholes, 1990; Flood & Jackson, 1991, p.173; Pidd, 1996, p.132; Maani & Cavana, 2000, p.22; and Jackson, 2003)

There are various critiques of the practical application of SSM in real world environments, particularly with regard to the complex, competitive and potentially coercive environments of commercial organizations. For example, the information and communications technology (ICT) industry and all who make use of ICT technologies and systems are inevitably entwined in the coercive, or power oriented, influences that pervade the overall culture of the ICT industry. Betz (2001, 2003), Flood and Jackson (1991), and Jackson (2003) make particular reference and critique of the difficulties of application of Mode I SSM approaches, as per Checkland's initial seven-stage model, in such 'coercive' environments (Flood & Jackson, 1991, p.188). The methodological processes used throughout this research is an adaptation of Checkland's seven stage Soft Systems Methodology (SSM) (Checkland & Scholes, 1990) and closely akin to that identified by Flood and Jackson (1991) and Jackson (2003) as being a Mode II SSM approach (See Figure 26) that progressively evolved as SSM matured as a workable, flexible and widely accepted methodology.

> *An SSM user who has fully internalised the methodology may not use the stages to guide his/her activity at all, but simply employ the methodology as a point of reference to make sense of what is being done in the real world. This is what has recently been called a Mode II usage of SSM as opposed to the more formal Mode I procedure*. (Flood & Jackson, 1991, p.172)

In this form, the inherent learning cycle and iterative nature of SSM is acknowledged and developed as necessary components in the 'whole' of addressing the identified problem or issue under investigation.

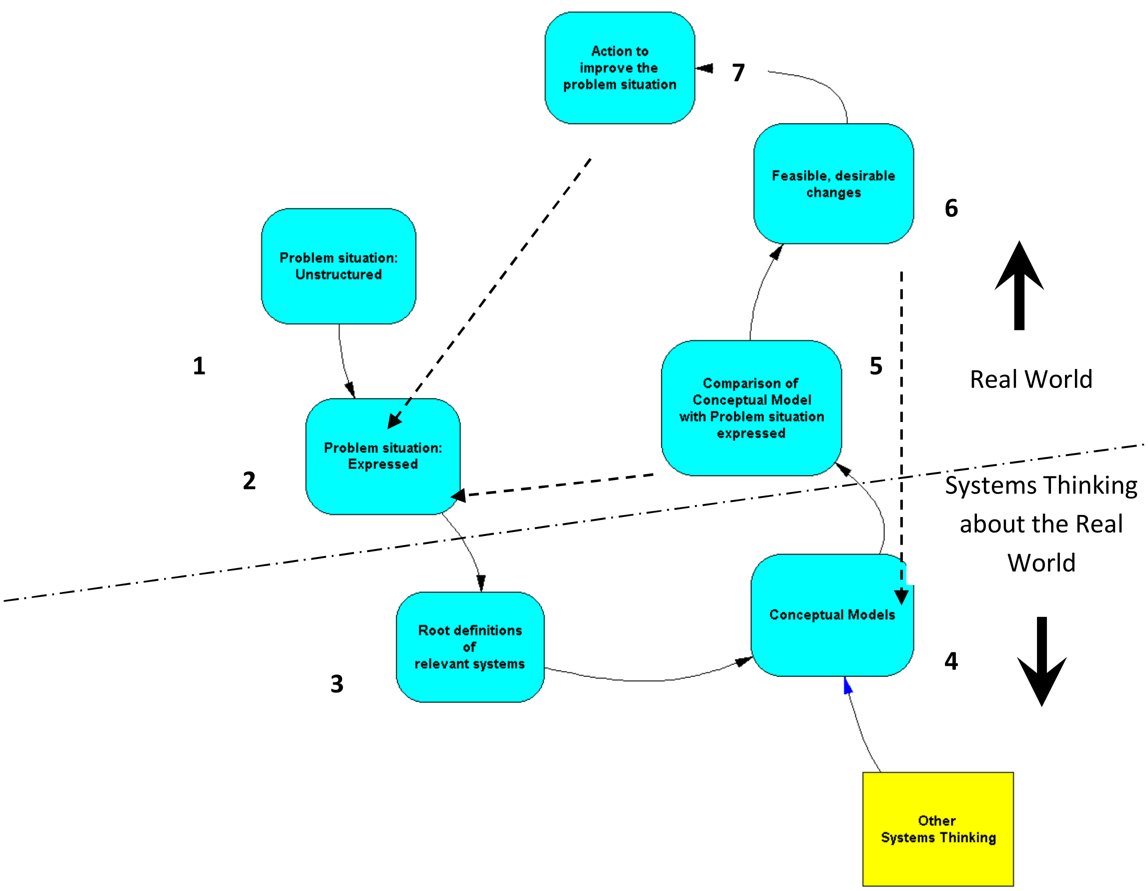


Figure 26. Adaptation of Checkland's Seven-Stage SSM Approach to: Mode II

(Derived from: Checkland & Scholes, 1990; Flood & Jackson, 1991, p.173; Pidd, 1996, p.132; Maani & Cavana, 2000, p.22; and Jackson, 2003)

3.7 Adaptive Grounded Soft Systems Methodology

This research program has employed soft systems methodologies 'as a point of reference to make sense of' (Flood & Jackson, 1991, p.172) the data derived from and grounded in established practice, accepted theory, and observed behaviours within related communities of practice (Strauss & Corbin, 1990). As such it is an adaptive form of Mode II SSM (Jackson, 2003) or more particularly, an Adaptive Grounded SSM approach (AGSSM). It is adaptive, in that it allows a range of empirical and interpretive approaches within its structure, including: critical thinking; socio-technical approaches; innovation and strategic thinking; and an inherent capability to adapt to change and new input from its surrounding environment. Grounded, in that it provides opportunity to 'ground' its primary source of data on the findings of the established literature and previous research activities and both past and current experience of related communities of practice (Glaser & Strauss, 1967; Strauss & Corbin, 1990). SSM, in that it follows the general mode and format of Checkland's approach, and specifically SSM Mode II, as being a strongly iterative and recursive learning cycle environment (Checkland & Scholes, 1990; Flood & Jackson, 1991; Jackson, 2003).

The Adaptive Grounded SSM approach (see Figure 27) introduces two specific additional stages (identified as 1b and 1c) to the seven basic stages in Checkland's fundamental model as outlined above in Figure 25. These two additional stages expressly provide the opportunity to 'ground' (Glaser and Strauss, 1967; Strauss & Corbin, 1990) the 'expression' of the problem situation (Checkland & Scholes, 1990; Flood and Jackson, 1991; Jackson, 2003) in existent/external experiential and theoretical perspectives (Clarke & Star, 2008).

Checkland specifically excluded considering other 'systems' oriented issues in the early stages of his SSM model (Flood & Jackson, 1991, p.170) preferring to introduce systems concepts at stages 3 and 4. He argued for using systems thinking about the world as stated in the 'problem situation expressed' occurring at or following stage 2, not as a means to address expressing the problem situation. One of the outcomes of this position is that existing associations and relationships that could inform the transition from 'problem situation unstructured' to 'problem situation expressed', remain unidentified and by Checkland's definition, 'unstructured'. This apparent anomaly is addressed in the AGSSM approach through introducing the opportunity to identify external experiential and theoretical considerations. In this particular instance, external theoretical considerations as exhibited in the experiences of researchers and practitioners involved with the introduction and application of virtual reality and related new media systems and technologies, as identified both in published documents and reports and the experiences of practitioners engaged in a range of virtual reality projects.

The additional stage 1b provides for the initial identification of such considerations 'related external experiential and theoretical considerations identified' and is specifically positioned in the 'Real World' context of actual experience (see Figure 27). The new stage 1c provides the additional opportunity to evaluate the nature and extent of influences such considerations have on the assumed problem situation 'problem situation evaluated against external considerations'. Stage 1c is considered to deal with the more abstract notion of evaluation and the potential for introduction of perception as derived from experience and thus is positioned in the SSM sector described by Flood and Jackson as 'Systems Thinking about the Real World' (see Figure 27).

Whilst making partial use of the general form of SSM with the addition of stages 1b and 1c as outlined above, this research also makes particular use of the supplementary input of other systems and methodological viewpoints at the SSM stage 4 (Conceptual Model) and illustrates an inherent cyclic or learning mode of engagement through reflective feedback of SSM Mode II (as per straight dotted arrow feedback lines in Figure 26).

Within all of this, the dominant perspective in this research program is that of the socio-technical: that technology in all its guises is an attribute of human endeavour and as such an integral component in human society, culture and behaviour, an approach that effectively amalgamates the inherent 'dualism of people and technology' (Coakes *et al*, 2002, p.1). Not viewing technology or a plethora of technological artefacts as separate 'controlling' agent or agencies, rather, seeing them as being embedded within human social fabric, both as consequence of societal evolution that in turn identifies potential problems (formulating need) and an inherent outcome of human ingenuity (meeting needs, resolving problems and formulating new social and technical approaches to perceived new opportunities) (Trist & Murray, 1990). It is a further characteristic of using such a 'grounded' research approach, that the analysis of existing publications, research reports, interviews, surveys, can identify a need for paradigmatic change that in turn can lead to innovation and 'Gestalt' like switch in current paradigm.

The adaptation to Checkland's SSM approach is outlined as follows in Figure 27 and Table 1. (Note: the column headed Research Activity in Table 1 elaborates each stage with regard to the research program activity)

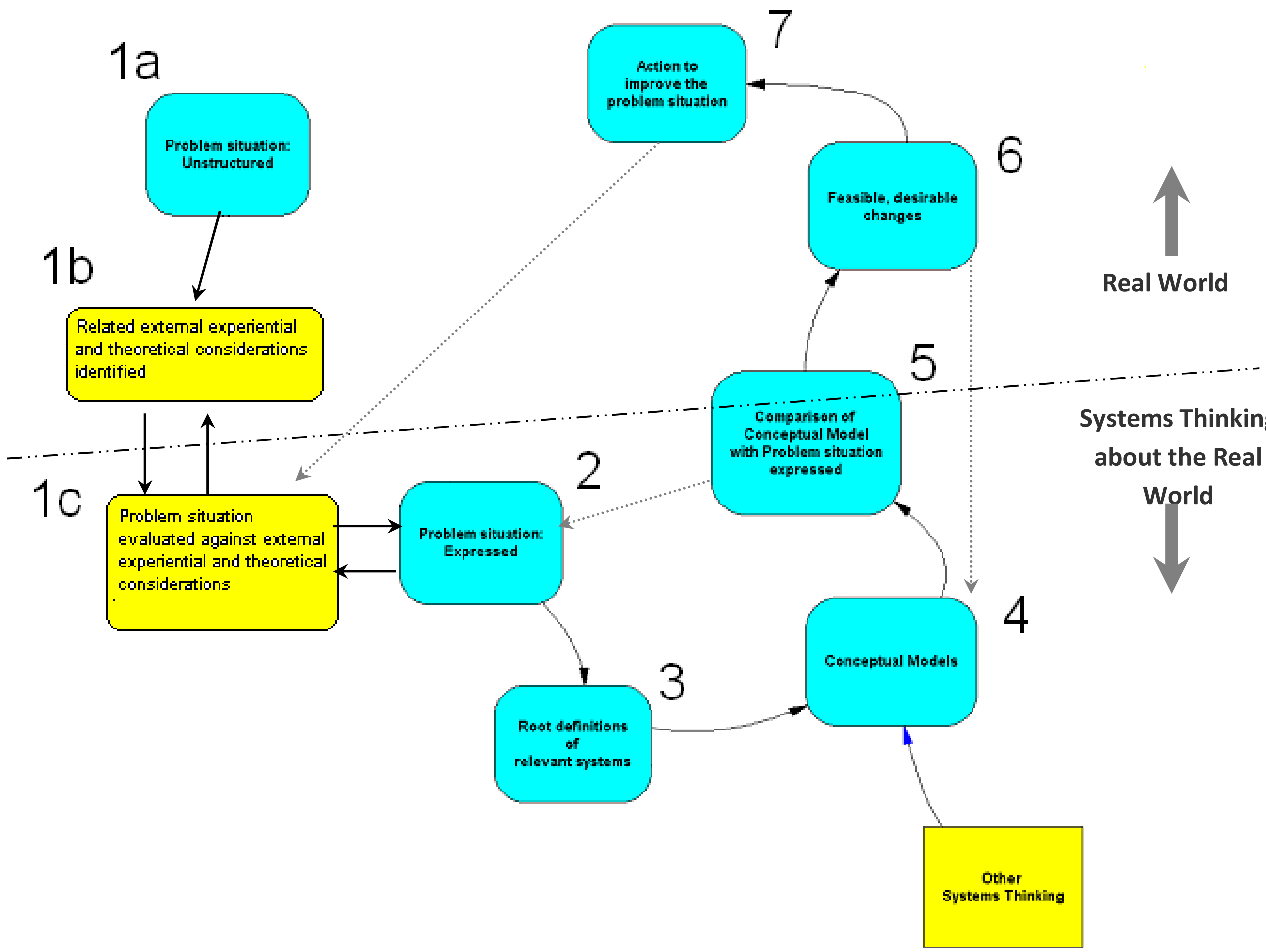


Figure 27. Adaptive Grounded Soft Systems Methodology Model

(Adapted from: Checkland & Scholes, 1990; Flood & Jackson, 1991, p.173; Pidd, 1996, p.132; Maani & Cavana, 2000, p.22; and Jackson, 2003)

Equivalent SSM Stage	Research Activity & Root Definitions
1a. The problem situation: unstructured	Identify Engineering and Technology based organizations with less than optimal performance and notably with limited use of advanced new-media visualization tools and systems as applied to management decision-making.
1b. Related external experiential and theoretical considerations identified	Identify related external experiential and theoretical considerations particularly as related to the introduction and application of virtual reality and related new media systems and technologies
1c. Problem situation evaluated against external considerations	Evaluate Problem Situation against external experiential and theoretical considerations.
2. The problem situation: expressed	Determine whether or not there are grounds for identifying necessary conditions that may apply to enable engineering and technology-based organizations to introduce and make effective use of new-media VR as a management tool
3. Root definitions of relevant systems	
Customers	A range of engineering and technology-based organizations including suppliers of visualization technology and systems.
Actors	A range of players across both executive management and support areas in organizations including: IT; corporate planning; engineering management; finance; and human resource management.
Transformation	Introduction of a transformative and potentially disruptive innovation (VR) to produce a shift from reliance on traditional executive management decision support processes to a more productive and performance directed use of dynamic, real-time, knowledge management oriented information access.
World view (or Weltanschauung)	A systems-based view of organizations as consisting of multiple related activities and players, functioning according to the relationships with and influences of internal and external conditions.
Owners	Executive management, company owners and shareholders, and the many internal company stakeholders, many of whom may be committed to traditional decision support tools and antipathetic to potentially disruptive change.
Environmental constraints	Existing: IT structures; executive support approaches and techniques; and current corporate core competencies.
4. Conceptual Models	Conceptual development of proposed taxonomy with input from various other systems thinking approaches and grounded theory.
5. Comparison of 4 with 2	Continuing analysis, testing and evaluation
6. Feasible, desirable changes	Proposed Taxonomy and Paradigmatic Framework enunciated.
7. Action to improve the problem situation	Proposed publication of taxonomy and development of software tools.

Table 1. AGSSM Research Activity as Adaptation of SSM Approach

(Adapted from: Pidd, 1996, p. 132; Maani & Cavana, 2000, pp. 21-22)

3.8 Summary of the Research Methodology and the Research Program

The methodological approaches as used throughout this research program are premised on the use of an adaptation of Checkland's Soft Systems Methodology. The central purpose is to identify and investigate systems elements that can be used to develop a taxonomy or classification of the core characteristics of engineering and technology based organizations that are virtual reality capable, or have the potential to make effective use of virtual reality systems in the management of such organizations.

The initial stage investigated existing published literature relevant to the introduction, application and strategic positioning of new media and virtual reality, with a particular emphasis on its use in engineering and technology based organizations, as well as experiential engagement with virtual reality research projects both within the University environment (RMIT I^3) and external industrial contexts. It utilises content analysis processes including discourse and interpretative analysis techniques, to gather data and identify relevant aspects of existing theory and practice, determine its current relevance and potentially identify any new aspects not incorporated or explained by theory and practice (Clarke & Star, 2008; Strauss & Corbin, 1990; Locke, 2001; Goulding, 2002).

Subsequent to the content analysis, an adaptation of Checkland's Soft-Systems-Methodology (Checkland & Scholes, 1990; Flood and Jackson, 1991; Jackson, 2003) is used in the development of relevant systems elements derived from interpretation of findings 'grounded' in the above content analysis and thematic development stage, primarily using category/priority-matrix analysis techniques on relevant publications. The systems elements are subsequently analysed to develop a relevant taxonometric structure, which is then tested through the use of a survey of industrial organizations.

Six core implementation strategies have been applied throughout the research program as follows:

1. <u>Extensive review of published literature and associated Category/Priority Matrix Analysis (as a Content Analysis instrument)</u> encompassing a wide range of published works, reports and related documents addressing practices in selection and utilisation of simulation technology and new media systems such as virtual reality, and developments in 3-D visualization technologies. The review also addressed issues in the role of innovation and technological change programs, strategic planning and strategic management, all with particular emphasis on the management of engineering and technology based organizations.
2. <u>Experiential engagement in and exposure to the design of virtual reality simulation systems</u>, in particular those involving three dimensional stereoscopic visualization strategies and associated technologies, particularly through access to the RMIT I^3 Reality Centre and other Virtual Reality Centre based systems. Direct engagement with industrial organizations involved with virtual reality research projects leading to development of various case study examples.
3. <u>Development of proposed theory informed taxonomy and classification framework</u> describing the behaviour and associated characteristics of the application of advanced visualization technology and simulation systems as effective tools supporting management decision making processes, specifically in engineering and technology based organizations and enterprises.

4. Observation, surveying and interview of users of Virtual Reality systems, as a specific means of collecting data about the causal influences and drivers on the selection, use and optimisation of virtual reality simulation systems, and the potential role for such systems in decision making environments.
5. Collation and data extraction from surveys of a range of companies classified as VR Users or Prospective VR Users and managers and staff involved in simulation and VR related activities.
6. Analysis of collected data as a means of testing the proposed taxonomy or classification framework, involving the development of a paradigmatic and taxonometric domain analysis tool and associated calculation of a Virtual Reality Index as a means of rating an organization's readiness for virtual reality style technology and systems.

Chapter 4:
Initial SSM Analysis & The Problem Situation 'Expressed'

4.1 Introduction to Initial SSM Analysis & The Problem Situation Expressed

This chapter is structured around the use of an adaptation of Checkland's original Soft Systems Methodology (Checkland & Scholes, 1990; Jackson, 2003) as illustrated in figures 26, 27, and 28 in Chapter 3. As such, this chapter addresses the following major components of the Adaptive Grounded Soft Systems Methodology being implemented as the prime research methodology:

1(a) The Problem Situation: unstructured

1(b) Related external experiential and theoretical considerations identified

1(c) The Problem Situation evaluated against external considerations

2. The Problem Situation: Expressed

3. CATWOE Root Definitions of relevant systems

- **C**ustomers
- **A**ctors
- **T**ransformation
- **W**orld view
- **O**wners
- **E**nvironmental constraints

The remaining SSM stages are subsequently addressed in the following Chapters 5, 6, and 7.

The approach used throughout the chapter presents accounts of six applied research projects as illustrative case studies related to the introduction of virtual reality and related simulation and visualization systems. The formal SSM 'problem situation' being addressed by the research program is subsequently developed and refined through AGSSM Stages 1a, 1b, 1c, and 2 creating a textual 'rich picture' of the problem situation expressed (Flood & Jackson, 1991). Overall, it constitutes a preparatory strategy for the conceptual development of the proposed taxonomy. As such it continues the multi-disciplinary approach of a Themed Knowledge Development allowing for multiple viewpoints from a wide range of perspectives. This approach allows for multi-disciplinary in the identification, collection and collation of formative data for the development of a taxonomy as a knowledge organization system or knowledge organization structure (Hedden, 2010). The findings and outcomes are derived from the published literature, as well as the author's engagement in multiple virtual reality projects, and interviews with experienced practitioners and participants in virtual reality projects both in Australia and the UK.

4.2 Virtual Reality Projects and Case Studies

4.2.1 Background to Virtual Reality Projects

Many hundreds of research and development projects involving the introduction and application of virtual reality technologies and related visualization systems have been undertaken over the past decade. A great many of such projects have been based within university research environments such as RMIT I^3 and/or in collaboration with commercial organizations. Whilst there continues to be a need for continuing research and development in new media and virtual reality related technologies and systems, it appears there is now a growing emphasis on understanding the actual role and use of such systems. In keeping with this shift from a focus on the actual technology to that of applications the author has been involved in a range of virtual reality projects as an academic consultant and as participant observer. These have involved the development and application of virtual reality tools and systems both through the operations of RMIT I^3 and independently with various 'user' organizations in both Australia and the UK. This experiential engagement is further documented in the following exemplar case studies derived from these projects. Note that company names and related product identifiers have been omitted at the request of organizations involved. This in itself is an indicator of the extent to which the use of such systems is considered to be a significant and sensitive component of commercial competitive advantage.

The following lists some of the more substantial project areas addressed, organization types and focus of the related project activities:

- Development of high-risk gas jet-fire and pool-fire simulations. Identified for application in both city and industrial-estate environments, undertaken by a major risk management consulting organization and supported through a Government research grant. Author as academic consultant and participant observer.
- Development of risk modelling and associated simulations for a proposed redevelopment of a large city-based railway station. Undertaken by a major risk management consultancy, in association with an engineering design and construction consultancy organization. Author as academic participant observer.
- Development of risk modelling and associated simulations for an high-risk traffic accident zone, involving a large road-bridge environment subject to high traffic volume, including large transport vehicles. Author as academic participant observer.
- Development of a collaborative virtual-design environment. Undertaken by a large global automotive manufacturer, with the author as local academic advisor, research supervisor and observer.
- Demonstration of a collaborative interactive multi-site virtual world product visualization and presentation. Undertaken by a large global automotive manufacturer with author as local academic observer.
- Development of risk modelling and associated simulations for a large, underground railway-station, in a high-risk fire situation. Project undertaken for a large state railway organization with author as academic consultant and participant observer.
- Development of a virtual world fly-over and detailed visualization of major traffic intersections and city streetscape. Undertaken for large suburban city council, with author as academic participant observer.

- Development of a virtual world fly-through of a new very large multi-storey building. Project undertaken by an architectural consultancy organization during building construction. Used to demonstrate to potential clients how the accommodation space could be configured/re-configured. Author as academic participant observer.
- Development of Defence training in virtual environments, undertaken by Defence with the author as local academic research supervisor and observer.
- Use of virtual world virtual reality systems for fly-though visualization of inventory data for a nation-wide hardware store. Developed and demonstrated by a large computer company and software development organization with author as participant observer.
- Development of fly-through visualization of a large city central business district for both local government planning and traffic management purposes, as well as emergency services management. Author as participant observer.

Examples of the many issues that arise in the introduction and application of virtual reality visualization projects can be seen in the following exemplar case studies of virtual reality projects derived from the above listing.

4.2.2 Illustrative Case Studies

4.2.2.1 Inter-VR Centre Simulation Project

A complex demonstration of collaborative user engagement and interaction using the I^3 large-scale Reality Centre systems involved the real-time connection of I^3 (Melbourne, Australia) with a similar Reality Centre facility located in London, UK. In this instance, the system was being used for a simulation of the latest model of a large global automotive manufacturer. Designers located at the London and Melbourne Reality Centre locations were able to view the simulation simultaneously and communicate using normal hands-free audio systems. Control of the simulation was however shared between the two locations. Thus, a designer in London was able to initiate design changes and have these displayed simultaneously in Melbourne for immediate discussion and decision on choice of design changes. Similarly, designers located in the I^3 Melbourne Reality Centre were able to introduce and make changes to the simulation in real-time with the new images being displayed in both London and Melbourne simultaneously.

Whilst specifically premised on demonstrating a collaborative design environment involving very complex and expensive visualisation tools, control systems and access to international telecommunication networks, this implementation also provided a unique demonstration of how management problems compounded by distance, time and space, can be overcome. It also demonstrates a system requiring sophisticated technical skills in the hands of at least one of the end-users at each end of the communications link. Matching this form of application to the context of a company boardroom environment clearly indicates a requirement for skilled technical support staff and/or specialised training for board-members. However, the use of such systems clearly has the potential to lead to development of conditions under which decisions can be made. This particular project also demonstrated the role of virtual reality systems in what may be considered as a synchronous communication process, wherein there is real-time communication in both directions and an occurrence of visual events at or about the same time, that is, simultaneous or real-time communication and collaborative interaction with a system model. Any slight delay between actions due to communications technology constraints had little or no impact on the demonstration, with ideas and decisions being considered and communicated in a short time-span, regardless of the geographical distance between participants.

There was however one significant constraint on the imaging and visualization being used in this application. Namely, that the images presented to users should represent the actual physical object as precisely as possible, including the physical dimensions of the vehicles being displayed on the Reality Centre projection screens. This requirement for direct correlation and image fidelity with the real-world characteristics of shape, size, and colour, places serious constraints on the particular form of imaging technology that can be used for such visualizations. Although, in most such cases the use of accurate scaling of the image relative to the actual object under consideration is sufficient.

4.2.2.2 Collaborative Virtual-design Environment Project

A large industrial manufacturer implemented a major design project involving the progressive conversion of existing CAD graphics used by some 200 parts and components suppliers, to create fully defined 3D virtual objects importable into multiple geographically distributed (global on-line) virtual reality supported design and development environments. In time, even subtle design changes within the virtual world version of the overall product will result in automated adjustments to the virtual design for the multiple component parts effected by any proposed change. Duly exported back to the manufacturing suppliers (again geographically distributed internationally) these adjustments may then result in appropriate re-engineering/design, re-tooling, and subsequent supply of new components much faster and potentially cheaper, than previous techniques and procedures.

This 'real world' example of both the introduction of 3D visualization based new media and the interaction between complex systems of systems, also demonstrates the continuing evolution and application of contemporary systems thinking as an holistic approach to the development of new ideas and their implementation. In this case, the introduction of a geographically distributed 3D virtual reality design environment providing an effective alternative approach to the use of traditional 2D based visualization design tools. The new approach introduces and integrates, in a systems context, contemporary new media based tools for problem definition and resolution in an area of considerable design complexity. In effect, it provides an example of the second characteristic, obsolescence, in the earlier discussion on the adaptation of McLuhan's Tetrad applied to virtual reality (see Chapter 2.4.5).

It also raises significant issues in relation to the need for distributed access to a common knowledge management system and information repository for key specifications, required characteristics and performance parameters. It also identified a critical need for rigorous systems of systems change management control, without which overall system coherence rapidly disassembles. Perhaps the most significant outcome of this project was the clear demonstration that innovative design changes in this form of collaborative virtual world environment are inherently subject to virtually immediate challenge and discussion by the multiple concurrent users, enabling rapid identification, analysis, and potential progress of technological innovation and associated change management. It also raises issues with regard to the need for contiguous technological systems coherence, both hardware and software based, across the many organizations involved.

4.2.2.3 Virtual Reality Centre Emergency Services Training Project

A 'semi-immersive' virtual reality simulation of fire and smoke conditions in a major underground railway station was developed in response to concerns about the safety of passenger and station staff in such conditions. This project addressed the management of fire related hazards and associated risk minimisation through training of station staff and emergency response teams for effective response and appropriate deployment and use of mitigation systems. The simulation used Virtual Reality Centre display technology and highly skilled media production personnel to provide a semi-immersive visual and auditory environment (complete with surround-sound effects of a panicking crowd and visual effects of serious fire and smoke activity). The design initially followed a prescribed model for fire, smoke, mitigation technology, crowd behaviours and decision-making as developed by the client organization.

However, when risk assessment specialists with specific expertise in fire behaviour and complex simulations reviewed the proposed model, they identified and challenged a range of assumptions and systemic engineering anomalies, apparent within the model and thus at risk of being translated into the final visualisation product. This experience strongly identified that development of such complex visualization products and virtual world simulations of real world conditions, clearly requires product specification based on sophisticated technical knowledge and understandings of the underlying principles on which product specification is established. Otherwise, there are serious risks that inherent weaknesses may not only appear, but even be amplified in their effect.

Whilst there was certainly clarity of purpose and a demonstrated strategic intent on the part of the client organization to initiate an innovative approach to an identified need for specialised training, the above limitations had the potential to create serious problems. This was particularly so as one of the key purposes for this simulation was to develop effective decision-making skills for emergency workers in situations of high stress. Semi-immersive interaction by participants was a required characteristic of this application. For example, pre-determined events were to be introduced to the participants with some degree of decision choice on response strategies, thus enabling user interaction with the system modelling. Subsequent de-briefing and analysis of decision choices could then lead to either revision or further targeted training. The actual visualization strategy used in this project focussed on cause and effect conditions in a particular context, where the users of the system would all be familiar with the physical environment being used. This translated to a design and production decision not to extend visualization to a level of photorealism. In this particular instance, this decision worked well, with computer generated animation graphics readily interpreted by users familiar with the environment. Subsequently, this development led to extended discussions with Police and Emergency Services over the role of immersive and semi-immersive visualization media and 3-D projection technology in emergency services training.

4.2.2.4 Risk-based Systems Visualization Project

The following is an example of an engineering risk management company seeking to explore the possibility of using the introduction of virtual reality systems and tools, to enhance and extend its service capabilities and thus consolidate its strategic position in the marketplace. The author acted as academic advisor during the development and implementation of the Internet-delivered virtual reality simulation and visualization product. In this instance the 'problem situation' was clearly expressed as determining and implementing the requirements for the development of a interactive simulation product. A product targeted at enabling engineering managers to assess risks and make planning decisions relative to identifying and assessing hazards and managing potential damage from fire or explosion resulting from spill of hazardous materials or damage to containment of hazardous materials. The software design and development for the project was funded through an AusIndustry Graduate Start Research Grant. In this particular instance, the consulting company has considerable experience in analysis of such environments and events and has in-house expertise in the modelling and simulation of:

- Jet-fire models resulting from rupture and ignition of high pressure gas pipelines
- Pool-fire models resulting from leakage and ignition of flammable liquids
- Explosion models resulting from catastrophic failure of containment or build-up of leaked volatile reagents prior to ignition
- Toxic cloud models resulting from the release and vaporisation of toxic chemicals (Robinson, 2002).

Whilst the mathematical modelling of the above scenarios is itself quite complex, the company's considerable in-house expertise and high level of competencies in these areas of analysis enabled it to undertake the complex modelling and simulation development work. In turn it was able to demonstrate that end-users unfamiliar with the complexities of such modelling could use the developed system in making effective decisions about managing hazardous environments and minimising risk of damage resulting from hazardous events. The final product used interactive visualisation strategies to design a site plan and determine optimum placement of hazardous materials for minimum hazard effect and design of hazard mitigation strategies (Robinson, 2002). In the initial stages of the project the imaging systems used were relatively simple with essentially 2-D, plan or elevation views. As the project progressed, so the imaging technology and systems were enhanced with 3-D visualization and fly-through effects. Similarly, adding more detailed imaging of physical parameters, such as: dimensions and scale, surface shape and texture mapping, environmental parameters such as walls, barriers and surface materials, added an enhanced level of realism (Robinson, 2002).

This desktop computer implementation of a virtual reality visualization project provides little 'immersion' in the media, as would be the case in a full virtual reality centre implementation. However, it attracted attention from a number of government departments and agencies for the effectiveness of its approach to addressing complex engineering problems of critical importance, using relatively low-order/low-cost virtual reality visualization technology (PC-desktop with Internet access). As a result of this innovative project the company was awarded a place as a Finalist in the TELSTRA and Victorian Government Small Business Awards program.

Such relatively simple implementations do however raise a number of questions about the direction and long-term efficacy of such plug and play techniques. There is for example a requirement on the developer of such systems to meet the most demanding of expectations for high-level understanding, skills and expertise in the underlying discipline (very clearly met in the particular case outlined above). However, as the complexity of the issue or problem being addressed rises, there may well be a level above which the requirement for advanced expertise and understandings of the actual end-user become more dominant. In this case, the plug and play virtual reality systems may falter or potentially fail to deliver meaningful outcomes. Determining whether or not such a critical point is likely in such systems and how to address it remains an unanswered challenge.

4.2.2.5 Major Traffic Intersection and Streetscape Visualization Projects

A large Local Government Council undertook development of a semi-immersive 3D virtual world fly-over and detailed visualization of a major traffic intersection and city streetscape as part of its City and streetscape planning and traffic management development activities. In this case, a Virtual Reality Centre context was used as a semi-immersive demonstration environment. Users were able to visually fly over the suburban area to view the site and then fly down to view from normal street level. This exercise demonstrated the potential for systems connectivity to existing land-use and cadastral data-bases and information repositories, to be able to identify a variety of essential landscape/streetscape/services features with a desirable degree of specificity and accuracy. Again, there was a clear requirement for close correlation between the virtual world visualization and the actual real world.

A related project involving a fly-through visualization of a large city central business district also demonstrated in a similar manner the value of such a visual survey for local government planning purposes, electricity, gas, and water supply planning and management services, and emergency services management. In the case of emergency services, the use of real-world visualization of streetscapes and buildings demonstrated the potential for use, in association with traffic management systems, in training staff for the deployment of emergency services vehicles and resources.

Both projects also identified the potential problem of inadvertently processing out-dated information derived from inadequately maintained data-bases and information repositories. Clearly, for such systems to be of genuine strategic value for decision-making they must be supported by reliable and validated data sources. They also need to be supported by technical users or technically skilled support staff with the relevant knowledge and skills to interpret and explain the interaction and integration of the various, and at times very complex, systems being represented/displayed.

Both of these examples used Virtual Reality Centre facilities for large-scale visualizations enabling group discussion *in situ*. It was also clear that desktop technology with access to such applications could be of considerable value to a wide range of potential users, including city council planners, engineers, property developers, energy supply companies, water supply and sewerage services, rail, tram, road management services, and emergency services.

4.2.2.6 Multi-story Building Visualization Project

An architectural consultancy organization development of a virtual world fly-through of a new very large multi-storey and multi-purpose building highlighted the potential for decision-making using a mix of imaging sources and visualization display systems. The project was initiated during the conceptual and design stages of the building and then progressively developed as the building was being constructed. The application used a mix of both actual photographic images and design graphics imaging. Integrating these images enabled the developers to create a highly realistic, and continuingly updated, fly-through visualization of the building as it progressed through construction stages.

The prime purpose for the visualization was to demonstrate to potential clients how the accommodation space in the building could be initially configured and subsequently re-configured should the need arise. The mix of real-world and graphics-world imaging in this case giving added potency to the value of the visualization. The potential to run this application on either a desktop or power 'notebook' computer provides further potency as it allows highly flexible utilisation and adaptability to the decision-making context. However, user interactivity was essentially limited to selecting the direction of view and movement of viewpoint. The actual interaction with the system model required considerable expertise to produce new adaptations and changes. A number of these projects have been initiated in recent times, with mixed reception. Whilst it can be clear what is being proposed in a general sense, there is again a significant degree of complex (design, building, and construction) technical knowledge and skill required to support 'effective' decision-making in such contexts.

4.3 The Problem Situation

4.3.1 AGSSM Stage 1a. The Problem Situation: Unstructured

Many complex ICT related issues face contemporary engineering and technology based firms and organizations. Such issues typically come both from increasing turbulence in their surrounding commercial/economic environment. For example, increasing flow rate of information into and out of organizations, as well as an increasing dependence on sources of information and knowledge processing. Similarly, from turbulence arising from continuing changes in, reliance upon, and need for, currency in their technology base. These influences collectively result in continuing adaptation of products, processes and skills as enterprises struggle to achieve and maintain competitiveness (Tidd *et al*. 2005; Tidd & Bessant, 2009). This in turn places engineering and technology based firms and organizations in a seemingly constant state of technology transition. The status of 'what is', becoming potentially quite unstable, even at times unpredictable beyond relatively short time frames. Managing such instability poses very real concerns and challenges for engineering and technology managers (Balogun, & Hailey, 2008; Tidd *et al*, 2005; Tidd & Bessant, 2009; White & Bessant, 2007).

The problem 'situation' being focussed on throughout the research is that of the uncertainty surrounding the introduction and use of virtual reality systems and virtual world based strategies and techniques in the management of engineering and technology based organizations looking to improve their performance. It is asserted that such organizations with limited or no history of experience in the use of contemporary new media (such as virtual reality) in support of management decision-making, are at potential risk of becoming culturally and commercially 'unsustainable' in an increasingly technologically literate marketplace.

Many large engineering and technology based organizations are aware of and make use of advanced visualization systems, including virtual reality systems and technologies, in their product and process design and development areas of engagement. However, few if any are aware of the potential for extending the application of such systems and technologies into the actual management processes of the enterprise, or at best are extremely wary of making such a radical transition in their existing processes. The extent to which the active use of virtual reality style new media has played a part in executive decision-making has until recently been limited largely by the absence of media literacy and practical skills and expertise in the use of new media at executive management levels. This constraint now appears to be rapidly retreating with both the growing maturity of new media and related technologies and its increasingly ubiquitous presence and subsequent building of expertise in its use, across all levels of society at large. However, the demonstrable outcomes are all too often at serious variance from what was originally or supposedly intended. This is illustrated in the list of virtual reality projects discussed earlier. Most, except the 'Inter-VR Centre demonstration project' had at best very limited definitive intentions, they were in essence explorations of what might or might not work, with in most cases a range of final outcomes.

The adequacy of boardroom decision-making relative to the handling of the introduction of new technology has a long and too often clouded history of variable success. The presence and extent of use of new technology in the corporate boardroom has been the subject of significant research by members of the European Institute for Technology and Innovation Management as commented on by Erkki Liikanen when European Commissioner for Enterprise and Information Society: 'They rightly advocate bringing technology and innovation into the boardroom. They claim that its absence is not unavoidable – the means exist to provide the board with the necessary support' (Liikanen (2004) in Probert *et al*, 2004, pp. ix-x).

Much earlier, 1980's futurist commentator Alvin Toffler's enigmatic predictions of the impact of innovation and change on what he called "The Museum of Corporate Dinosaurs" (Toffler, 1985, p.1) provides a level of insight into the need to manage innovation and change programs through his perceptions of industry and corporate failure to pro-actively embrace change as a strategic tool. The result, as he saw it: non-adaptive corporations, corporate dinosaurs (Toffler, 1985) locked into the past through out-of-date strategies, inefficient processes and costly mistakes in design, resourcing, quality, timelines, and skill miss-matching, or, in the contemporary language of today, potentially 'non-sustainable' organizations.

4.3.2 AGSSM Stage 1b. Related External Experiential and Theoretical Considerations

Few organizations develop their own ICT systems and technologies, predominantly, such systems are externally sourced and configured. This is very much the case with contemporary virtual reality systems and new media in general. Continuous technological development in electronic technology and in particular its related areas of application in transmission media, telecommunications, imaging, audio, and digital computing, have created conditions in which the underlying ICT technology bases of most enterprises have undergone constant innovation and change, seemingly independent of the final user base.

So also the associated communities of practice have undergone continuing social, cultural and organizational change, with at times dramatic discontinuities. Rachel Lauden (1984) writing from the perspective of a philosopher of science and Professor of Science and Technology Studies at Virginia State University, similarly argued that technological change evoked influence from a wide range of factors including, but not limited to the cognitive, social, organizational and economic environments of an organization. She further emphasised the key role of an organization's skills, expertise and knowledge base: 'Besides the well known economic, political and social influence on technological change, shifts in the knowledge of the practitioners play a crucial role in technological development' (Lauden, 1984, p.2). Whilst this may be so with regard to the fundamental technology bases for production and manufacturing activity, it has not as yet been as evident at the 'Boardroom' level, although the telematics mechanisms and communications techniques common to social networking (smart phone, iPod, iPad, SMS, Blog, and roaming data-base access) are progressively appearing at executive levels (Fraser & Dutta, 2008).

Effective change management strategies not only address technologically focussed issues, but also the myriad of issues and concerns that require serious communication, consultation, engagement and commitment, both with and on the part of both management and staff (Afuah, 2003; Balogun & Hailey, 2008; Ettlie, 2000; Tidd & Bessant, 2009; Zegveld, 2006). Afuah (2003) makes a particularly pertinent observation that goes to the core of successful innovation and change strategies: 'It takes a good strategy, but... it also takes an appropriate organizational structure, systems, and the right people to implement the strategy. Yes, it takes people' (Afuah, 2003, Preface pp.vii-viii). The core constituents of an organization are not simply its technology, its rules and regulations, its processes and procedures, but primarily those who populate it, from shareholders through executive management to the general staff, full-time, part-time and casual workers. It is in effect the skills, expertise and attitude of an organization's people that constitute the core competence and intellectual capital of the firm, that primarily enable it to carry forward innovation and change (Prahalad & Hamel, 1990). However, such simple statements also carry with them embedded complexities as reflected in the constructs of: 'shared vision, leadership and the will to innovate' (Tidd & Bessant, 2009, p.101).

The role of contemporary new media in the continuing evolution of human culture is a growing reality, in a world in which the networked communication of information across and between interested communities of practice is increasingly a prerequisite condition for both social and business engagement (Boczkowski & Lievrouw, 2008; Castells, 2004). In effect, Castells' 'networked society' (Castells, 2004) requires that we develop new modes of communicating and representing new ideas and concepts, using new constructs of epistemological and ontological reasoning and extraction of meaning from virtual or synthetic world experience. This raises many questions about the capacity of the user to perceive, let alone understand and duly interpret, meaning embedded in complex images and virtual environments (Desouza & Hensgen, 2004). In developing sophisticated imaging systems and technologies, we need to be cognizant of the inherent complexity of our visual perception processes and various mechanisms and constraints that impact on the user's ability to process complex visual information and extract meaning (Danesi, 2002). Visual perception involves integrating elements of an image to establish meaning, whilst at the same time segregating and differentiating objects within our field of vision, separating them from their backgrounds to similarly extract meaning from their images (Friedhoff & Peercy, 2000; Lacy, 2009). Thus, a variety of cognition factors affect our capacity to process and extract meaning from the images of the world that surrounds us (Danesi, 2002) and by extrapolation, from the imaging of virtual world data being displayed and explored in virtual reality and virtual world environments.

4.3.3 AGSSM Stage 1c. The Problem Situation Evaluated Against External Considerations

Determining potential indicators for not just feasible, but viable technological innovation, has been a challenge addressed by many (Christensen in Dorf, 1999). Whilst much research has focused on the characteristics of the innovation process and specific exemplar innovations, determining how to select a particular innovation from a range of potential or competing entrants has proven to be a complex task. Many seemingly worthy innovations fail the tests of diffusion and adoption and are lost. How then to structure decision-making for innovation contexts? Rogers (2003) researched these issues over many years and has described decision-making in innovation contexts as the set of processes through which the innovator: initially identifies the innovative idea and associated knowledge; develops a commitment or 'attitude' towards the idea; makes a determination or decision to act on the idea; and formulates an implementable approach and strategy to carry the innovation forward.

Rogers further goes on to describe three specific types of innovation decisions resulting from innovation related decision-making in the context of organizational decision-making:

1. *Optional innovation-decisions: choices to adopt or reject an innovation that are made by an individual independent of the decisions by other members of a system.*
2. *Collective innovation-decisions: choices to adopt or reject an innovation that are made by consensus among the members of a system.*
3. *Authority innovation-decisions: choices to adopt or reject an innovation that are made by a relatively few individuals in a system who possess power, high social status, or technical expertise.*

(Rogers, 2003, p.403)

Hargadon (1999) building on earlier work by Rogers (circa 1962) describes three predominant research trajectories that appear to help define successful diffusion and adoption of technological innovations. Characteristics of the innovation: For example, the extent of any advantage it may provide over existing practices or products, its compatibility with existing processes and the extent of its complexity. Characteristics of the adopter and the adoption decision: Most commonly these are characterised by organizations that either engage in early adoption practices or explicitly delay the adoption decision and in turn become 'late adopters'. Characteristics of the social environment surrounding the population of potential adopters: Communication processes and the characteristics of the social systems and structures within which the organization operates are the key influences here (Hargadon, in Dorf, 1999).

Another approach to decision making for innovation comes from the earlier works of Prof. Michael Porter (1980, 1990). Porter's view was drawn from the perspective of an economist rather than a technologist and endeavours to link technological innovation to the five forces he describes as driving industry competition. His work is generally expressed as a sophisticated SWOT analysis (Strengths, Weaknesses, Opportunities, and Threats). Whilst widely accepted and practiced in the commercial sector and informative about the market positioning strategies for firms, it also appears to have inherent limitations, particularly when considering the role of technological innovation in firms operating in the ICT (information and communications technologies) sectors (Tidd *et al*, 2005).

The five forces that Porter (1980) ascribes to driving industry competition are: Relations with Suppliers, Relations with Buyers, New Entrants, Substitute Products, Rivalry amongst established firms. He subsequently asserts that: 'The goal of competitive strategy ... is to find a position in an industry where a company can best defend itself against these competing forces or can influence them in its favour' (Porter, 1980, p. 4). Porter went on to argue that there are four generic market strategies that apply: Overall cost leadership; Product differentiation; Cost focus; and Differentiation focus, with a necessary choice that companies must make: Innovation 'leadership – Taking the position of industry and market leader, with all the inherent risks associated with being 'first to market', handling new technology, new ideas, new knowledge, new processes, new skills. Innovation 'followership' – The status of being 'late to market', allowing the leader to take the risks and brunt of problems resolution, requiring strong competitor analysis skills and a capacity to compete on costs in subsequent manufacturing stages (Attributed to Porter in Tidd *et al*, 2005, p.121; Johnson *et al*, 2008).

Porter's framework is inherently highly adversarial in nature; as such it is difficult to see a comfortable or readily workable locus for strategic alliances and collaborative engagements between firms, and their suppliers (two widely utilised strategies in the ICT industry). Whilst a valuable tool for examining and understanding historical changes and re-distribution of power across and within industry sectors, Tidd *et al* (2005) argue that it only partly addresses effective innovation planning and management strategies focused on the future: 'Porter's framework underestimates the power of technological change to transform industrial structures, and over-estimates the power of managers to decide and implement innovation strategies' (Tidd *et al*, 2005, p.123).

The potential to use new visualization systems such as virtual reality to explore complex collections of data, to visualize data far beyond the normal modes of bar-charts/graphs/pie-charts is of particular interest. Given the widespread development of new information management systems and the associated growth in the numbers of data sets and quantity of data and information being collected and stored for ready access, new forms of data interrogation and display are essential for effective decision making (Jones, 1996). New visualization systems such as virtual reality are one means of addressing these issues and the multi-dimensional analysis that they invoke. Accordingly, virtual reality toolsets for data visualization have continued to develop in both complexity and sophistication of application, the generic guideline being to provide an avenue for users to interact directly with their data, whilst effectively immersed within it.

Applying our understanding of these factors to the mechanisms of immersive virtual reality media and their potential place in the management processes of organizations, can enable us to better understand and use the key parameters that can in turn enable an effective experience of immersion in a simulated or virtual environment, and then, to extrapolate or adapt such meanings, where relevant, to our understandings of the real world. Betz (2003) calls on the earlier work of German philosopher Immanuel Kant (circa 1800) to explore and explain something of the mind's capacity to comprehend the world around us: 'Reasoning determines what the mind does with sensory inputs, or perception. Mind assembles sensory data into conceptions, representations of objects – pictures, images, representations, ideas of things existing outside the mind, outside the self – external in the real world... An external world filled with objects is the world about which the mind constructs mental images and concepts' (Betz, 2003, p.403). Whilst Betz was seeking to explore and explain something of the mind's capacity to comprehend and make rational determinations about the world around us, his subsequent imputation and use of Kantian styled argument implies a form of *a priori* reasoning in our comprehension and interpretation of images and sensory stimulation from our surrounding world (Papineau, 2004). Nothing could be further from the truth when dealing with rampant virtuality in some immersive synthetic world environments, where nothing is necessarily what it seems and may well have no actual referent in the real world (Hunsinger, 2008). This potential for confounding of the senses raises many issues in relation to the evolution of 'virtual' working environments and the concept of virtual companies, organizations, and in effect virtual social worlds. Many such environments appear to have no real world existence other than their image or presence in cyberspace, for example the islands and organizations in SecondLife, or even the seemingly ubiquitous presence of the 'Amazon.com' bookshop, curtesy of access to the internet and the world of virtual (or read 'real') shopping via the world wide web.

There is also a further aspect to perception that goes beyond the above largely physiological exposition: the use of images and synthetic environments as representational mechanisms that provide insight and/or the means of exploration of ideas. In effect, this involves a means of invoking a new way of thinking, whether about the old, the new, and the unknown or at best, areas or issues with a high level of uncertainty (as may often be the case in company management decision-making contexts). This implies taking virtual reality and new media imaging and user sense stimulation to a new level of process. For example, in a 'Boardroom' context, as a means of exploring 'possibilities', searching for hidden associations or similarities between unlike parameters, explorations in design where new concepts that could not be constructed or easily realized in the real world, can be created as imagined and their potentials explored and investigated. As such, a new means of communicating ideas, the explicit use of communications media as thinking 'tools' in our framework of cognitive models that we use and apply to thinking about, and our knowledge and awareness of our world (Boellstorff, 2008; Friedhoff & Peercy, 2000; Heim, 1993, 1998).

4.3.4 AGSSM Stage 2. The Problem Situation: Expressed

The nature of the 'problem situation' being addressed throughout this research can be summarised as:

- determining what necessary conditions an engineering and technology-based organization should meet in order to successfully introduce and make effective use of virtual reality style new-media as a management tool.

Consideration of the many factors influencing engineering and technology based organizations relative to decision-making support systems and in particular the use of advanced visualization tools and systems, provides a basis for this proposed expression of the 'problem situation' and subsequent conceptual analysis for the proposed taxonomy.

4.3.5 AGSSM Stage 3. Root Definitions of Relevant Systems

4.3.5.1 Proposed General Root Definition

The following approach of developing 'root definitions and conceptual models to explore perceptions of the real world' (Checkland, 1993, p.223) as expressed in the preceding exposition of the problem situation, enables identification of the many incipient systems and issues that impact on the introduction of virtual reality into engineering and technology based organizations. In turn it helps to place the established problem situation in a SSM context. Such 'root definitions' provide insight into the many elements and influencing factors that can affect change in both the operational 'real world' as outlined and addressed in the foregoing stages (1a, 1b, 1c, and 2) and the virtual or 'logical' structural and process connections between constituent components.

In this particular instance, the following general root definition is proposed:

> 'The proposed solution (the proposed taxonomy) is to be expressed as a theoretical construct, a virtual model of a set of perceived relationships that it is argued collectively influence engineering and technology based organizations in such a manner that, a clear and demonstrable understanding and use of such relationships, skills and competencies, can strategically position such organizations to effectively transition from traditional forms of management decision making, to achieve higher levels of performance and potentially induce paradigmatic change across or within specific sectors of the organization, through the effective use of virtual reality systems and technologies in decision making.'

The following sections address the classic Soft Systems Methodology CATWOE statements relative to the above general root definition.

4.3.5.2 Customers

A range of engineering and technology-based organizations including suppliers of visualization technology and systems.

In a systems thinking context, the 'customers' root definition represents the many people or organizations that can or could either benefit from or conversely be impacted on, either directly or indirectly, by the proposed solution to the expressed problem situation. In this instance the research has been strongly focussed on addressing the needs, potentialities, capabilities and competencies of engineering and technology based organizations and by default the owners and shareholders of such enterprises. This may include a wide range of enterprises from engineering design consultancies, manufacturers, service organizations, resource based organizations (such as mining companies, extractive and processing plants) and ICT equipment and software suppliers. Examples of these can be seen in the various enterprises undertaking virtual reality projects as outlined earlier.

As the capability of new and evolving technologies (and particularly new media) continues to grow, so also does the potential for them to impact on virtually all aspects of company products, services, processes, markets, customers, suppliers, and requisite skills and production technologies in turn. As such, this constitutes a certain recipe for potential organizational instability and uncertainty: 'The more volatile the business context, the more uncertain the assumptions. In the presence of disruptive technologies or rapidly changing business models, valuations become highly suspect and must be evaluated and adjusted frequently' (Applegate *et al*, 2003, pp.124-125). Constant changes or adjustments to shareholder expectations of organizational performance, coupled to continuing change in technology-base and an increasingly technologically focussed/aware customer expectations, are invariably a forerunner to uncertainty both within an organization and in its surrounding environment, including both its customers and elsewhere in its supply chain.

4.3.5.3 Actors

A range of players across both executive management and support areas in organizations including: IT; corporate planning; engineering management; project management; finance; and human resource management.

Across all of the above forms of engineering and technology based organizations it is primarily the executive decision makers, group managers and information management personnel that constitute the communities of practice that are the primary potential users for the proposed taxonomy. This was particularly evidenced in the virtual reality project outlined earlier in 4.2.2.4. In this instance, the project was strongly supported by and in turn influenced the two key company directors responsible for setting the organization's strategic direction and technological performance. Successful diffusion of a given innovation through an organization (or other social system) can be very much constrained by the nature of an organization's decision making regime, almost regardless of identified need or potential benefit from the innovation, except where defined innovation processes and guidelines for innovation-decisions have been instituted within the organization. Early adopters (an expression first proposed by Rogers) within an organization can have a significant influence on subsequent diffusion, although still constrained by the essentially social structures and attitudes of the organizational members (Hanson, 2008; Rogers, 2003).

4.3.5.4 Transformation

Introduction of a transformative and potentially disruptive innovation (VR) to produce a shift from reliance on traditional executive management decision support processes to a more productive and performance directed use of dynamic, real-time, knowledge management oriented information access.

The outcome of transformation can be seen in the potential for taking conventional management practices, often idiomatic to particular organizations or industry sectors, and using the presence and application of new technology as a means to institute paradigmatic change. Change that is strategically actioned across both the practices of executive management and the enterprise as a whole, incorporating corporate and technological competencies, practices, knowledge and skills, and strategic positioning relative to competitors. The large manufacturing organization instituting a global virtual design environment (see project outline in 4.2.2.2) clearly understood the significance of instituting substantive and strategic change or 'transformation' in the way it undertook and managed innovative design in a highly competitive and dynamic environment. Whilst change, in its many forms and levels of intensity, may be an endemic (and at times seemingly chaotic) feature of technology based organizations and firms, all such organizations are affected to some extent by current norms, market expectations, and pre-conceptions, about the nature and characteristics of contemporary or new technology of the day. This leads to the presence of a discernible ruling technological paradigm or theory at any point in time, at least within given industry boundaries.

However, such paradigms need to be seen and interpreted in terms of the specific strategic needs, innovation potential and operating conditions of the individual firm or organization. Ulhoi and Gattiker (1999) strongly express the view that there is strong connectivity between a current or ruling technological paradigm and the processes of technological innovation or: 'normative prescriptions for the direction technological change must take' (Ulhoi & Gattiker, 1999, pp.7.88-7.89) and through which an organization actively engages in its innovation processes. In this regard they subsequently found it to be paradoxical that few seemed to consider the institutionalising of technological development within the firm or with regard to setting the direction and shape of technological trajectories. The extent to which the social structures and norms of the firm both influence and are influenced by resident technology and innovation practice or the introduction of new technology, techniques and innovative processes, is a critical factor in determining the currency and influence of a perceived technological or techno-practice paradigm: 'The domination of technological paradigms is due not only to technological forces but also to social, political, and organizational forces. This calls for a stronger focus on the social embeddedness of the technological innovation process' (Ulhoi & Gattiker, 1999, pp.7.90-7.91).

The concept of paradigm as used above by Ulhoi & Gattiker (1999) is largely derived from the work of Thomas Kuhn (1962) and his framework for scientific development. It also leads to considering the role of internal paradigmatic frameworks addressing the technological and technology management orientation of firms. (The role of a paradigmatic framework relevant to the introduction of new media and virtual reality technology into a firm is developed further in chapter 6.4) Kuhn's work, and in particular his notion of scientific paradigms (Kuhn, 1962) in turn has raised considerable conjecture and argument over the years, both supportive and against. Gutting (1984) positions Kuhn's work, in particular his construct of 'paradigm', and its function in relationship to understanding advances in science, as providing a means of modelling or providing exemplar forms of process and practice: '…that is, universally recognized scientific achievements that for a time provide model problems and solutions to a community of practitioners' (Gutting, 1984, p.49). Gutting also goes on to comment on the extrapolation of Kuhn's work into the field of technological innovation and development and associated technological change, as argued by Edward Constant (1984). In doing so, he identifies in Constant's work the development and definition of the notion of technological revolutions and perceives this as representing a shift from Kuhnian paradigmatic thought: 'In Kuhnian science… scientific revolutions are simultaneously innovative and eliminative… Constant's technological revolutions, by contrast, need not (and typically do not) represent an either/or choice for the technological community. They occur "when a new tradition of practice comprising a new normal technology is embraced" by any community of practitioners' (Gutting, 1984, p.53).

This interpretation of Constant's work on technological revolution certainly describes the current evolution of new-media technologies and the development of new 'communities of practice' embracing new-media and drawn from across and within industry, commerce and society at large, with the potential for inducing 'paradigm switch' through radical change. New-media and advanced visualization technologies in particular, provide a clear technological revolution in terms of enabling new innovative practice (for example: using immersive or semi-immersive visualization techniques to extract meaning from a body of data) and bold new terms of engagement with both old and new challenges (for example: using virtual meeting spaces in a virtual world environment to resolve real-world problems).

Other approaches to paradigmatic frameworks development have also evolved to both explain and facilitate innovation practice. For example, in attempts at the modelling of new business information systems, new approaches to business decision making, identifying sustainable competitive advantage mechanisms, and in more recent times the modelling of knowledge management systems and practices (Blecker, 2005; Sanchez, 2001). Such alternative approaches are typified by the following:

- From: Tom Peters and his 'passion for excellence' in the early and mid 1980's (Peters & Waterman (1982) and Peters & Austin (1985))
- Through: the 're-engineering of business' approaches espoused by Hammer (1993) Champy (1995) and others in the mid 1990's.
- To: 'knowledge management for business model innovation' as per the more recent works of Yogesh Malhotra (2000, 2001) Ulrich Franke (2002) Thorsten Blecker (2005) and others.

The constructs of radical, or discontinuous, or disruptive innovation and change, or paradigm switch, and their effects on organizations have been addressed by many researchers and authors over the past 40 years since Kuhn (1962) first described his notion of paradigm change in scientific development. Including, but not limited to: Arnold, 2003; Betz, 2003; Bower & Christensen, 1995; Chandy *et al*, 2003; Christensen, 1997; Christensen *et al*, 2008; Katz, 2003; Knights *et al*, 2002; Tidd & Bessant, 2009; Tidd *et al*, 2005; Tushman & Anderson, 2003; White & Bessant, 2007.

4.3.5.5 World View

A systems-based view of organizations as consisting of multiple related activities and players, functioning according to the relationships with and influences of internal and external conditions.

Industrial sectors are highly diverse with continual technological change the norm in many industrial sectors, however, not all organizations maintain a presence in the latest form or implementation of current technology. Any given industry sector will normally contain organizations that vary from early adopters of new technology, to mid-range adopters and late adopters. Accordingly, there are at any one time a wide range of technological processes and related management systems in place within a given industry sector. Whilst industry leaders generally set the direction and pace of new technology development, occasionally a smaller more flexible organization can change the landscape with the introduction of a new product, or adaptation to an existing product or system, or as in this case re-engineering a new approach to planning and managing the organization.

An issue often raised in relation to the introduction of innovation and technological change is that of the perceived prevalence of a technology push syndrome. In this mind-set, generally the purview of the techno-evangelist, all things are viewed possible as long as we follow the technological leader and work co-operatively to push back the barriers to technological change and acceptance of new ways of doing things. An alternative and more pragmatic approach to this issue involving the concept of Technology-Push-Market-Pull, is discussed by Martin (1984) in the context of technological strategies for companies engaged in developing innovative new products and processes. Certainly, in today's world of continuous development and convergence of electronically based digital media there can occasionally be seen examples of break-through technology that breaks through previous barriers of feasibility: 'A revolutionary innovation, such as radio and the computer, can be viewed as a technology-push-market-pull synergy because it seeks to satisfy an un-manifested but nevertheless latent user need. Often, as with radio and the computer, the innovations are both technologically and socially revolutionary' (Martin, 1984, p.57).

Similarly, the evolution of electronic communications systems since the introduction of the telegraph (circa 1840) may be interpreted as having diffused over time to its current representations in the global telecommunication systems, the internet and world-wide-web, and the ubiquitous mobile phone. Clearly, in both these above examples there have been many and continuing technology developments and innovations and the necessity of implementing over time complex technology transfer mechanisms to facilitate global diffusion, not of one particular product, but of multiple systems and products which between them are the embodiment of the particular concept. The history of technology transfer and its diffusion illustrates that it is an inherently complex set of processes. Seemingly simple or obvious developments fail, whilst others succeed (Swann & Watts, 2002).

Understanding the management of innovation and change, whether the introduction of new technology, new production processes, or indeed the introduction of new products or services, has challenged executive management, educators, strategic planners, authors, academicians, pundits and entrepreneurs alike for many years. It requires a wide-ranging comprehension of the many influencing factors and complex technological, socio-technical and socio-economic processes that must be aligned in order to bring about effective, and successful, change (Christensen & Raynor, 2003; Hanson *et al*, 2008). Technological change is itself an endemic fact of life in any technology based organization. It must also be recognised as having wide ranging impacts and influences on both the organizations technology base and potential for productivity as well as potentially impacting on the social structures, behaviours and societal norms within the organization: 'the more radical the nature of technological change, the more profound and complex the social interaction it generates, and the more innovative institutional changes it necessitates' (OECD, 1988, p.13). It also adds substantially to the complexity of the role of management in such organizations on a continuing basis.

4.3.5.6 Owners

Executive management, company owners and shareholders, and the many internal company stakeholders, many of whom may be committed to traditional decision support tools and antipathetic to potentially disruptive change.

The need for continuing technological and process change has a shared ownership across industry. The historical record is clear that failure to innovate leads inexorably to stagnation and deterioration. The challenge is for potential owners to accept and take ownership of new approaches to managing knowledge intensive environments and the use of new technologies as significant support tools in contemporary decision-making (see illustrative project examples in Section 4.2.2.). For all the attention on the need for and seeming inevitability of technological change, particularly with regard to digital convergence in ICT technologies and related virtual tools, organizational strategists invariably in turn bring the focus back onto understanding the nature of a given organization and the values, norms and expectations that underlie its organizational culture and the extent to which its participant members take ownership (Child, 2005; Katzy, 2006).

A strong corporate 'strategy focus' is not in itself sufficient, it needs to be reflected in, embedded in, supported by and deployed through the organization's internal culture: 'the skilful execution of the strategic plan must be socialized and reinforced to followers through a strong organizational culture' (Sosik *et al*, 2004, p.193). An organizational culture that perceives value and benefit in meeting the challenge of developing and growing competencies in the face of competitive pressure is more likely to internalise the need for technological change and to find ways of developing ownership in new processes, procedures, products and services (Katzy, 2006). Thus, a performance oriented organizational culture can effectively 'empower' its members and effectively 'raise the collective intelligence and performance capacities of technology-dependent organizations' (Sosik *et al*, 2004, p.193).

Thus, it is essential that the culturally aware enterprise take account of the determinants of its internal culture and the value and potentially critical role of its competitive advantage embodied in the organization's intellectual capital, as represented by and embodied in its participant members and communities of practice (Amidon, 2003). Identifying and harnessing organizational culture and the skills and capabilities that collectively make up an organization's intellectual capital, are essential components in meeting the challenge of achieving competitive advantage that can be sustained over any length of time: 'The probability of developing a sustainable competitive advantage increases when firms use their own unique resources, capabilities, and core competencies to implement their strategies' (Hitt *et al*, 2005, p.72). Addressing such an array of issues and developing such a culture and focus in engineering and technology-oriented organizations, is very much a growing and significant challenge for contemporary engineering and technology management practitioners.

4.3.5.7 Environmental constraints

Existing: IT structures; executive support approaches and techniques; and current corporate core competencies.

The growing presence of new media technologies and systems is directly impacting on the skills and expertise required of company decision makers. The increasing presence of 'virtual' organizations with virtual boardrooms and meetings held via networked communications is increasingly the norm. In developing a strategic vision of how, when and where sophisticated new media and virtual reality systems may best be incorporated into an organization, it is essential that skills in strategic thinking are in turn matched with strategically oriented organizational processes (Betz, 2001; Hanson *et al*, 2008; Johnson *et al*, 2008). Lorino and Tarondeau (2002) elaborate further on this construct of strategically oriented processes as being those processes within an organization, or external processes which the organization is able to access, which can have significant influence on company performance and with potential to leverage sustainable competitive advantage. In particular, they identify two conditions that must be satisfied: they must impact on performance; and they must create discernable value: 'strategic processes or sets of processes must have a substantial impact on some aspect of strategic performance… strategic processes must be able to create value on a sustainable basis' (Lorino & Tarondeau, 2002, p.136). The ability to determine when and where such opportunity lays and how to select, develop and use such strategic processes, is clearly the purview of the strategic thinker. In effect, the concept of strategy is essentially behind everything an organization does (Hanson *et al*, 2008; Johnson *et al*, 2008, 2009; Magalhaes, 2004).

Professors Johnson, Scholes and Whittington (2002, 2008, 2009) have addressed these issues extensively over the past 20 years in their explorations of corporate strategy and strategic management in a wide range of organizations. They provide a disciplined overview of the many factors affecting strategic thinking in corporate environments and lay strong emphasis on the connectivity between effective strategic positioning of the organization, developing an organization's strategic capabilities and associated core strategic competencies, and sustaining competitive advantage in the market-place (Johnson *et al*, 2009).

Probert (2004) and his team of researchers engaged in researching technology management issues and the possible impacts of technology on boardroom-based decision-making and associated new ways of thinking and supporting decision-making, make the critical observation derived from their research into European enterprises, that the roles played by technology and innovation in an organization are strategically critical to sustainable success: 'The role of technology and innovation in achieving sustainable business success is of such significance that both should be considered as an integral part of the business strategy' (Probert *et al*, 2004, Intro.pp.xi; xiii; xiv). Understanding the underlying issues of strategic context, strategic position, strategic purpose, the parameters affecting strategic choice, and rigorously thinking and acting with strategic intent, are then essential characteristics for successfully managing the contemporary technology based enterprise (Johnson *et al*, 2009).

Understanding the technological context of the company and its technology strategies, in addition to understanding its economic and competitive environment, provides a further level of meaning to decisions taken in regard to engineering and technology management and its relationship to the strategic positioning and direction of the company (White & Bessant, 2007). Again, refer to earlier illustrative project examples in Section 4.2.2. Probert (2004) asserts that effective management of an organizations technology base and related innovation and change management are primary causal factors in successful performance management 'It is not an exaggeration to assert that the successful economic performance of an enterprise is now largely dependent on the quality of its technology and innovation management' Probert *et al*, 2004, p.3).

Continuity and change are two contiguous concepts, both essential strategic components in the quest for sustainable competitive advantage and yet seemingly diametrically opposed. Continuity, in the sense of continuing quality of an organization's products and services, change, in terms of continuous improvement and performance enhancement, very often fuelled by innovation and enlightened management of change. Yet, another concept also applies, 'growth', without which an organization effectively stands still, stagnates, and very likely goes into decline. To a very great extent it is the level of continuous improvement and enhancement through innovation practice that can enable companies to effectively compete, remain vital and grow (Katzy, 2006; Sobel Lojeski & Reilly, 2008).

4.4 Formative Data Outputs for Virtual Reality Visualization Projects

The following Table 2 is a listing of 'critical parameters' relating to the implementation of various virtual reality visualization projects, as identified above and used as a source of empirical base data. As such, they represent formative data outputs resulting from and grounded in the author's engagement with virtual reality visualization projects.

Identified Critical Parameters	Comments
Innovation climate	History of innovation and use of new approaches, adaptability to change, next generational future orientation
Re-engineering orientation	History of capability and potential for future adaptation
Strategic Management climate	Established corporate strategic planning environment
Preparedness for change	History of adaptability and effective change management
Commercial focus	Focus on economic environment, industry expectations, competition, viability of new technology to enhance enterprise development
Corporate competencies	High-level internal skills & expertise, particularly as evidenced through innovation, creativity, and a Human Factors orientation.
Cross sectoral	Engineering/technology/business/defence/govt. etc.
Service orientation	Acknowledgement of Quality parameters as critical in achieving competitive service levels
Customer focus	Acknowledgement of customer expectations and enterprise capabilities to enhance customer services
Existing expertise	Exploitation of existing simulation capability and technology base and enterprise focussed expertise
Technology focussed	Both on visualization products and new product and service mechanisms utilising new media technology
Systems Thinking oriented	Focus on relationships, and modelling of complex organizational &socio-technical issues
Strategic Thinking oriented	Business and Technology Strategy focussed, strategic intent evidenced
Task oriented	Strong focus on modelling and production of visual elements to achieve project outcomes
Decision oriented	Focus on effective decision making as a significant outcome of project activity
Business Planning orientation	Established practices and procedures in place, strong interest in business process re-engineering
Experimental focus	Prepared to experiment and test
Knowledge management Processes	Established knowledge base and development of knowledge management systems
Information management processes	Established expertise in enterprise ICT systems
Visualization	Strong focus on visualization supporting decision making
Collaboration	Strong focus on interactivity and collaboration in design and decision making
Community of Practice orientation	Engagement with relevant communities of practice in product/service development
New Media	Strong focus on new media capabilities, communications, terminal equipment
Simulation	Strong focus on use of simulation systems and techniques for interacting with data

Table 2. Formative Data Outputs for Virtual Reality Visualization Projects

4.5 Content Analysis Using Category/Priority Matrix Analysis

The previous sections of this chapter have demonstrated the application of SSM Root Definitions to identifying issues central to the thematic development approach used in identifying and analysing documented research and published works relative to the three thematic areas of interest and the eventual development of the proposed taxonomy. Congruent with this approach has been the use of content analysis to analyse relevant published materials based on pairwise comparison in a category/priority matrix derived from the work of Saaty and Vargas (2001) in their development and application of Analytic Hierarchy Process (OHP). This section provides an exemplar listing of charts derived from a category/priority matrix analysis of two selected publications used throughout the extensive review of literature and subsequently used in the identification and development of core elements in the following conceptual analysis for the proposed taxonomy.

The use of a category/priority matrix (Saaty, 2006; Saaty & Vargas, 2001) represents a typical 'grounded' approach to analysis of published works in which the key purpose is to identify significant issues raised throughout the publication and the context in which such issues are raised, thus identifying core relationships between key categories. As such, it facilitates identifying embedded relationships between content material and the building of hierarchy in content, both from rational and intuitive perspectives (Saaty & Vargas, 2001). Selection of categories used throughout these analyses is initially derived from chapter summaries in the individual publications. New categories are then added throughout the process as and when they are identified in the publication. It should be noted that the terminology used in the 'categories' identified in the analyses are strictly as per the terminology used in the individual publication. Many such categories whilst labelled differently by various authors can be identified as closely correlated (although not necessarily the same) with other categories albeit labelled slightly differently by other authors, for example: strategic technology management and information systems strategic management.

The following Pareto graph styled charts as derived from the category/priority matrices for two particular publications referred to several times throughout this chapter, document both the frequency of significant references to identified key categories within the publication and the frequency of references to specific categories in the context of, or with specific reference to, other identified categories, thus identifying key relationships between specific categories. The hierarchical structure of the subsequent analyses plus formative outcomes from analyses of virtual reality projects and thematic development through the analysis of publication and research reports, provides the data used in identifying and analysing the 'System Elements' for the SSM analysis used throughout Chapters 5 & 6 and subsequent assembly of the proposed taxonomy. The two publications used in Figures 28-37 are:

- Probert, D., Granstrand, O., Nagel, A., Tomlin, B., Herstatt, C., Tschirky, H. & Durand, T. (2004) *Bringing Technology and Innovation into the Boardroom*, Basingstoke: Palgrave MacMillan.
- Clarke, S. (2001) *Information Systems Strategic Management: An Integrated Approach*, London: Routledge.

The central themes and focus of these two publications, as illustrated in hierarchical form in these charts, can clearly be seen as: new technologies; innovation management; core competencies; technology management; information systems; corporate strategy; technology-based; and social theory. In addition, the strength of relationships between these various categories and others (as in frequency of correlation) is also illustrated.

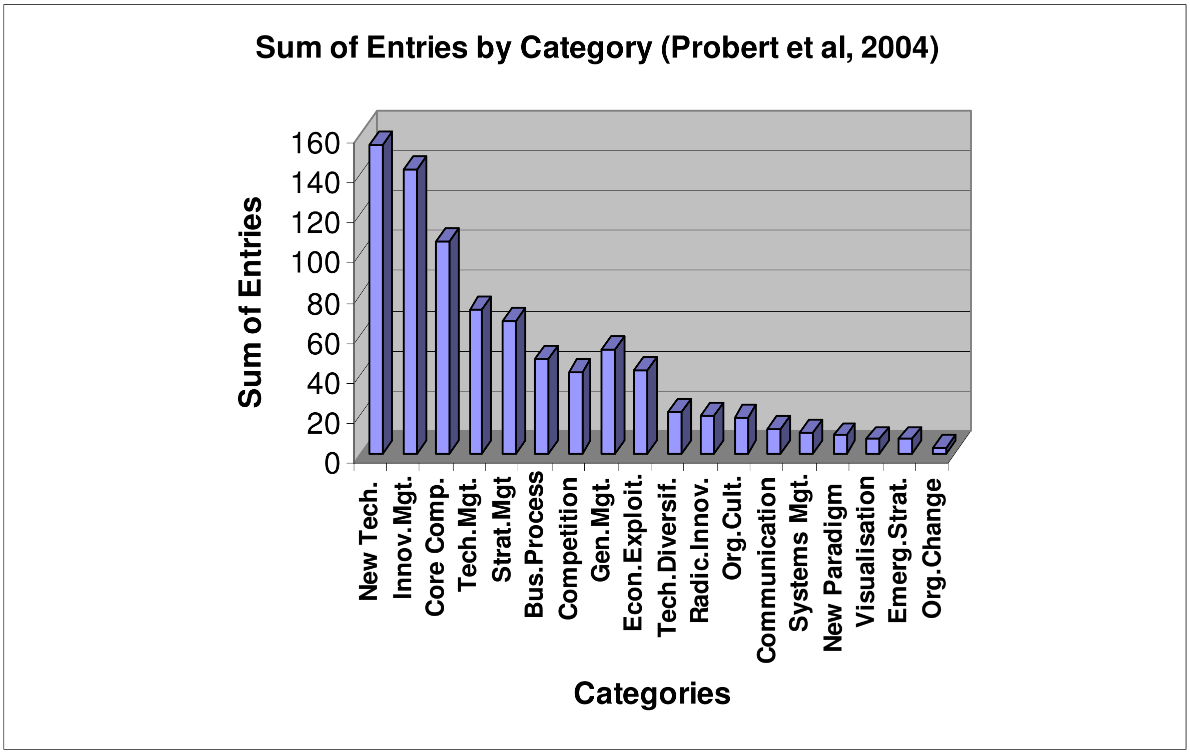


Figure 28 Sum of Entries by Category (Probert *et al* 2004)

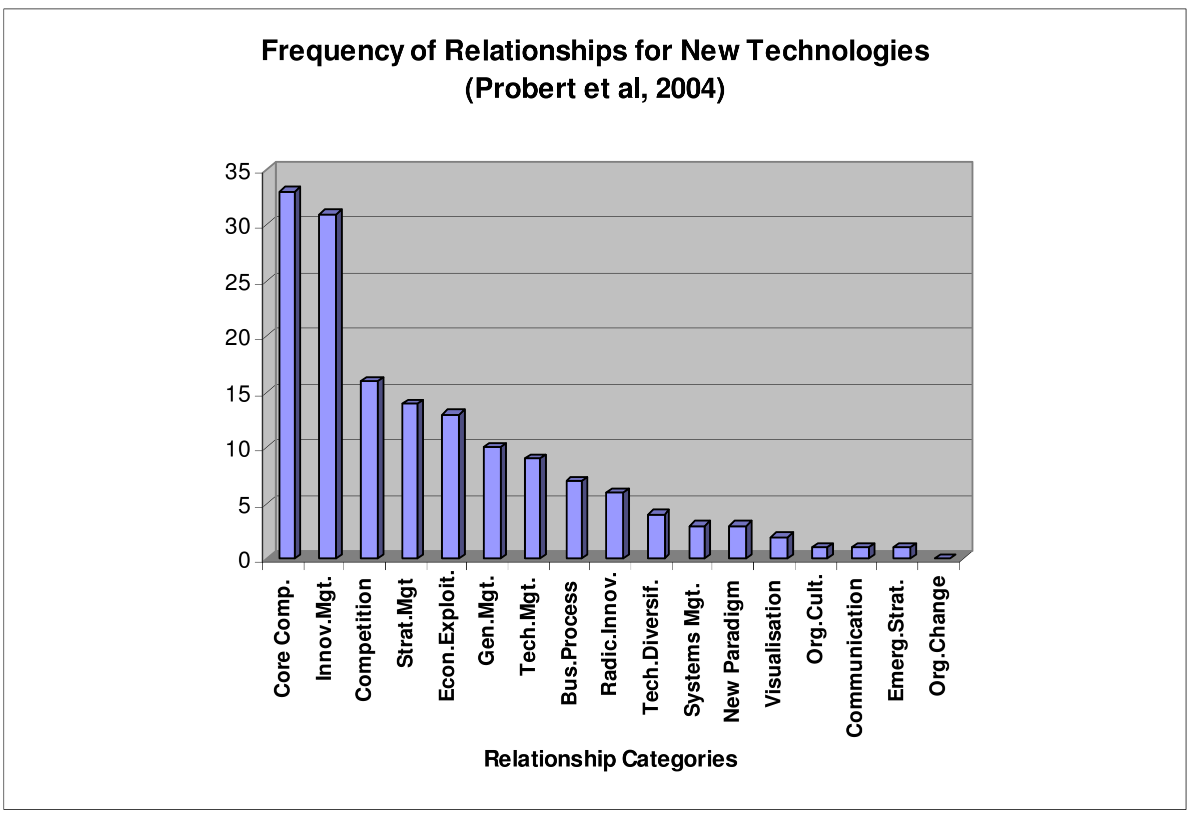


Figure 29 Frequency of Relationships for New Technologies (Probert *et al* 2004)

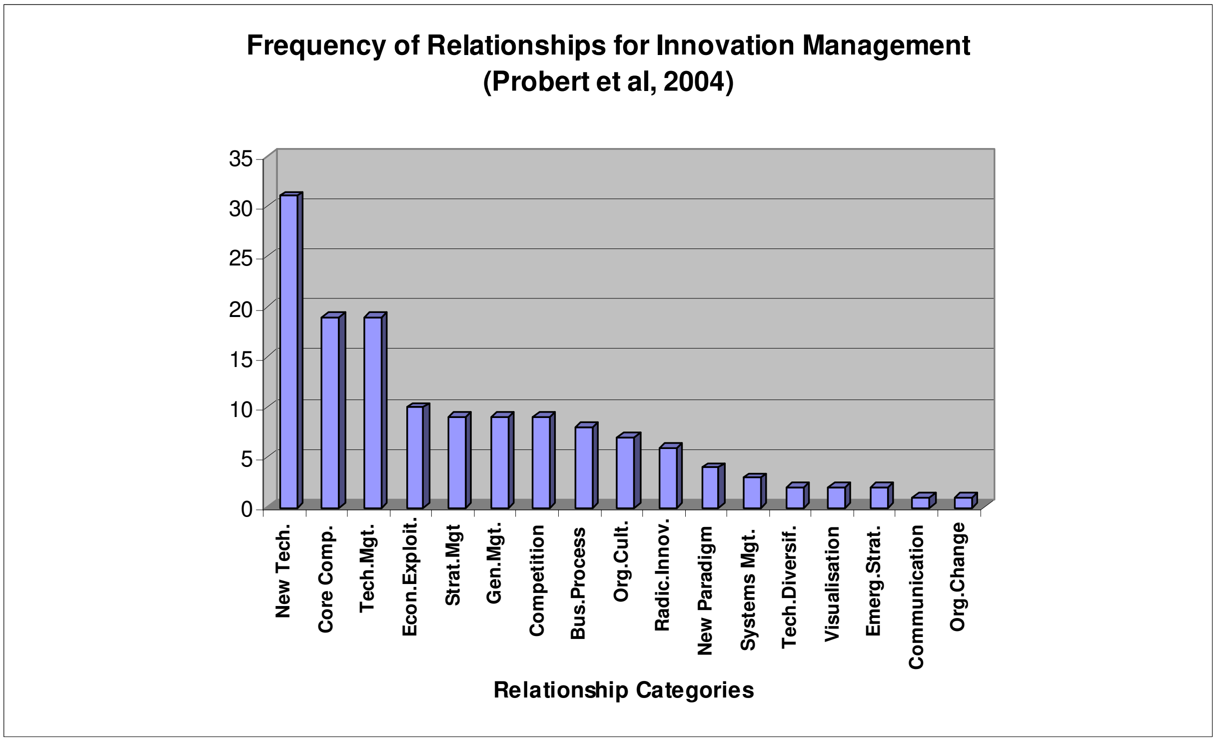


Figure 30 Frequency of Relationships for Innovation Management (Probert *et al* 2004)

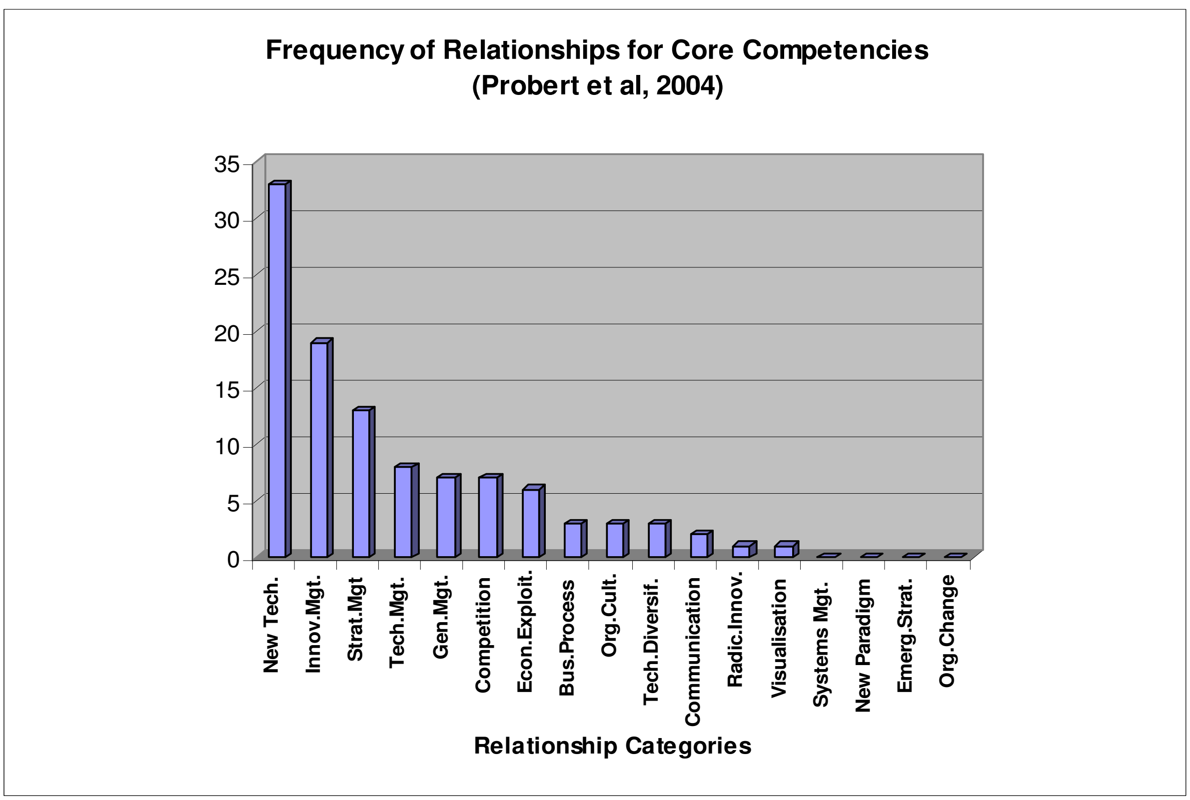


Figure 31 Frequency of Relationships for Core Competencies (Probert *et al* 2004)

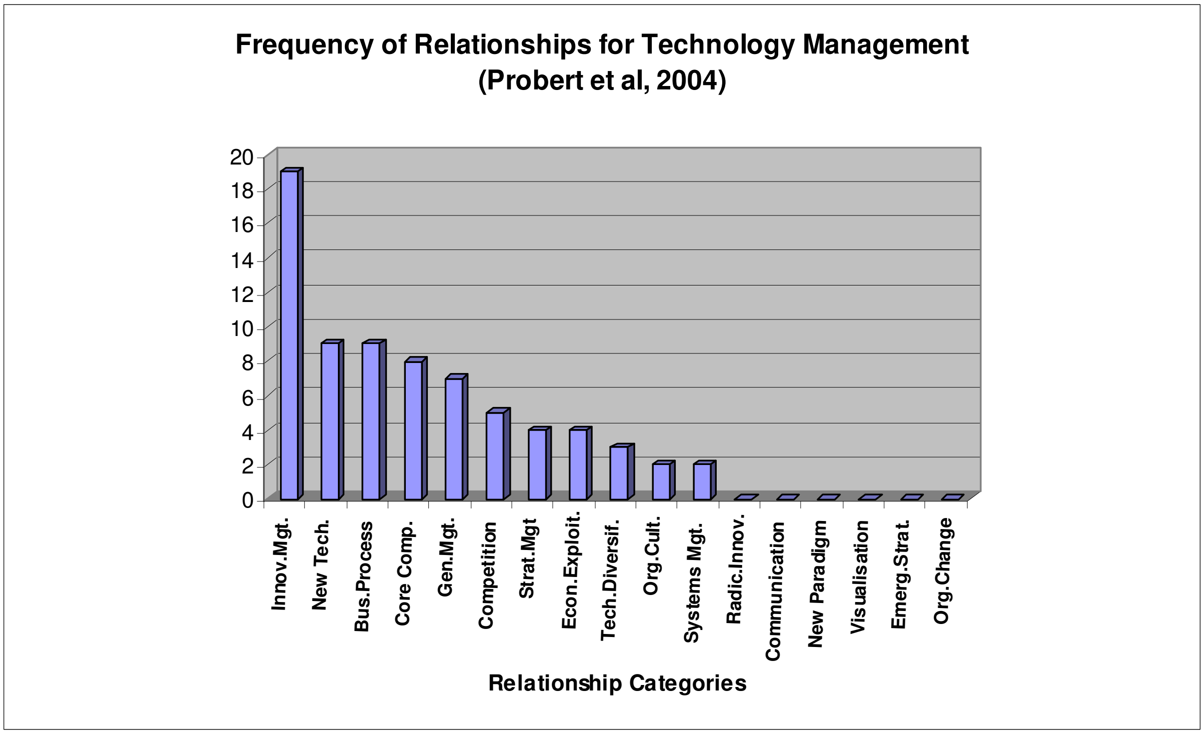


Figure 32 Frequency of Relationships for Technology Management (Probert *et al* 2004)

From the above summary graphs relating to the category/priority matrix analysis of Probert *et al*, 2004, *Bringing Technology and Innovation into the Boardroom*, it can be seen that strong relationships have been identified between the major categories of: New Technologies, Innovation Management, Core Competencies, Technology Management, and Competition. Further moderate relationships are demonstrated with Economic Exploitation, Strategic Management, General Management, Business Processes, and Radical Innovation.

Interestingly, each of the major categories demonstrate a very strong relationship with one or two other categories, followed by relatively strong relationships with another two or three categories, then a plateau of moderate relationships followed by diminishing weak relationships.

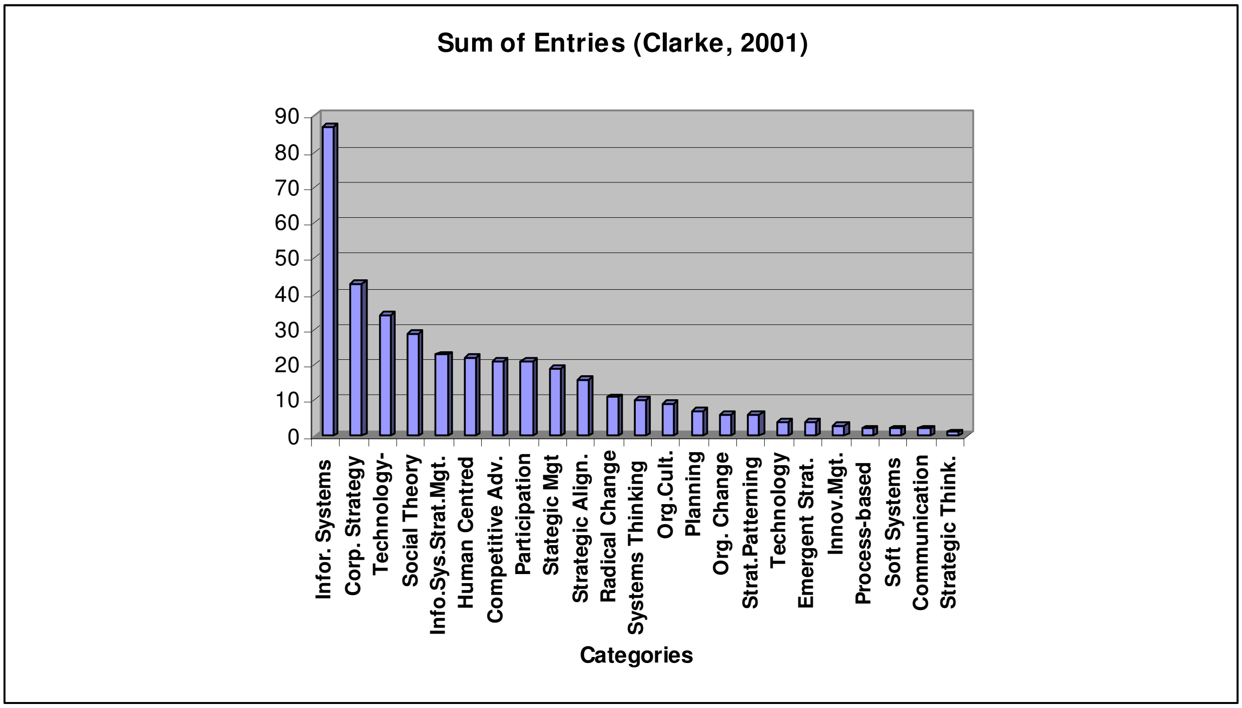


Figure 33 Sum of Entries by Category (Clarke, 2001)

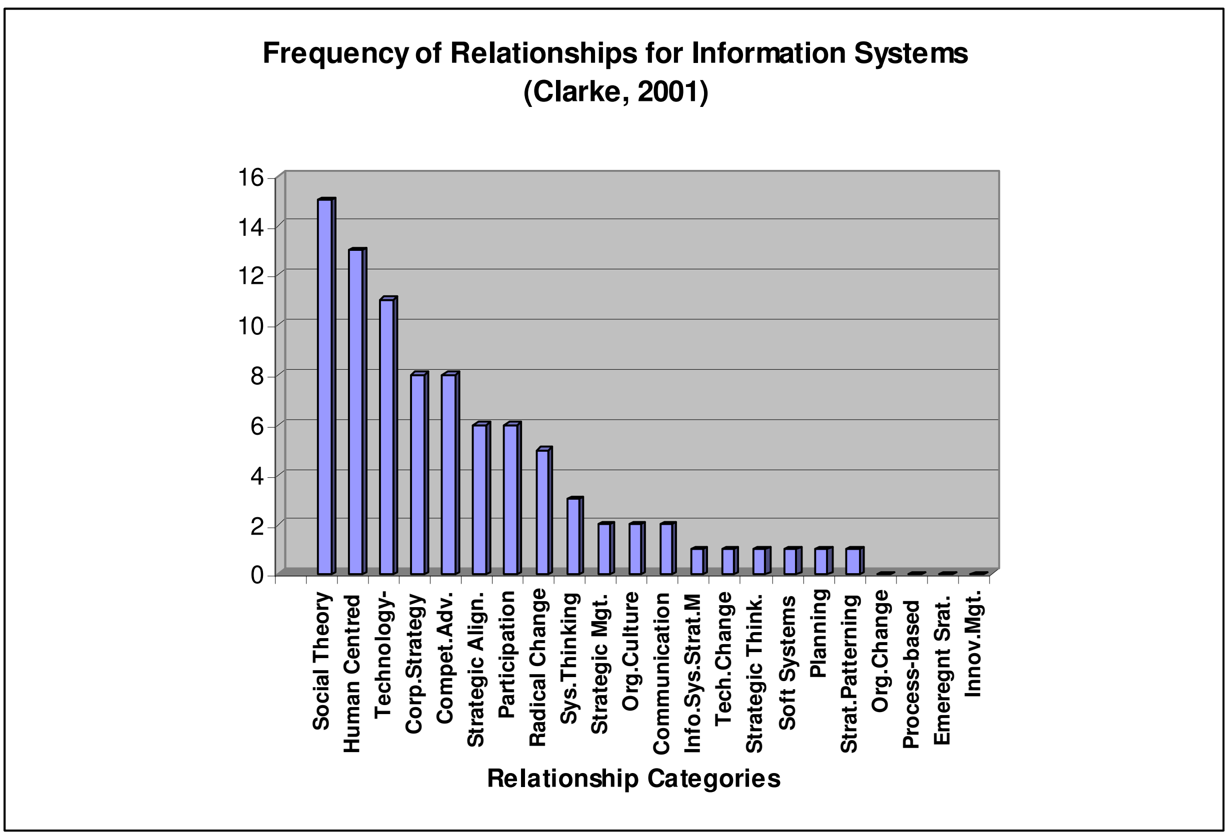


Figure 34 Frequency of Relationships for Information Systems (Clarke, 2001)

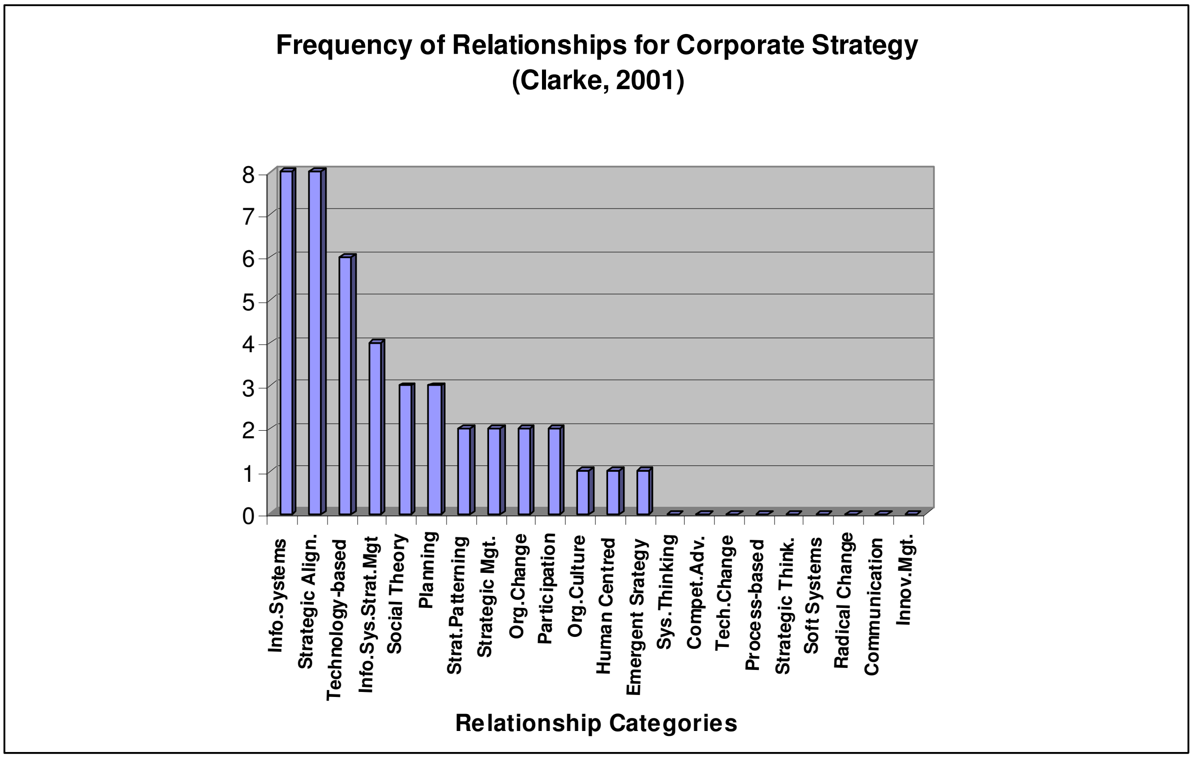


Figure 35 Frequency of Relationships for Corporate Strategy (Clarke, 2001)

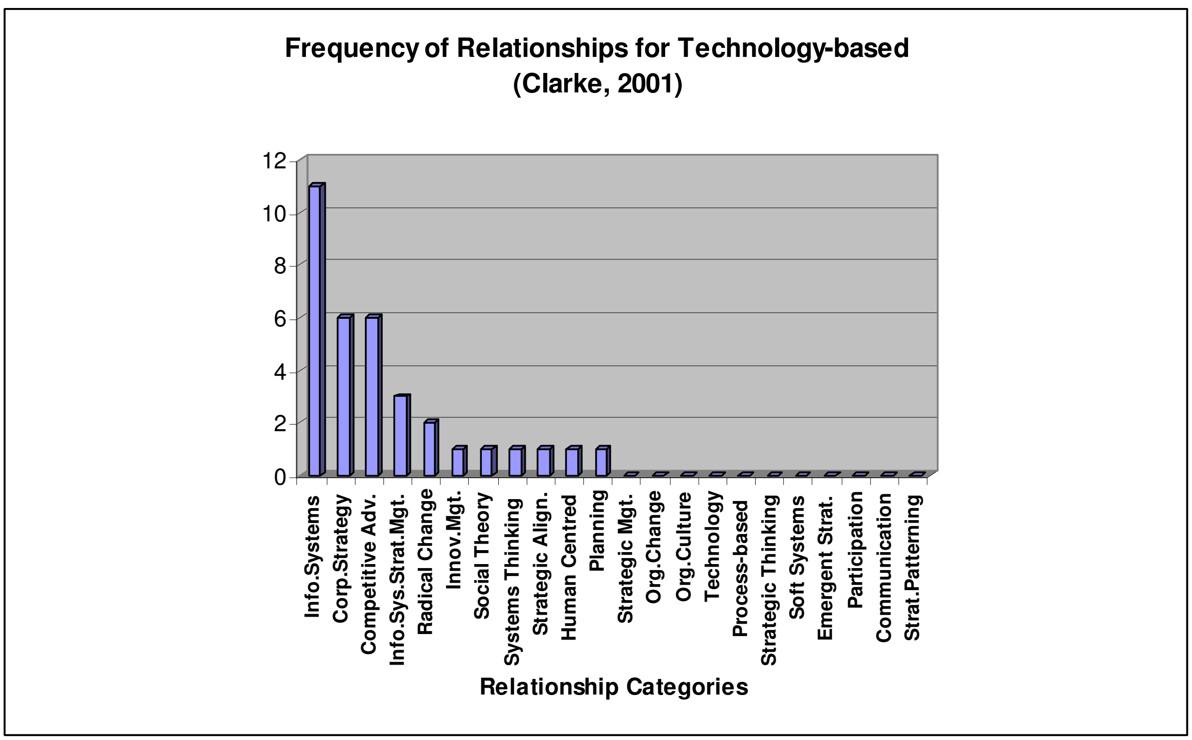


Figure 36 Frequency of Relationships for Technology Based (Clarke, 2001)

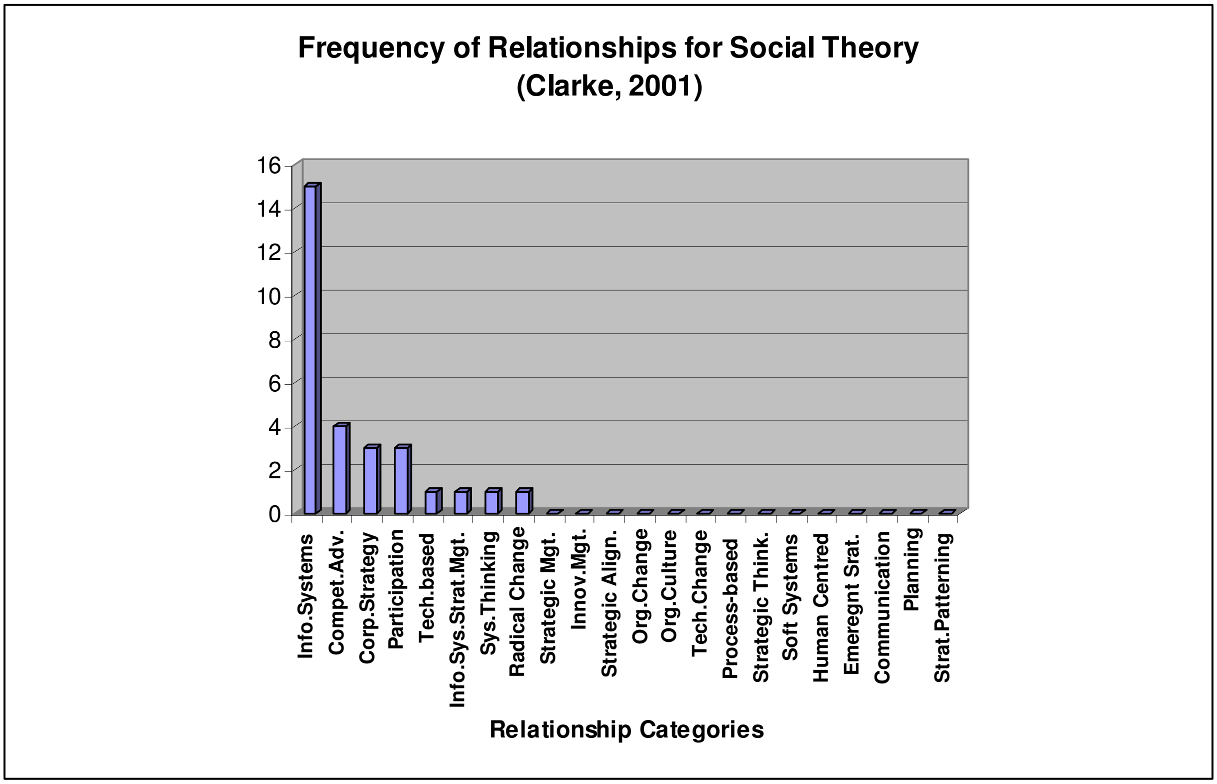


Figure 37 Frequency of Relationships for Social Theory (Clarke, 2001)

From the above summary graphs relating to the category/priority matrix analysis of Clarke, 2001, *Information Systems Strategic Management: An Integrated Approach*, it can be seen that strong relationships have been identified between the major categories of: Information Systems (ICT), Corporate Strategy, Technology, and Social Theory. Further moderate relationships are demonstrated with: Information Systems Strategic Management, Human Centred issues, Competitive Advantage, Participation, Radical Change, Organisational Change, and Strategic Management.

Again, each of the major categories demonstrate a very strong relationship with one or two other categories, followed by relatively strong relationships with another two or three categories, then a plateau of moderate relationships followed by diminishing weak relationships.

4.6 Initial SSM Analysis & The Problem Situation Expressed: Summary

This initial SSM analysis chapter has largely focused on establishing an initial response to the first three stages of Checkland's SSM approach as outlined in Chapter 3. This has been done with regard to investigating the 'problem situation' and further extending the analysis of published material to determine what organizational attributes characterise engineering and technology-based organizations, specifically with regard to the potential use of advanced simulation and visualization technologies and systems in management such as virtual reality.

Information and communication technologies (ICT) now form core assets of and play strategic roles in, the majority of contemporary organizations. In particular, the continuing growth of communications capabilities and the subsequent potential to interface in real-time geographically (globally) distributed functions, has changed the way enterprises operate and compete in an increasingly demanding, competitive and technology sensitive marketplace.

Continuing shifts and changes in underlying technology base (particularly ICT) and concomitant adjustments to essential corporate core competencies and related organizational intellectual capital, require a refined sense of strategic direction and organizational purpose, connected to enlightened technological resourcing and related technology management strategy. This continuous technological re-orientation and associated adjustments in organizational culture, carries with it significant challenges for firms historically dependent on their technology base as their prime differentiator in the market place and source of competitive advantage. The strategic development of a performance oriented organizational culture that facilitates the introduction, evaluation, adoption and diffusion of innovation, can further empower an enterprise to successfully implement paradigmatic change and the introduction of potentially disruptive technologies and innovations.

The concepts of 'systems' approaches and systems thinking (in effect, taking a broadly defined holistic perspective) are critical to understanding how multiple influences, internal and external, affect performance in the context of innovation and change in engineering and technology-based organizations. Similarly, the 'strategic positioning' of an organization in order to leverage competitive advantage from its specific capabilities, particularly with respect to its technology and core competency bases, is a critical exercise. This involves not only corporate/executive management but also engagement across the organization and adaptation of and to the overall organizational culture of the enterprise. Thinking at a level of personal and corporate core competencies and acting strategically, become essential characteristics for success.

Overall, this chapter has identified that any attempt to successfully introduce such 'new media' as a radical and potentially transformative innovation must take cognisance of the many, and at times conflicting, issues as raised and discussed throughout this thematic development process. In turn, the thematic development process has endeavoured to place this research program within appropriate academic and applications contexts and to bring together further extensions to the existing body of knowledge and understandings of the impacts on communities of practice of the introduction of new media virtual reality relative to the following multiple, disparate, but related areas:

- The continuing evolution of electronic and telecommunications based media and meta-media
- Management of engineering and technology based organizations
- Virtual reality systems and related technologies
- Soft Systems methodologies and systems thinking approaches.
- Visualization systems
- Innovation and change management
- Strategic management and strategic thinking
- Simulation systems
- Developments in cognitive science and contemporary management science
- Decision support systems.

In keeping with the general tenets of a Grounded Approach as used in the initial stages of the program's research methodology (see chapter 3) in which emergent theory is essentially grounded in the existent data, this chapter in turn further develops the construction of a soft-systems 'rich picture' or 'rich description' (Jackson, 2003) as initially developed throughout the Chapter 2 Literature Review and Thematic Development. This approach is used to directly reflect the viewpoints and findings of the many researchers whose collective works and development projects form the backdrop to this research program and provide key formative data inputs to the subsequent conceptual analysis stages. In turn, it directly relates to the development of the various systems elements later identified and used in the conceptual analysis stage discussed in Chapter 5 and subsequently used in the analysis of a Virtual Reality Centre User Survey in Chapter 7.

Chapter 5.

Conceptual Analysis for Proposed Taxonomy

5.1 Introduction to Conceptual Analysis

This chapter discusses approaches to conceptualizing a Taxonomy or classification system, relating new media virtual reality systems and technologies to their potential application in the management of engineering or technology based organizations. The conceptual analysis draws largely on formative data derived from the content analysis of a wide range of associated publications and documents, thematic development throughout the preceding chapters, and engagement in and analysis of multiple virtual reality projects. It represents the 4th and 5th stages of the adaptive form of the AGSSM methodology being implemented. (See Chapter 3.8 Figure 28: Adaptive Grounded Soft Systems Methodology Model, and Table 4: AGSSM Research Activity as Adaptation of SSM Approach)

5.2 Conceptual Issues

5.2.1 Conceptualising what is being addressed

The research program has used a used a wide range of information and data sources including experiential engagement in a wide range of virtual reality projects. However, in using this approach, the research program has not simply relied on collecting large numbers of descriptive case studies of virtual reality implementations and then analysing them to extract meanings relative to the introduction of new ICT technologies as a means of inducing an innovation and change atmosphere within existing decision making environments, and identifying apparent commonalities across multiple case studies in order to formulate an empirically derived prescriptive model. Whilst potentially possible, such a narrow approach to understanding the role of strategic technology in management decision-making also carries inherently high risks (Goodwin & Wright, 1998; Tidd *et al*, 2005). In effect, whilst previous developments and practice may have been successful, and indeed may continue to be so, the fact that they came from or grew out of earlier organizational formats, technological bases and communities of practice, may in turn hinder perceptions of necessary conditions for future oriented innovation and practice. Constant (1987) describes this as a ‘presumptive anomaly’ [Constant (1987) in Bijker *et al*, 1987, p.225]. It also reflects the essence of what has been described as ‘Einstein’s Dictum’ that: ‘problems can’t be solved within the mind-set that created them’ (attributed to Einstein in Hawken, 1999, p.6). Or, as Langdon Winner observes in somewhat colourful language: ‘After the bulldozer has rolled over us, we can pick ourselves up and carefully measure the treadmarks. Such is the impotent mission of technological ‘impact’ assessment’ [Winner (2004) in Kaplan, 2004, p.107].

Rather, the approach taken throughout this research is focussed on identifying the presence of theoretical effects on organizations and as such is more alike to the situation where new insight or interpretation of practice (albeit typically scientific or technological) may directly intervene in current technological practice or communities of practice, even where such practice may in itself be an outcome of related earlier innovation (Constant, 1987). 'The old system still works, indeed still may offer substantial development potential, but science suggests that the leading edge of future practice will have a radically different foundation' (Constant (1987) in Bijker *et al*, 1987, p.225). The focus then is on addressing theoretical aspects of technology-based organizations, their structure, culture, behaviour, and their approaches to and strategic positioning relative to technological innovation and change management, their technology bases albeit with a particular focus on ICT based visualization systems, technologies and related processes and their associated communities of practice.

Given the range of organizations involved with, or with potential to become involved with, the innovative use of new media virtual reality systems, it is clear from the above that contexts of application are highly diverse when applied across multiple industry and commerce settings. Thus these contextual parameters and their causal influences need to be explored and understood by the implementing organization rather than passively accepting externally imposed and rigidly defined structures, processes and constraints. In effect, the introduction of innovation and technological change is 'fundamentally a social process… (which) cannot be imposed on our societies; they have to be introduced through institutional adaptation and a process which mediates between differences of interest' (OECD, 1988, p.11). In turn, this suggests that the proposed taxonomy and classification system resulting from this research should also be relatively 'open' and readily subject to adjustment and 'adaptation' to best fit varying organizational contexts of application.

5.2.2 Conceptualising Innovation Issues

Given the above observations and the wide range of views canvassed in the foregoing chapters, it becomes apparent that the proposed classification system and its application requires an understanding of both the innovation decision making context and various parameters associated with the implementing organization. Multiple contextual issues and queries thus arise:

(a) What issues critically influence the innovation management decision to use new media and virtual reality?
(b) What is the organization's underlying technology base?
(c) What are the organization's associated skills, expertise and corporate competencies?
(d) What is the selected technology itself and its intended application?
(e) What is the organization's strategic thinking and planning capability?
(f) What is the organization's propensity for engaging in innovative practices? and
(g) How flexible or adaptable is the organization's internal culture?

These are to be addressed in the following discussion. Constant (1987) refers to these factors as relating to three social *loci* for technological practice: 'the technological community, the complex organization (usually corporate) and the technological system' (Constant, 1987, in Bijker *et al* 1987, p. 224). In effect, Constant's observation reflects recognition of the embeddedness of social processes in technological change (OECD, 1988).

The following Table 3 illustrates an approach based on extrapolating Martin's (1984) framework for evaluating commercial innovations in general, to evaluating the application of virtual reality technology and systems in particular, based on Martin's interpretation of a Popperian refutation model. It demonstrates a case of translation from the generalised context of technical innovation in commerce to that of the specific application of a radical, revolutionary technological innovation (such as virtual reality technology based systems) in the management of engineering and technology based organizations and enterprises.

1. The technological component of the application(s) must be seen to be "demonstrably feasible". In this regard the selected new media virtual reality technology and associated software and systems must firstly perform reliably, consistently and in accord with its technical design specifications. Secondly, it must also match the technical requirements of the project in which it is being utilised.
2. The implementation of the technology-based/supported program should be "demonstrably feasible" in terms of the costs and associated resource overheads, system performance and the achievements or outcomes.
3. Occupational health and safety aspects such as ergonomic design of equipment and user-interface should be in accord with user expectations and legal requirements. Similarly, equipment must meet any environmental requirements or constraints.
4. Technology-based programs should address current policy objectives, both in terms of new technology and associated skills development, the introduction of added value to products and services, and building overall competitive advantage.
5. Alternative options for the development of new media virtual reality based projects should be competitively evaluated both against each other and against known traditional forms of program implementation, to determine which alternative is most efficacious and to establish what, if any, advantage is to be gained from a new approach.

TABLE 3. Martin-Popperian Model Applied to Introduction of New Media Virtual Reality Technology & Systems (Derived from Martin, 1984)

Whilst reflecting the key issues identified by Martin (1984) neither the above re-statement (see Table 3) nor Martin's own proposed framework, provide readily measurable quanta or an explicit regime for establishing evaluative protocols. Popper's regime of refutation, whilst feasible in a simple binomial form (proposition refuted or not refuted) requires more rigorous application than is readily apparent in the above framework. To be effective, each refutation challenge must be addressed through a set of measurable parameters. Assuming these could be developed, the model in Table 3 may well be adaptable for use as a strategic planning tool. It also provides a blunt reminder of the reason why it is essential that organizations contemplating engagement with technological innovation and change must understand the risks they face when entering the sphere of technological innovation. It is one of the curiosities of technological innovation over many decades of applied research, theory and practice, that typically less than 5% of innovations successfully diffuse into the marketplace, with the remaining ~95% either failing to achieve viability or to diffuse into the marketplace, or suffering very short life-cycles.

There is a degree of poignancy in reflecting on the processes of diffusion from a scientific viewpoint whilst considering diffusion in a technological innovation context. To the scientist, diffusion is an irreversible process that reflects the level of entropy in a system wherein a fully diffused process is one that has reached or is approaching its maximum state of entropy or random distribution of energy within the system. It can also be considered an interesting analogy to a technological innovation that through widespread paradigmatic change has achieved its maximum penetration across its ostensible marketplace. However, it also can be seen as a directional condition in that to the scientist it represents a unique directional flow from something in a state of high concentration to and dispersing through something else that exists in a lower level of concentration, having the effect of increasing the concentration of the resultant mixed solution or material. This represents a serious challenge when used to describe and explain the diffusion processes of successful technological innovation. Whilst it may be possible to describe an innovating organization as having a high density or concentration of knowledge and skills in particular areas of expertise specific to its technological innovation, and conversely to consider the prospective marketplace to be low in knowledge and skills in such specific area of expertise, these conditions do not of themselves ensure diffusion, more than likely this would lead to the opposite effect where a recipient organization with significantly low expertise in the area of interest is subsequently unable to action or maintain necessary technological support systems. Although, certainly the above entropy analogy is interesting to consider with regard to the use of technological innovation as a tool for inducing paradigmatic change within organizations with an active interest and necessary level of skill and expertise in the area of innovation and change.

5.2.3 Infusion as Endogenous Technological Innovation

There is an alternative position for considering the success or failure of technological innovation and its application, that of successful innovation within the innovating organization itself, a sense of ‘infusion’ rather than externalised ‘diffusion’ across a marketplace where the organization is essentially open to the aggressive onslaught of competition. Innovation within and across the operations of a company has the potential to internalise strategic positioning of a technological innovation or adaptation and change of process. As such, it may be seen as a social process of re-positioning the organization’s focus on requisite skills and expertise, developing new internal competencies, and extending the scope of the organizations internal culture to acknowledge and action the necessary transitions from the old to the new, and exploring new opportunities and challenges from a different point-of-view. In effect, such re-positioning can constitute a re-energising of the organization through commitment to innovation and subsequent change. In the case of introducing new media virtual reality systems and technology, it may well be that the most significant adaptation is in the form of encouraging and ‘infusing’ a new way of thinking about, or instilling a new approach to addressing the demands and challenges of an increasingly media savvy and hyper-competitive environment in the real world. Infusion used as a form of Endogenous technological innovation.

5.2.4 Visualization as Innovative Transfer Media

Another approach to considering the introduction of new media virtual reality as technological innovation is that of considering visualization systems as a form of 'transfer media'. That is, to consider simulation-based visualization as a representation medium for transferring, and indeed transforming, transcoding and translating information between users, to: enhance; develop; and sustain organizational knowledge and understanding. One of the most widely known and iconic examples of the power of visualization as a transfer media is the seemingly simple London Underground Map.

This simple topological diagram developed in 1932 by engineering draughtsman Harry Beck (and subsequently expanded on rather than fundamentally changed as more lines and stations were added) describes in a simple geometric arrangement, the structure of the 400+ kilometres of underground rail lines that wind, twist and turn under London. It captures in a unique way the relationships between the various lines, such that the million plus passengers who use the 'tube' each day can visualize where they are, where they are going and what station comes next (Craig, 2000). Beck used the metaphor of straight horizontal lines, vertical lines and 45-degree lines to represent displacement without particular regard to actual distances between stations. The London Underground map is a simple visual representation of the 'idea' of the underground rather than a normal topographical map (which in the case of the London Underground would be horrendously complicated and messy). Card *et al* (1999) described this process as 'seeing' an idea: 'The ubiquity of visual metaphors in describing cognitive processes hints at a nexus of relationships between what we see and what we think' (Card et al, 1999, p.1). It is also a classic exemplar of a 'semiotic' iconic sign as per the work of Saussure (1974) and Peirce (1958) in developing semiotics and semiology as a science of meaning in symbols and signs (Lacy, 2009; O'Shaughnessy & Stadler, 2002).

The challenge raised by the London Underground map in relation to the use of new media based visualization and virtual reality related imaging techniques as potential transfer media in formal decision-making, lays in the application and interpretation of its formal logic. The map is a seemingly simple, yet complex, two dimensional visual illustration of the logic of 'sequence' of events (sequential London Underground stations) and parallelism between train line routes, but not geographical relationships such as distance, shape or form. Similarly, much system data collected by organizations provides limited insight into the totality of processes involved in the organization and the extent of relationships between them. The challenge here is, can new media virtual reality visualization systems and multi-dimensional virtual world approaches, provide opportunity for improving holistic/global understandings of an organization's position relative to competitors, and comprehension of the many relationships between a multitude of variables and influences that impact on the organization's technological competencies, products and services quality and performance, and subsequent position and standing in the marketplace.

This in turn leads to considering how we contextualise what we see and thus what we perceive to be the information content and relevance of what we are seeing. Gordon (1996) expresses this as a function of the environment or ecology within which we operate. In this instance, the environment or ecology that we are considering is that of a technology based organization or organization with a strong orientation to the use of technology, and the potential use of visualization media to assist decision-making. The implications that flow from this include that the user should be able to actively explore visualised data to see, perceive, or interpret meaning from the resultant images in such a way as to enhance the efficacy of management decision making. However, determining exactly what form such imaging should take raises a number of issues. Not least of which has to do with the transfer of images, perceptions and meanings between organizations, or even between divisions of the same organization.

Organizational culture is a significant influence on perception and thus potentially on the way we interpret and apply meaning to image content. Gordon (1996) raises significant questions about the complexities and influence of culture on the way we interpret images and perceive meaning. Similarly, he is concerned about the nature and characterisation of imaging used in virtual worlds. Such as, whether or not image representations should directly reflect our experience of the natural world, or should evolve as a new form of representation, for example using a new form of iconography to represent data characteristics. Whilst beyond the scope of this research program, the development of such new data representation forms is likely to be of significant interest as virtual-world data representation modes become more widely accepted. It is here that Peirceian semiotics (Lacy, 2009; O'Shaughnessy & Stadler, 2002; Peirce, 1958) may have a role to play in both the impressing of implicit meaning in imaging and the explicit expression of meaning through imaging.

In the context of this particular research program, the potential is for using new media virtual reality based information visualization as a transfer medium in a specialised form of knowledge management strategy, specifically to access an organization's information resources and intellectual capital or knowledge assets, to enhance knowledge based innovation and subsequently organizational performance and effectiveness (Beerli *et al*, 2003; European Union *et al*, 2010; Henczel, 2001). As such, it also provides opportunity to explore such ICT-enabled data information resources in ways that enable both new insights and the evolution of new ideas (Friedhoff & Peercy, 2000).

As a new idea in itself, using virtual reality to access, explore and leverage better decision making from an organization's knowledge assets, must inevitably be subject to all the usual barriers and constraints associated with introducing and implementing innovation and technological change. The successful translation of such an idea through: feasibility study; evaluation; formal proposal; planning and resource allocation; development and prototyping; testing; implementation and performance monitoring; is a complex process with all stages capable of producing a significant drain on organizational resources. It requires consistent attention to detail, planning, careful monitoring, negotiation, training and visionary management. This is especially so where it entails introducing new technology, such as virtual reality, that almost certainly requires new skills and expertise (at least initially) and makes an additional demand on existing physical and human resources (not only ICT based). This is all particularly so when there is limited evidence other than theoretical studies, to support a contention of improvement in overall organizational and economic performance (outside of engineering or defence related design environments in the case of virtual reality systems and technologies).

5.2.5 An Initial Grouping Abstraction

The following Table 4 illustrates an exploratory approach using an initial grouping abstraction based on assembling shared associations or properties between organizations and virtual reality related products and services. In this instance, the abstractions of structure and behaviour are used to explore possible internal attributes and associations and develops an outline of possible object classes which can be further developed to form classification trees to represent categories of things (physical or logical) and implied or real (measurable) relationships (Bowker & Star, 1999; Oliver *et al*, 1997).

	Structure			**Behaviour**		
	Aggregation (of identifiable Parts)	***Interconnection / Relationships (between parts)***	***Properties (of parts and the whole)***	***Composition (of the general formed by aggregation of the particular)***	***Function (of the individual or of groups)***	***Characteristics (of the individual or the aggregated groups)***
Organization	Clearly defined internal structure Single entity or structured as a conglomerate or an alliance sharing common structures Resource based Skills based Technology focussed	Established lines of authority for Command & control Identifiable communication pathways Product & service flow and interchange protocols established	Quality oriented Stable Viable Unique Productivity driven Stakeholder defined or serendipitous	Singular/ individualistic or multi-layered / controlled Sum of the parts or internally contestable	Production Control Planning Design Finance Defined Ad-hoc Variable	Aggressive Passive Assertive Responsive Stable Consistent Predictable or Unpredictable
VR Product or Service	System of systems or singular? Multi-vendor product based or singular?	Compliant with standard / industry protocols or a proprietary design	Coherence Conformity to a meta-view Technology driven or customer driven	Stable or coherent pattern of behaviour in accord with design expectations or requirements	Clearly defined functionality Actualised or envisaged	Fast – slow Reliable/ Consistent Precise Predictable or unpredictable User friendly

Table 4. An Initial Grouping Abstraction: Structure and Behaviour

This approach to developing a classification framework utilises the technique of identifying and developing object classes, attributing to them specific properties and identifying functions/methods/operations performed by them. It is thus possible to develop a class definition that incorporates common class attributes and functions. There are however, inherent risks in following this particular approach too closely. In general: ‘Classes define a category of things, where all the members share certain structural and behavioural traits... They are members of a class and as such share the common behaviour and properties but, they also have a distinct identity apart from the class’ (Oliver *et al*, 1997, p.42).

It is this aspect of how to incorporate ‘uniqueness’ of organization or product that constitutes a serious challenge to this overall task, as it may also lead to the situation where: ‘The more specific it is the easier it may be to use in a particular implementation. This weighs against the portability and reusability of the object design. It may be hard to adapt to an alternate architecture if the structure model is too narrowly defined' (Oliver *et al*, 1997, p.42). Considerable care is thus required in the assignment of attributes and particularly functions, as these largely define the overall functional requirements and subsequent performance parameters used in the classification process.

Allowing for the above concerns, in this case, for an organization or VR product or service, the stratagem of identifying core object classes and attributing key properties, relationships, functionalities, core competencies, and behaviours, has largely formed the basis of the proposed taxonometric classification framework. (This process is subsequently explained and elaborated on in following chapter sections)

5.2.6 Conceptualising Technological Change Issues

Addressing approaches to technological change issues is strongly influenced by two dominant patterns of thought and practice generally considered as being formed around the Harvard Design and Planning School approaches (circa mid 1960s) and the later Emergent School approach (circa mid 1980s). These significantly impact on the approach taken by an organization to develop strategy and strategic planning/strategic management and thus approaches for implementing and managing technological change and the associated impacts that such activities inevitably create.

The first dominant pattern is epitomised by the key rationalist schools of thought that evolved through the early 1960's and first published in 1965 as the Harvard or Design School approach attributed to Andrews, and its successor (again in 1965) the Ansoff or Planning School approach attributed to Ansoff (as attributed in Forster & Browne, 1996). These schools of thought appear extensively throughout the literature and practice of strategic planning as significant developments in the early formalisation of strategic management approaches. In each case the processes of planning are defined and explicit in their role and purpose, with the Planning School approach being essentially a hard science approach to management (Carlopio, 2003; Forster & Browne, 1996). By the early 1980's, Professor Michael Porter, also from Harvard, extended the earlier Design and Planning School models with his strong economic theory approach to the problems of strategic analysis (Forster & Browne, 1996). Porters work (Porter, 1980, 1990, 1996, 1998) re-focussed strategic analysis on understanding the environment in which companies operate and the impact and processes of competition.

The second dominant approach varies significantly to the above strategic planning oriented formats and has been variously described as the evolutionist or 'Emergent School' of thought (Carlopio, 2003). It has appeared in a number of forms including: Managing for Excellence (Peters & Waterman, 1982 and Peters & Austin, 1985); Resource-based View (Prahalad & Hamel, 1990, and Sterne, 1992, as attributed in Forster & Browne, 1996); Entrepreneurship (Legge & Hindle, 1997). These approaches are largely focussed on the nature and character of the organization and its internal capabilities and competencies of its members. Response to technological change is thus a facet of internal capability and willingness to change in response to some external impulse or perceived opportunity. To the Emergent School of thought, planning as such is of secondary importance other than as a means to an often ill-defined end.

Whilst focussed primarily on the characteristics of strategy rather than the apparently pragmatic issues of technological change, understanding these schools of thought and practice and the extent to which they have influenced or are present in an organization is essential to undertaking successful change management in an organization. For example, from a Design School approach in particular, when looking to the development or introduction of new technology such as new media virtual reality within an organization, it is critical that planning, preparation and resourcing address the following key issues. These include: the need to incorporate measures and related transitional arrangements for adjustments from earlier strategies and techniques and similarly, the need to include detailed economic forecasting; the requirement to address setting achievable goals and performance objectives; and especially, to address how to exploit opportunities arising from potential new outcomes and features. Surprisingly, these issues all too often remain poorly specified in new technology introduction projects [Betz, 1993, 2003; Liikanen (2004) in Probert *et al*, 2004].

Additional significant factors also arise from introducing virtual reality technology and related systems, certainly under a Design School approach. These include, but are not necessarily limited to: ensuring that organizational communication structures, information ownership and access issues are addressed prior to commencement or attempted introduction of new technology systems; determining that Human-System interface technologies are appropriate for stated requirements; implementing appropriate strategies for ensuring human-factors issues and attendant risk factors are addressed at the outset, including appropriate training for participants; ensuring that support services for both technology and systems are available and affordable; and critically, ensuring that interface strategies to existing systems and services are accurately specified, costed and implementable.

Whereas, from the Emergent School of thought, the following might be seen as the more significant drivers for change in relation to introducing virtual reality and virtual world technologies and systems: perception of changing character of work within the organization and its customer and supplier base; view of virtuality and virtual societies as a cultural norm; capacity to think ‘outside the square’ a criteria for success; efficiencies to be collectively derived from individually driven performance factors; common overall purpose; success driven from the customer through response to customer need; in-depth understanding of products and services and capacity for rapid adaptation; willingness to incorporate or withdraw new or current technology as deemed appropriate.

Both these dominant patterns of thought and practice incorporate approaches that reflect potentialities for the implementation and use of new media virtual reality. They also reflect the following observation by Betz (1993): ‘Today there is no permanent technology advantage for any firm. There are only temporary lead times in technology. This makes managing strategic technologies essential for long-term survival’ (Betz, 1993, Preface p.xvii). This observation does simply apply to the design, development and introduction of new technologies and applications into the marketplace, but also to the introduction and uptake of new technologies within 'user' organizations.

5.2.7 Decision Support Issues

Various tools have been formulated to assist management to identify and understand the operational status of organisational activities. These have varied from ubiquitous spreadsheet modelling products focussed on data-capture and monitoring, to sophisticated enterprise-wide business intelligence processes and knowledge management tools incorporating: decision support systems; query and reporting; online analytical processing; statistical analysis; forecasting; indexing and locus of corporate skills, and expertise, products, services and practices (Orna, 1999).

The use of visual media to assist management decision making and performance management is certainly not new, examples include the use of spreadsheet generated graphs and charts through to sophisticated data-mining tools such as: Purple Insight's MineSet, a data mining and real-time 3-D visualisation software; AVS, consisting of a large library of modules for visualization of geometry and field data; NetMap, a visualization tool for exploring relational databases; MatLab and Mathematica, numeric computation and visualization software. Such systems provide sophisticated imaging metrics (object size, shape, position, colour, intensity, in addition to three dimensional X, Y, Z) to effectively represent complex data in 8 dimensions. The use of 3-D virtual reality and immersive visual simulations as advanced interactive graphical user interface may thus be seen as a further step in a continuum of application tools for decision support.

If for example, knowledge assets are to be a significant component in the application of new virtual reality technology then it will be essential that effective knowledge creation strategies, knowledge based tools for process design and planning, and innovative methods for knowledge capturing and knowledge re-use, are both available to management and are adequately resourced and maintained throughout the organization (European Commission *et al*, 2010). This for example could be through identifying the locus or source of such knowledge, ascertaining and evaluating its potential value-adding capability to the organization, and subsequently through timely and effective information collection, collation, validation and analysis, its targeted internal distribution. It will also be necessary that the role of knowledge management and advanced visualization presentation processes and tools is clearly defined and agreed on by management (whether executive or line-based) and supported effectively. This is particularly so in relation to planning and implementing new and potentially disruptive technologies in the strategically critical area of supporting effective decision making.

5.2.8 Epistemological and Ontological Issues

A further aspect in the conceptualisation of the introduction and management of strategic technology tools such as virtual reality, relates to the interplay between epistemological and ontological aspects of virtual world building and virtual reality simulations. That is, the interaction of epistemology (what we know) with ontology (what we perceive as being, or reality). This interplay provides an essential theoretical backdrop to the development of the proposed classification schema and planning framework.

An interesting correlation can be seen with the work of Professor Ernest Boyer in the development of his theoretical framework of scholarship. Whilst Boyer's work focussed on the role of academicians and the academe, it also raises key issues in relation to the interplay between epistemology and ontology. Boyer's work encapsulates the purpose of incorporating opportunity for students and academic staff to collaboratively engage in the process of research as being primarily about: 'disciplined inquiry and critical thought' (Boyer, 1990, p.69). In this integrative context of academician and student, together, scholars in the sense that each within their established role carry a responsibility for ensuring disciplined inquiry and critical thought is demonstrably at the root of their findings, writings, and arguments. Boyer's classification system or four part theoretical model for thinking of scholarship specifically incorporates four core components that relate to the activities of scholarly research and investigation, but which could readily be extended to include the context of managing strategic technology: 'The Scholarship of Discovery; The Scholarship of Integration; The Scholarship of Application; The Scholarship of Teaching' (Boyer, 1990, p.16). Boyer's own words give a sense of the power of bringing students and the academe into active engagement in research-based activity as a teaching and learning strategy: 'The scholarship of discovery, at its best, contributes not only to the stock of human knowledge but also to the intellectual climate of a college or university. Not just the outcomes, but the process, and especially the passion, give meaning to the effort. The advancement of knowledge can generate an almost palpable excitement in the life of an educational institution' (Boyer, 1990, p.17). Similarly, the introduction of new knowledge or a new knowledge-based innovation can bring a new sense of leadership and achievement within an organization.

Within Boyer's theoretical construct of scholarship it is readily possible to see how the engagement in research/investigative activity can meet the demands and rigour expected of scholarship in contemporary academic thought. Involving as it does the transition from disparate elements of data through development of coherent information and the application of critical thinking and synthesis in its eventual interpretation, interpolation and application to meaning. It also identifies a possible theoretical structure for considering the way a company may address its development of knowledge and skills and their application as corporate competencies, in the context of development, implementation and use of strategic technology. Table 5 provides an example of correlation between the application of Boyer's scholarship model in an educational context and the application of its underlying tenets to a corporate strategic technology context.

Boyer Scholarship Model in an Educational Context	**Corporate Strategic Technology Context**
The Scholarship of Discovery	• Knowledge Acquisition
The Scholarship of Integration	• Integration of Concepts
The Scholarship of Application	• Implementation in the Real World
The Scholarship of Teaching	• Nurturing & Developing New Skills

Table 5. Boyer Scholarship in a Strategic Technology Context

Within this framework, the application of virtual reality based simulations can be quite readily located within the Integration of Concepts stage. However, it is also quite feasible to consider possibilities for the formulation and exploration of new ideas (Knowledge Acquisition stage). Both of these stages clearly relate to the epistemological aspects of the corporate strategic technology context. At the ontological level, there is the monitoring and evaluation of implementation programs (Implementation in the Real World) and the use of VR and simulation tools for training and skills development (Nurturing & Developing New Skills). The epistemetric and ontologic issues addressed in Boyer's scholarship model may thus have direct relevance to managing strategic technology and determining its most effective role in a corporate strategic technology context.

Another approach to considering epistemological issues comes from the work on multiple intelligences by Howard Gardner, Professor of Cognition and Education, Harvard University. Gardner submits that human intelligence and the way we learn, develop and use knowledge, can be attributed to our use of multiple ways of seeing the world, reacting to the world, and thus perceiving the world and resolving problems that impact on us (Gardner, 2004, 2006). He proposes eight different intelligences that humans apply to the acquisition of knowledge and our capability to solve complex problems within defined cultural contexts: Linguistic Intelligence; Logical-mathematical intelligence; Musical intelligence; Bodily-kinaesthetic intelligence; Spatial intelligence; Inter-personal intelligence; Intra-personal intelligence; Naturalistic intelligence (Gardner, 2004, 2006).

Gardner argues that people not only use a range of these intelligences, but may also tend toward a preferred or dominant intelligence. His list of multiple intelligences is of particular interest in that it specifically identifies: Logical-mathematical intelligence (or number/reasoning smart); Spatial intelligence (or picture smart); Bodily-kinaesthetic intelligence (or body smart) (Gardner, 2004, 2006). The epistemological ramifications of Gardner's work with regard to the use of virtual environments involving advanced visualization and haptic devices, is significant. The inter-relationships between visualization and proprioception (sense of position or locus in space) in virtual environments suggests that users with advanced learning skills and cognition in these three areas, or multiple intelligences, are more likely to succeed in their application or use of virtual reality technologies as sophisticated tools. (This is in itself an area for further research.)

5.2.9 Mind Mapping Approach

Determining and formulating a starting point and deciding which issues to focus on, how to establish their relative importance, and their relationships, poses a serious challenge. Figure 38 provides an initial 'mind map' of possible key areas for inclusion in the proposed classification framework. Subsequently, Table 6(a) to 6(c) provides a further collection of identified issues (as derived from identified Formative Data Outputs generated by content analysis of published material reviewed in Chapter 2 and virtual reality projects reviewed in Chapter 4) and begins the process of internal classification of taxonometric parameters that need to be addressed in the conceptual analysis stages and beyond. At this early stage of conceptualising, the contents of Figure 38 and Table 6(a-c) essentially constitute a concept or mind-mapping exercise, bringing together common issues and identifying possible causal or deterministic influences, without endeavouring to ascribe precise classes, attributes, relationships, implied priorities, or possible levels of criticality.

Issues identified in the mind-mapping exercise and tabulation are grounded in the preceding discussions and referenced resources. The issues listed reflect wide ranging theoretical perspectives effecting engineering and technology based organizations, particularly those engaged in innovation practices, as well as reflecting typical issues raised in case studies and analyses of simulation and visualization systems. The concurrent analysis grounded in these key resources is also the basis for and subsequent choice of: domains; factor lists; and elements; as listed in Section 5.7 and Tables 7, 8, 9, 10, 11.

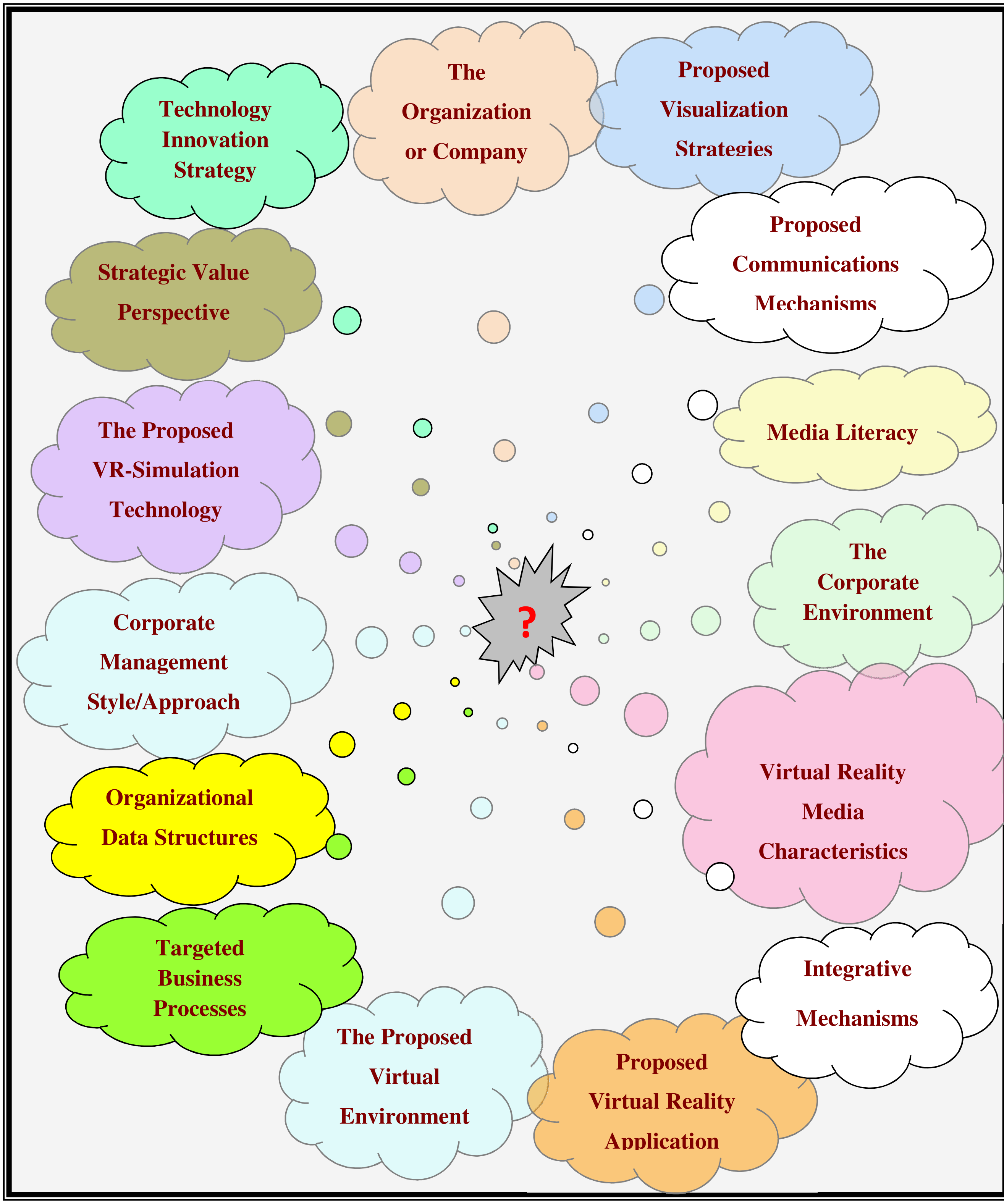


Figure 38. Initial Mind Map of Possible Key Areas for Classification

Possible Foci of Classification	Possible Critical Parameters	Comments
VR Media Characteristics	Interactivity	Extent and timeframe issues
	Immersion	Extent, sense and purpose of
	Integrity	Accuracy and translational capability to real-world analogies
	Fidelity	Of experience, image/sound/touch etc
	Information Intensity	Extent/volume of data-sets and extent of specialised data-access required to achieve the above
Proposed VR application	Adaptable	Purpose-built versus generic in form and use
	Explorable	Providing access to contents of knowledge management systems
	Portrayable	Providing specific illustrative characterisation of given information set
	Pre-representation	Early design stages
	Current representation	Performance monitoring/decision analysis
	Post-representation	Marketing/production stages
Proposed VR-Simulation Technology	Current technology base	Changing versus stable?
	New Technology	Established and known or completely new?
	Single User	Individual workstation based?
	Multi User	VR-Centre style?
	Lifetime	Upgradeable or replaceable?
The Corporate Environment	Innovation climate	History of innovation or a new approach?
	Re-engineering orientation	Capability or potential only?
	Strategic Management climate	Established corporate strategic planning environment?
	Preparedness for change	History of adaptability?
	Commercial or Govt.	Interpretation of economic environment
Proposed Virtual Environment	Representative of the ‘Real’ world	Compliant with natural laws?
	Conceptual world only	What constraints/boundaries?
	Relationships to company or organization	Conceptual or real?
	Interactive	Real-time Data manipulation?
	Multi-use communication	Geographically constrained or global?

Table 6 (a) Initial tabulation of ‘What is being Classified’

Possible Foci of Classification	Possible Critical Parameters	Comments
Proposed Communications Mechanisms	Telepresence	User-user interactive
	Telerobotics	User-equipment command & control
	Real-time	Within what constraints?
	Delayed-time	Or time-displaced
	Revised-time	Slowed down or speeded up
	Interaction	Wide-ranging or constrained?
	Position tracking	Local view, continuously adaptive viewpoint, or remote such as GPS orientation
Organization or company	The people	Internal Skills & expertise, adaptability to change, innovative, creative
	Industry sector	Engineering/technology/business/defence/govt. etc.
	Corporate policy environment	Performance oriented?
	Products/services	Quality certified?
	Customers	Customer expectations
	External marketplace environment	Industry expectations and competition
The Corporate Management Style/Approach	Innovation oriented	A 'new approach', coming off an 'S' curve?
	Continuity of current approach	Extrapolation of existing simulation capability or technology base
	People focussed	Human factors oriented?
	Technology focussed	Either by product or production mechanisms
	Systems Thinking oriented	Understand relationships between organisational units or components, people, participants, environment.
	Strategic Thinking oriented	Business and Technology Strategy focussed
	Task oriented	Such as design/robotics/production
	Decision oriented	Such as policy/strategic planning
Targeted Business Processes	Business Planning orientation	Established practices and procedures?
	Best Practice Processes	Quality Management orientation?
	Strategic Planning Processes	Established or new?
	Knowledge management Processes	Established or new?
	Information management processes	Established or new?

Table 6 (b) Further Tabulation of 'What is being classified'

Possible Foci of Classification	Possible Critical Parameters	Comments
Organizational Data Structures	Formalised	By whom? Industry compliant?
	Secure	Strategies in place to ensure?
	Machine independent	Transportable across platforms?
	ICT formatted	If not why not?
	Ownership	Company? Service organization? Licensing company?
Media Literacy	Multimedia literate	Level of functionality?
	Digital imaging literate	Level of functionality?
	Telematics literate	Level of functionality?
	Virtual reality literate	Gaming only or otherwise?
	Phenomenal Media Literate	Including Haptics?
Proposed Visualization Strategies	Simple or complex	Graphs/charts or complex shapes/sizes/colours interplay
	2-D or 3-D	Object or field oriented
	Pre-set/pre-determined	Constrained by programming
	Real-time Adaptable	User Interactive
	Graphics or photo-realistic	For what purpose?
Strategic Value Perspective	Mission critical	Within what constraints?
	Operations management	Performance monitoring/research/control
	Future direction oriented	According to whose direction
	Current status oriented	Within what systems constraints/boundaries
	Historical record oriented	For what purpose?
Technology Innovation Strategy	Competition oriented	Against which competitors?
	Innovation class	Basic, incremental or next-generational?
	Commercially viable	Connected to company business planning?
Integrative Mechanisms	Technology functional analysis	Functional alignment? Using what parameters?
	Corporate skills & expertise requirements	Old, existing, new?
	Customer expectations	Customer driven or Supplier led?

Table 6 (c) More Tabulation of 'What is being classified'

5.3 The Strategic Context & Organizational Environment

Establishing an effective strategic context for the proposed taxonomy for virtual reality technologies and systems in management-related contexts invokes reflection on many of the issues raised throughout the previous chapters and foregoing discussion.

5.3.1 The Strategic Context

Although based on concepts initiated some 20 years previously, immersive virtual reality systems have only recently become accessible to the broader community of technology-based organizations through the impact of continuing technological development, leading to both substantial performance enhancement and significant cost reduction in IT assets. Whilst used extensively for some years by large corporations in product and systems design roles (aerospace, automotive, oil & gas industries, defence, movie/entertainment industry) virtual reality systems and technology is now potentially accessible by an increasingly wider range of small to medium sized enterprises and organizations. In this regard, the application of new media virtual reality systems in management environments constitutes an innovative strategy capable of being implemented in a wide range of organizations and of impacting on all aspects of company activity including: product design; manufacturing and production planning and control; marketing; quality management; risk and feasibility assessment; skills training; financial performance appraisal and monitoring, and market analysis.

It can further be argued that new media virtual reality technology and systems constitute a radical revolutionary technology (Martin, 1984, 1994; Malhotra, 2000, 2001; Betz, 1993, 2003) with inherent capability to become a disruptive technology and potentially capable of inducing a strategic discontinuity or technology shock (Arnold, 2003; Betz, 2003; Bower & Christensen, 1995; Christensen, 1997; Hill & Jones, 2004; Tidd *et al*, 2005). 'Radical technological changes – or more intuitively called 'technology shocks' – are frequent causes for changes in the competitive structure of industries. Market leaders lose their dominant positions, new entrants appear; in some cases the borders of industries are redefined, in some instances, former market leaders disappear entirely' (Arnold, 2003, p.xi). In the context of ubiquitous new media and the extension of its applications portfolio to include virtual world and virtual reality applications, the above scenarios are potentially very real. New media products, systems, and applications are in a constant state of flux and adaptation, potentially capable of inducing a continuing condition of change in existing products and services that is at the same time incremental with regard to current applications, but also potentially discontinuous through the introduction of radically new technological platforms, products and services, for example the now rapidly diffusing Apple iPad.

This is of particular relevance when considering the strategic context for introducing virtual reality into existing organizational structures and established management decision making processes and procedures. The work of Professors Bower and Christensen (1995) at Harvard Business School, in identifying the characteristics of 'disruptive technologies' and their impact on corporations, provides a further backdrop:

> *The technological changes that damage established companies are usually not radically new or difficult from a technological point of view. They do, however, have two important*

characteristics: First, they typically present a different package of performance attributes – ones that, at least at the outset, are not valued by existing customers. Second, the performance attributes that existing customers do value improve at such a rapid rate that the new technology can later invade those established markets. Only at this point will mainstream customers want the technology. Unfortunately for the established suppliers, by then it is often too late: the pioneers of the new technology dominate the market.

(Bower & Christensen, 1995, in Harvard Business Review Jan-Feb 1995 pp.43; 53).

One message inherent in the work of Bower and Christensen (1995) Christensen (1997) Chandy *et al* (2003) and emphasised by Arnold (2003) is that reliance on established practice and technological *status quo* can be fatal, if not viewed with a healthy scepticism of its longevity and a clear perception of how and when strategic change can and should be introduced.

It is commonly argued that virtual reality technology and systems are as yet not mainstream, although early adopters within the aerospace, automotive, oil & gas industries, defence, moviemaking and entertainment industries, have demonstrated clear benefits and advantages from its application. The gestation period has been an extended one, largely due to high entry barriers such as and running costs and technological constraints on performance. Both of which have now largely diminished to acceptable, or at least useable, levels with continuing incremental improvements (Hill & Jones, 2004). Continuing technological developments, particularly with regard to display systems, computer processing power, and software development tools, will continue to provide escalating capabilities whilst growing competition and capability among suppliers can also be expected to continue to bring entry costs down. Previous entry costs of $2-3M for a basic Reality Centre (for example: RMIT University I^3 Virtual Reality Centre) through $15-20M for more complex installations (for example: Loughborough University Virtual Reality Centre) effectively cut most, if not all, small to medium sized enterprises out of the initial market.

However, with rapid and continuing improvements in display technologies, such as large (1.4m+) high definition plasma screen panels currently available at considerably less cost than projection technology; plus an increasing range of options for assembling the requisite computer processing power; and a wider choice of development tools and systems; it is quite readily predictable that entry costs for basic medium-sized virtual reality centre style wall display systems will continue to fall (Hill & Jones, 2004). This implies that such technology will increasingly become more widely and competitively available, with rapidly increasing higher performance levels, and reducing entry cost structures. These are all classic features of a technology (or as in this case, a range of integrated technologies) reaching or at least approaching critical mass or a capability to initiate a technological discontinuity in its targeted marketplace (Betz, 1993, 2003; Hill & Jones, 2004; OECD, 1988; White & Bessant, 2007).

In the case of considering the potential entry of new media virtual reality technology as a significant and affordable decision support tool for management, its disruptive character lies primarily in regard to its potential to displace existing presentation add-ons to data-warehouse and data-mining structures and traditional information processing systems and significantly extend the capability of new contemporary knowledge management systems. In effect, through providing a 3-D virtual interface to an organization's corporate knowledge, whether in the form of spreadsheet entries, data logging, databases, image libraries, planning documents, product designs, communication systems, or virtually any other form of recorded corporate memory or knowledge assets (Chen, 2006). Whilst the array of integrated technologies involved in providing virtual reality capability continues to evolve, rapidly, the capabilities and technology oriented corporate core competencies of potential commercial actors or market players also requires significant resourcing and development, if companies are to position themselves and develop their strategic attitude such as to be able to utilise such new technologies effectively and to strategic advantage. Clearly, not all enterprises will fit within the new media virtual reality marketplace. However, where an historical focus for virtual reality systems over the past decade has been on product design processes, service oriented enterprises have also begun to identify strategic opportunities for entry into the virtual reality marketplace.

5.3.2 The Organizational Environment

The introduction of advanced computing systems (and thus an inherent capacity to produce sophisticated visualization) may be expressed as a strategic decision or a strategic movement by an organization. However, such decisions or movements do not come easily or without meeting various pre-conditions in the corporate or organizational environment, if such decisions and movements are to have a realisable prospect of success. There must of necessity be an identified need to be met, whether within the company, or externally such as in its customer base (whether existing or projected). Such a need may of course be at any one or more of a number of differing levels. For example: at a systems level; a product or service level; a process level; an application level; or performance issues at any one or more of the above. Similarly, there must an understanding or functional knowledge (or at least access to it) about both the identified need and the proposed new technology enhancement. This in turn implies that knowledge, expertise and skills capable of matching the technological capabilities with the existing or projected environment and its identified requirements, are thus a necessity. Overall, this reflects a process of ensuring the existence of necessary corporate core competencies and a capability to achieve 'knowledge-to-value' transformation.

The existence of a Quality perspective, although not altogether a necessary condition for strategic decisions or movements, does however provide a significant adaptation in an organizational environment. Beckford's (2002) observations about the strategic and normative nature of management decision making in relation to Quality perspectives brings a different light on the point and purpose of such decisions or movements and the technology base that supports them (Beckford, 2002). The virtual reality visualization project examples illustrated in Chapter 4 (drawn from a very large field of such projects) illustrate something of Beckford's Quality perspectives. For example, in the case of the Risk Management consultancy, there was a very clear expectation that their development of visualization technology would help further position them favourably within their identified market sector. As such it was clearly a strategic decision and the implementation of the system a strategic movement by the company. In turn, the company demonstrated concern that the quality of the product/service being developed should meet the company's internal expectations of quality (in effect a normative decision making perspective). The actual visualization strategies, risk and decision analysis used were focused on using techniques and technologies currently commonly available within their discipline area and familiar to their established client/user base. The potential to meet customer expectations was thus relatively assured. As the system matured and developers, clients and other stakeholders became more aware of potentialities, so the system has progressed to more complex levels of implementation. Reliability of the systems and viability of the actual decision outcomes derived from their use will take time to determine.

In the case of the fire training simulation and training project, there was clearly a decision taken to move directly to sophisticated graphics/visualization strategies. With concerns over ensuring emergency services capability and occupational health and safety issues, this project was also clearly positioned as a strategic move within Beckford's (2002) notation, although the actual activities being supported were essentially operational in nature (training). Further developments are expected to arise from this particular pilot project. Again, reliability of outcomes is yet to be established. Similarly, in the case of the demonstrated capability to provide real-time, or synchronous, complex simulation and interaction between remote Reality Centres in Melbourne and London, there was an initial decision to utilise complex visualization technology, in this case using the full image handling capabilities of the SGI based Reality Centre. At a strategic level this reflected the continuing move within the automotive industry towards large-scale simulation and associated simulation-based critical testing and evaluation of products and processes. In this particular case study it is notable that the purpose has largely moved beyond actual technical/engineering issues as a driving force to that of an embedded discussion on the rational for design decisions and associated decision making, potentially requiring the engagement of executive or management level staff. This is of particular relevance to the envisaged future application of new-media virtual reality systems at executive and management level and reflects the earlier findings of Probert *et al* (2004) with regard to the active engagement of an organization's executive and Board level personnel in the use of advanced technology.

In this regard, decisions made within such an environment become progressively more oriented towards being normal operational expectations. The implications of such moves clearly include the expectation that users within such environments are either equipped with the skills and expertise to operate such systems, or at least meet pre-requisite skills requirements that can enable them to be able to quickly adapt to and develop such skills and expertise. Thus forming an example of the establishment of technologically oriented core corporate competencies as necessary conditions for successful innovation, at least at the technical/technological level. It may similarly be argued for such competencies as may be required to analyse and interpret complex data and information being presented in advanced visualization environments, where such new competencies are more likely to require interpretative skills and expertise.

Other, far more complex simulation and visualization systems exist and are currently being developed. This research has identified that there is a need to understand the characteristics of the strategic context and the decisions being made within such environments, as well as the initial decisions being made about whether or not organizations should progress to the introduction and utilisation of immersive or semi-immersive visualization media and associated decision support and knowledge management systems.

5.4 Corporate Strategic Capabilities

The capabilities specific to an organization may vary widely, from the mundane: how to run a business meeting, to the more esoteric: how to design, build and populate virtual worlds. Some capabilities will be considered fundamental to the tactical or effective operational aspects of running an organization: such as how to set-up and operate a payroll system. Other capabilities may reflect more strategically oriented goals and purposes: such as how to identify the need for a specific type of virtual world that is both relevant to and of value to a particular marketplace or group of companies. Effective strategic positioning of an enterprise or organization requires an appreciation of, and directed attention to, developing corporate core, or strategic capabilities and competencies. That set of knowledge, expertise, skills, and technological capacity, along with the ability to think outside the square that so often characterises the successful innovative enterprise and informs and to some extent explains a company's competitive strength.

Another way of thinking about inherent characteristics and capabilities of an organization is to address what is often termed the internal corporate culture of an organization. Clearly, if members of the organization are going to engage in creative and innovative thinking, and to place achievement of significant strategic goals as their prime purpose, then the organization as a whole is going to be affected. Being able to assemble this, at times potentially volatile, mix of capabilities, attitudes and values, and directing and managing them as an integrated set in a value chain consisting of human resources expertise, defined processes and coordinated functions, provides a substantial proportion of the necessary conditions for strategically positioning an organization to both compete successfully and establish sustainable advantage.

Understanding the nature and characteristics of the enterprise's products and services, current or projected, the economic and competitive environment that it operates or intends to operate in, and being able to clearly enunciate a definable strategic competitive advantage, provide at least some of the essential building blocks for establishing core competencies and a strategic position. Thus, innovation and bright ideas do not of themselves provide effective strategic positioning nor constitute the totality of corporate core capabilities and competencies. Understanding the organizational context and environment (both internal and external) further provides a backdrop for identifying and understanding organizational behaviours that can characterise a specific organization or enterprise, its products and services. Sanchez (2001) provides a detailed set of definitions that can also help clarify some of the key terms being used here and in the literature associated with: skills; capabilities; and competencies:

> *Skills are the attributes an individual has to do things.*
> *Competency is the set of skills that an individual can use in doing a given task.*
> *Capabilities are repeatable patterns of action that an organization can use to get things done... capabilities use or operate on other kinds of assets (like machines and skills of individuals) in the process of getting things done.*
> *Competence is the ability of an organization to sustain coordinated deployments of assets and capabilities in ways that help the organization achieve its goals.* (Sanchez, 2001, p.7)

The concept of corporate strategic capabilities and core competencies thus encompasses all aspects of the enterprise including: its management team, those engaged in the day-to-day operations of production and services delivery, planning and controlling, marketing, supply and provisioning, packaging, warehousing and despatching, finance, and human resources planning. Collectively then, the existence and utility of strategic core competencies and capabilities throughout the enterprise establishes potential for exploiting opportunities, developing and delivering products and services which, through providing enhanced performance, quality or price, generate added value for customers and shareholders alike. Strategic core competencies are then a mechanism for creating conditions conducive for leveraging and establishing competitive advantage.

It is here, in this concept of the holism of the enterprise, being able to strategically and holistically view the organization and its knowledge base, intellectual capital and core competencies in terms of expertise, skills and capabilities, organizational performance and culture and technology base, that the proposed taxonomy and the effective use of virtual reality style visualization technologies and systems may deliver its greatest benefits and added value. To be able to assist the CEO to identify and establish the strategic: who; what; when; where; and how; of the organization, quickly and accurately, may in turn assist in leveraging strategic positioning of the organization and help build essential conditions for sustainable competitive advantage.

Given the development of a corporate strategic attitude throughout the organization, how can we position a technology or media, such as virtual reality, as a strategic tool or element to leverage strategic advantage? Several issues arise from this question. For example: What purpose is to be served through the introduction of the new technology as phenomenal media? Where is it to be placed? Who is to take responsibility for it? When will it be introduced and for how long? How is it to be used? What skills are required and are they available? What facilities and services are required and are they available? What connectivity is required to existing or legacy decision-support systems? What cost, initially and continuing, and what return on investment timeline?

Such seemingly simple questions are at risk of attracting simplistic answers, whereas in fact the issues they raise are all tightly interconnected and collectively provide the basis for an extended exercise in systems thinking and related analysis prior to attempting a realisable positioning statement. Sometimes also called strategic alignment or strategic fit, it is about being able to develop and position the organization's internal resources, competencies and strategic capabilities to realise or leverage advantage in the external environment.

5.5 Organizational Stakeholder Issues

Developing a strategic attitude within management, staff and other related stakeholders (eg. shareholders, board members, financial supporters, and community leaders) constitutes a necessary condition for any organization positioning itself for strategic advantage. For an organization directing its intent at incorporating the introduction of such radical and potentially disruptive technologies as virtual reality, it is of critical importance. Introducing new media virtual reality as a management tool may suggest at the outset that there is to be a particular or restricted coterie of users and thus a semblance of have and have-nots among the organization's implicit stakeholders. Strategy focussed leadership then must take account of the need for new skills and expertise both within those work-groups directly affected, as well as those in support roles or seemingly less directly effected. In actuality, it is the whole organization that is impacted on by significant technological change, and the response of the whole organization that sets the agenda for overall success or failure, regardless of the individual technological change being introduced. Difficulties there may well be in times of transition, but where it is the intent of the organization to pursue and implement technological change, then change there most certainly will be, one way or another. Thus the very process of placing complex (or otherwise) technology within an organization highlights rather than establishes predictable trajectories and inevitable intersects in the interests of embedded stakeholders. Where such trajectories are set by the interests and directions of the organization and then compounded by the presence of new technology and related innovation.

If management is intent on creating or extending a divide within the organization, whether it be knowledge based, skill based, or just plain in-house politics of dog-eat-dog, then a divided organization it will almost certainly be, regardless of the introduction of new technologies. If on the other hand, management is focussed on achieving corporation-wide strategic attributes and directing them at addressing and achieving strategic advantage, for example through harnessing its corporate knowledge base, human capital and the best available technology, then damaging stakeholder problems are far less likely to arise. Rather, stakeholder focus will be more likely to be on how to exploit opportunities, add value and subsequently gain benefit.

However, a range of complex and interconnected socio-cultural issues at the organizational level may well arise from the introduction of virtual reality technology and related advanced visualization systems. For example: In the case of introducing high level virtual reality systems and technology such as CAVE or Reality Centre facilities, there may be a tendency for an increase in centredness of decision-making culture versus distributed decision-making. Such a condition may be brought about by the need for a small group of highly skilled specialists to manage and operate the VR technology and systems and a subsequent need to restrict access to and operation of such facilities due to costs or complexities of physical or ICT access. In the case of new media level virtual reality systems and technology, wide spread almost to the stage of ubiquitous, new media skills may well be found throughout the organization regardless of formal skills assessment or perception of formal corporate competencies. However, there will still be requirements for formal training and specialisation in specific application software and systems and the interconnection of specialised interface technologies where appropriate. The Degree of acceptance of technology in management culture can also be an issue, where this may vary widely from complete and unquestioning acceptance to all out rejection. Technology push (cybernetic determinism), where the push for increasing complexity in technology base is apparently independent of identified need -versus- Market-pull (naive expectancy), where technological change is seen as being in response to a growing demand or explicitly defined need. Occupational health and safety issues can be of concern, particularly with regard to extended exposure of personnel to immersive synthetic environments and virtual worlds and the regular use of interface devices, such as haptic gloves and head-mounted displays or 3D shutter glasses. Clearly, hazard and risks analyses are required in such cases. Stable and containable costs with identified and sustainable return-on-investment options for shareholders and financiers are similarly of concern.

Allowing that the most directly affected group of stakeholders are the actual users of the systems, the actual human-VR system interface, the extent of skills and expertise required to operate such systems, and the cognitive and physiological demands on users are issues of significant importance. Kalawsky (2000) reported a number of key issues relating to human factors in virtual environments following a major human factors research project at Loughborough University. This research was undertaken for the Joint Information Systems Committee of the Higher Education Funding Councils in the UK:

> *The majority of human factors research in VR has concentrated on health and safety aspects or the more fundamental human factors issues of perception and empirical performance. Unfortunately, very little research has been undertaken on the usability of a complete VR system. There are methods for evaluating the performance of traditional human-computer interfaces but these techniques are not directly applicable to a VR system because of its different interface attributes* (Kalawsky, 2000, p.92).

Computer literacy itself then goes only so far. Beyond that there is a whole new world of engagement to be addressed in the handling and effective use of synthetic environments and virtual worlds. Clearly, there are opportunities here for significant ongoing research into both human-VR system performance appraisal techniques and measurement approaches, and the development of more intuitive human-VR system interfaces. An unknown factor to date is the extent of acceptance by end-of-the-line customers of products, processes, services, that have been developed and implemented through the use of virtual world technologies. The success of virtual reality systems in developing the latest model automobiles, racing cars and aircraft, computer games and special effects in movies, have been widely touted by marketing agencies as success stories but little appears to have been done to actually assess end customer viewpoints.

5.6 Systems Modelling Issues

Using conceptual models to explain or help our understandings of events, processes, or complex issues, has been a long held and established practice in virtually all areas of scientific thought and endeavour. It also has been the centre of considerable philosophical debate about purpose and role. Modelling involves bringing together and examining or postulating on the interplay between established theory, observed practice, and expectation cum hypothesis about possible new behaviours. Models are: 'the intellectual tools that help us understand phenomena and build bits and pieces of experimental technology. They enable us to intervene in processes and to create new and hitherto unimagined phenomena'.(Hacking, 1983 as attributed in Turnbull, 1991, p.23). Similarly, we can view models or systems-based modelling in particular, as a means of examining and exploring known phenomena in the real world by endeavouring to identify and explain their behaviour: 'The purpose of constructing a model is to understand reality by organizing it. The model represents reality but it is not reality' (Schoderbek *et al*, 1990, p.289).

Developing a systems-based modelling approach provides a useful means of identifying the many disparate issues (such as organizational behaviours) that appear to impact on organizations attempting to use sophisticated visualization technologies such as virtual reality, whilst also providing a means of examining possible relationships between such issues, enabling an appraisal of their possible effects on an organization. In this particular research, we are endeavouring to develop a useful analysis and business tool that can be used for a wide range of engineering and technology-based organizations rather than just one specific company. Thus the model must be of a generic form that can be applied to a wide range of enterprises and organizations. Flexibility in structure, implementation and interpretation is thus an essential criterion for such an approach.

It is also critical to recall that the modelling approach being proposed is intended to facilitate better understanding of organizational attributes and their possible relationships, with particular emphasis on the potential for, and impact of, introducing sophisticated simulation and visualization technology and systems. As such, it is intended to provide an exploratory model that can enable an organisation to assess its capabilities and potentialities in relation to the application and use of complex visualization technology and systems. Certainly, it is not intended to be a prescriptive rubric or cybernetics based approach as per a classical scientific method or analytic thinking approach invoking a prescriptive or deterministic model.

The approach taken throughout this research is essentially an adaptation or variant of that known as a soft systems methodology (SSM) approach whose data input is primarily 'grounded' in the in-depth literature review of relevant current theory and practice (and thus the extensive use of direct quotation throughout this work) and observation of committed virtual reality user organizations. This approach provides the requisite flexibility and capability of being able to be applied to multi-facetted issues in a range of situations (for example, multiple organizations with a range of structures and core competencies in this instance).

In large measure this has been undertaken through using a published literature based grounded process and its embedded thematic analysis to develop a rich-picture of organizations, virtual reality systems and technologies, and then to identify the key parameters of interest: Domains; Factor Lists; System Elements. 'Analysis, in soft systems approaches, should consist of building up the richest possible picture of the problem situation rather than trying to capture it in systems models' (Jackson, 2003, p.183). Central to the approach taken has been that of taking a holistic view of organizations and industry and indeed of particular technologies. This in turn suggests an appreciation for the connectedness or relationships between the many factors influencing technology selection and implementation and variation in the nature of different organizations.

This use of systems thinking and soft systems based approaches can in turn lead researchers to potentially identify the same system factors and elements associated with a particular phenomenon, but to in turn assemble them in different ways. To produce subtly different models that in effect reflect the researcher's individual viewpoints on the issues being addressed, or as in accord with their individual insights into those issues and surrounding causal influences, or as informed by the uniqueness and experiences of particular organizations. In this respect, attempting to model organizations in general with their rich tapestry of influencing factors, people, and events, provides a serious challenge.

5.7 Taxonomy Systems Elements & Fields

The various thematic issues evolving through and essentially 'grounded' in the earlier chapters and the preceding discussion, make it clear that the systems elements and fields required in the following analysis must address two significant areas of interest:

1. The prospective virtual reality user enterprise
2. New media virtual reality systems and technologies

These in turn appear throughout the earlier thematic and content analysis approach and particularly as identified in a wide range of key resources outlined in Section 5.2.9 and Table 6(a,b,c) to be strongly influenced by the following key issues:

<u>The prospective virtual reality user enterprise</u>

- Organizational issues
- Sociological issues

<u>Virtual Reality Media</u>

- Technological issues
- Phenomenal media issues

Accordingly, in developing an approach for analysing organizations and assessing their preparedness for the use of advanced visualization technologies and systems, new media virtual reality in particular, four key areas of interest are proposed as four core 'domains' as follows:

1. **Organizational Domain**
   Representing corporate or institutional perspectives
2. **Technological Domain**
   Representing key issues associated with the core technologies proposed
3. **Sociological Domain**
   Representing the broader societal perspectives
4. **Phenomenal Media Domain**
   Representing the key characteristics of phenomenal media.

Again, as per the earlier thematic analyses and grounded data development it is proposed that each core Domain in turn would contain one or more core Factor Lists which represent main areas of interest or concern relative to its native Domain. These proposed Factor Lists are further outlined in Table 7.

Domain	Factor Lists
Organizational	Human Factors Operational Factors Strategic Factors
Technological	Product Specific Factors Enabling Technology Necessary Technology Base
Sociological	The Individual Group Factors Broader Societal Factors
Phenomenal media	Sensory Factors Engagement Factors Perceptual & Cognition Factors

Table 7. Key Domains and Factor Lists

Each factors list can in turn be populated by multiple Elements constituting the core issues impacting on organizations and to be addressed by the taxonomy as a whole. Some elements may also appear in more than one Factor list and in more than one Domain. In practice, users may wish to adjust distribution of elements between Domains or even introduce new elements as per their own perceptions of criticality and relevance. A selection and possible grouping of such elements is shown in the following Tables 8, 9, 10, 11. Again, these elements are largely derived from the earlier thematic and content analyses of associated publications, reports and papers, and analysis of data grounded in the selection of key resources and related original documents and discussions with practicing managers and virtual reality users.

In practice, the use of such systems elements would be structured in a data collection instrument such as a survey with a column for rating each element, for example based on a 5 point Likert scale. This would enable an individual organization to assess its capacity, capabilities, and strategic positioning in relation to the potential introduction and application of virtual reality technology and systems. In practice, no one organization is likely to view all such elements as being vital indicators of its current or potential performance. Thus, the current lists cannot be totally exclusive or complete by any means, rather, they provide an example of the kind of elements that target organizations may choose to use in structuring Factor Lists to make such assessments.

In this case, they cover all aspects of the organization, technology, surrounding society, and the characteristics of phenomenal media, thus they provide something approaching Jackson's *richest possible picture of the problem situation* (Checkland & Scholes, 1990; Jackson, 2003, p.183).

Clearly, there is a need for continuing research into the nature of such system elements and their individual and collective role in and impact on engineering and technology based organizations considering the introduction of advanced simulation and visualization technologies and systems. Similarly, there is a need for further research into the way such organizations and their organizational performance can in turn be interpreted through analysis of a selection of such system elements. In its current then, the structure and content of the taxonomy must be such that it should enable management to identify relevant strengths and weaknesses in their organization, and thus facilitate effective preparation for the inevitable impacts from introducing and implementing substantive, and potentially disruptive, technological change, a form of Gestalt analysis of the perceptions and world-view of the organization (Chen, 2006; Kuhn, 1962, 1996).

Domain	Factor Lists	Elements	
Organizational	**Strategic Factors**	Core Competencies Innovation windows Risk Management Competitiveness Lead-times to market Information Intensity Intellectual Capital Added value Change management Globalisation External Economic environment Knowledge management Strategic Positioning Leadership capabilities Organizational culture Research orientation Service Provider Reliant on Technology	Industry sector ethnographics Sectoral Transformations Changes in the nature & organization of work Spread of technology in the workplace Global competition Global village concept Strategic attitude Ethics Technological impact Risk taking Imagination & creativity Technology skills & competencies Corporate memory IT orientation Tech/product developer
	Operational Factors	Time-cost profiles Resource Requirements Productivity Skills Data-integrity Simulation skills Communications Defined Operational Systems Planning & control Process re-engineering Performance management Quality management Organizational complexity Organizational structure Organizational formalisation Corporate memory Internal economic environment Dynamic Tech. Environment	Skills upgrading Technology skills and competencies Functional requirements Structural requirements Support requirements Systems thinking Team orientation Risk management Core competencies Organizational processes Upgradability Longevity Cost-performance Security OH&S Technology User IT orientation
	Human Factors	Ergonomics OH&S Cognition aspects Specialist skills required Innovation and Creativity Culture Ethics Decision making skills Communication skills	Ease of use Communication Skills Leadership capabilities Interpersonal skills Teamwork orientation Strategic attitude Systems thinking Intellectual capital Motivation

Table 8. Factor Lists and Elements in the Organizational Domain

Domain	Factor Lists	Elements	
Technological	**Product Specific Factors**	Cost-performance Useability Quality parameters Customer expectations Competitiveness Lead-time-to-market Functional requirements Compliance with customer functional requirements & needs Product differentiation Realism Virtual workspace Ergonomics Mediated environments Spatiality Research orientation	Longevity Upgradability Object attributes Movement Tele-robotics Tele-presence Availability 3D surround sound 3D stereoscopic vision Visualization Time-cost Repeatability Information rich environments Latency Illusion
	Enabling Technology	Availability Cost-performance Skills required Support requirements Structural requirements Security Systems integration capability Functional requirements Resource requirements Ease-of-use Tele-robotics Human interface systems Position tracking Display systems	Longevity Upgradability Technological complexity Transparent Systems integration Visualization 3D stereoscopic vision Stereo-vision 3D surround sound Image fidelity Acoustic fidelity Haptic fidelity Tele-communications
	Necessary Technology Base	Availability Structural requirements Support requirements Skills requirements Security Functional parameters IT orientation	Upgradability Longevity Cost-performance Complexity Advanced computing Resource requirements

Table 9. Factor Lists and Elements in the Technological Domain

Domain	Factor Lists	Elements	
Sociological	**The Individual**	Ergonomics Visual acuity Auditory acuity Work satisfaction Motivation Ethics Meaningful work Technology skills and competencies Imagination & creativity Team participation Communication skills Visualisation Specialist Technology skills & competencies OH&S Cognition aspects	Organizational culture Virtual workspace Innovation culture 3D surround sound Immersion Engagement Interactivity Presence Tele-presence Movement Illusion Realism Strategic attitude Interpersonal skills Leadership capabilities Decision making skills Competitive
	Group Factors	Social organization of work Management of change Occupational health & safety Skills upgrading Geo-spatial distribution Job displacement Job creation Competition	Geo-spatial factors Spatiality Core competencies Organizational culture Job redesign Risk taking Team engagement orientation
	Broader Societal Factors	Technological impact Virtuality as Social phenomenon Industry sector ethnographics Sectoral transformation Changes in the nature & organization of work Spread of technology in the workplace	Geo-spatial factors Globalisation Competitiveness Risk Management External economic environment Increasing global competition Global village concept Socially responsible/Ethical behaviours & norms

Table 10. Factor Lists and Elements in the Sociological Domain

Domain	Factor Lists	Elements	
Phenomenal Media	**Sensory Factors**	Visualization Auditory stimulation Visual stimulation Haptic stimulation Functional requirements 3D surround sound	3D stereoscopic vision Proprioception Visual acuity Auditory acuity Dynamics
	Engagement Factors	Immersion Engagement Interactivity Presence Communication Tele-presence Tele-robotics Transparent systems integration	Functional requirements 3D surround sound 3D stereoscopic vision Movement Geo-spatial factors Ergonomics Safety
	Perceptual & Cognition Factors	Spatiality Illusion 3D-stereoscopic visualization 3D-surround sound Dynamics Repeatability Realism Virtual work-space	Functional requirements Presence Mediated environments Information rich environments Latency Immediacy Virtuality Imagination Ethical behaviour & norms

Table 11. Factor Lists and Elements in the Phenomenal Media Domain

5.8 Virtual Reality as an Instrument for Paradigm Change

The notion of considering scientific and technological progress and the impact of technological change processes as a form of societal paradigm change or Gestalt switch was first elaborated by Thomas Kuhn in 1962. Whilst it raised much argument, for and against, it provides a useful means for examining and analysing both societal and organizational preparedness for technological change. Kuhn (1962, 1996) explained his concept of paradigm change using two discrete forms or differing viewpoints he described as: Disciplinary Matrix: in effect a form of global theory or fundamental change; Exemplar: a more broadly defined form of change with potential for extrapolation to a variety of situations and conditions (Kuhn, 1962, 1996; Turnbull, 1991). Interpreting Kuhnian paradigmatic change has invoked considerable argument and alternative viewpoints:

> *Critics and commentators have paid considerable attention to Kuhn's first usage of the term paradigm as a global theory that defines possible questions and acceptable answers. While this focus raises important problems about how paradigms structure scientist's experience and the difficulties of translating and moving between paradigms, it misses the crucial sense of paradigm as exemplar, which Kuhn himself saw as central in understanding how scientists learn how to make sense of the world* (Turnbull, 1991, p.22).

In the particular case of this research program, the concept of paradigm change is applied to examining and analysing an organization for its readiness for change and the introduction of virtual reality systems as a potentially disruptive technology (Bower & Christensen, 1995; White & Bessant, 2007) capable of impacting on all aspects of the company, including its: skills and expertise base; products; services; base technologies; processes; and structures. In this regard, the introduction of virtual reality systems clearly relates to the characteristics of Kuhn's disciplinary matrix style paradigm change. However, when looking to the internal structures, processes and relationships with an organization there are clearly areas where Kuhn's exemplar approach applies:

> *Paradigms are not primarily agreed-upon theoretical commitments but exemplary ways of conceptualising and intervening in particular empirical contexts. Accepting a paradigm is more like acquiring and applying a skill than like understanding and believing a statement* (Rouse, 1987, as attributed in Turnbull, 1991, p.22).

To express the potential impact of paradigm change on an organization or to determine its capacity/capability to undergo such change, it is necessary to consider a range of situational and other necessary conditions for such change to occur. The disruptive technology character of virtual reality systems and technologies implies that organizations entering the business arena where access to such technologies is in itself an essential condition for competitiveness, and indeed possible commercial survival, must be capable of embarking on significant internal re-thinking, re-engineering, and absorbing and directing potentially damaging technical and human turbulence (Arnold, 2003; Betz, 2003; Bower & Christensen, 1995; Hill & Jones, 2004; Malhotra, 2000, 2001; White & Bessant, 2007).

Determining the need for change, the nature and criticality of the influences affecting the need for change, the direction of such change and its desirable outcomes, is certainly a clear starting point before thinking about introducing or dramatically modifying products, processes, or technologies and having to deal with the concomitant demands for additional expertise and skills. A shift in an organization's basic paradigm or way of going about its business, suggests significant forces are at work that demand management attention, allocation of resources and a company-wide will to change. Simply attempting to change a company's technology base because of a salesperson's spiel is hardly a rational or business-like way of managing shareholder resources, gaining support from staff and other stakeholders, or attempting to build company value (Johnson *et al*, 2002, 2008).

In considering the affective impact of paradigmatic change on organizations and industry sectors at large, the following approach of identifying possible 1^{st}, 2^{nd}, and 3^{rd} order effects from new technology introduction, provides an additional technique for better understanding the locus of such impacts from the introduction of new media, such as virtual reality and how they potentially influence widespread change and thus the introduction of paradigmatic change:

- 1^{st} Order effects may be seen as an introduction into an organization of increasing amounts of new media technologies that, in particular, support virtual reality and 3D visualization systems. Initially these may take the form of advanced PC desktop machines and VRML software systems, advancing to power workstations and 3D CAD systems, eventually to larger more powerful processors and full-scale virtual reality systems.

- 2^{nd} Order effects may be seen as an increasing aptitude within an organization to make effective use of new-media and associated systems such as virtual reality and advanced visualization. This in turn would of necessity be reflected in shifts and changes in skills and expertise requirements within the organization and a growing dependency on such systems and the skills sets required to drive them.

- 3^{rd} Order effects may be seen in the increasingly widespread use of virtual reality technology and systems across industry sectors as the norm, as the use of such systems predictably increases competitive advantage for adopters at the expense of non-users. Examples of these effects may be seen in early adopter industry sectors such as: aerospace, automotive, and gas and fuel exploration. All three such sectors have had a decade of extensive use of virtual reality type simulation systems and make widespread use of virtual reality in a range of aspects of design, testing, feasibility studies, and risk assessments.

5.9 Conceptual Analysis Summary

This chapter has addressed a range of issues associated with the conceptual development of the proposed taxonomy or planning framework. It has developed an innovative approach to gaining insight into organizations and their potential to utilise new advanced information visualization and simulation systems and the continually changing and developing technology bases associated with them. In doing so it has placed an emphasis on the potential of strategically positioned technological innovation to leverage enhanced performance and competitive advantage. In particular it has addressed the development of innovation and change management with specific reference to the introduction of new technology and related systems and their diffusion in the marketplace. In doing so it has drawn in particular on the works of: Martin, 1984, 1994; Betz, 2003; Rogers, 2003; to develop an analysis applied to the use of virtual reality technology. It also makes use of various strategies to initiate preliminary abstractions and mind-mapping approaches to facilitate tabulation of potential areas for classification (See Figure 38 and Table 6 (a) (b) (c) and subsequently Tables 7, 8, 9, 10, 11).

Sections 5.2.2 and 5.2.3 include discussion and analysis of an extrapolation of Martin's Popperian framework model for evaluating commercial innovations (Martin, 1984) as applied to the introduction of new media such as virtual reality (see Section 5.2.2, Table 3). This clearly identifies areas to be addressed in the transition of technological capability from a typical technologically based design context to the more socio-technical environment of management decision making. This analysis also strongly identifies the risk parameters that apply to such technological transitioning. The subsequent analysis and further discussion highlights these risks as representing a serious challenge to successful technological innovation, particularly as seen in the potential diffusion of a technology (such as virtual reality) having or requiring a high density or concentration of advanced technologically focused knowledge and skills. These risks and associated concerns are further discussed through Sections 5.2.3/4/5 and developed through Section 5.2.6 in an analysis of strategic management and technological change issues. It makes particular reference to two dominant 'schools' of management thought and practice: the Harvard Design and Planning School approach and the later Emergent School approach. A further extrapolation to identifying specific decision support systems that may be enhanced through extended visualization strategies is addressed in Section 5.2.7. It also makes particular reference to the potential for virtual reality systems to provide enhanced knowledge creation, knowledge capturing, and knowledge re-use (European Commission et al, 2010).

It then progresses to establishing a strategic context and organizational environment for the proposed taxonomy and identifies virtual reality systems and technology as being capable of impacting on all aspects of company activity. In particular, the application of new media virtual reality systems and technology within the decision making environment of an organization is identified as being both a radical and potentially disruptive innovation, a positioning that strongly implies that organizations must be both aware of and well prepared for the introduction and application of such an innovation and its potential effects, before attempting its introduction. Sections 5.3, 5.4 and 5.5 in turn address corporate strategic capabilities, core competencies and organizational stakeholder issues and their impact on the capacity of an organization to engage in the level of creative and innovative thinking required to attempt the introduction of a significant new technology such as virtual reality and the use of virtual world data modeling. The focused development of specialized knowledge, skills and expertise as essential and strategically oriented 'intellectual capital' of the enterprise, can bring an intensity of purpose and capability that can infuse corporate culture with both the power and the passion to achieve, and to further leverage competitive advantage from a challenging innovation.

Sections 5.6 and 5.7 outlines and commences the processes of systems modelling and identifying potential systems elements and fields for the proposed taxonomy. This stage of the conceptual analysis has drawn largely on data derived from the preceding content analysis and review of associated publications and documents. Specifically, the development of domains of interest, systems elements and factor lists has been drawn from the category/priority matrix analysis of multiple publications and reports as demonstrated using exemplar cases in chapter 4.

As discussed in Chapter 5.7 the tetrad of four Domains of interest is proposed as:

1. **Organizational Domain**
2. **Technological Domain**
3. **Sociological Domain**
4. **Phenomenal Media Domain**

The proposed Factor Lists associated with each Domain are documented in Chapter 5.7 Table 7 whilst a further breakdown incorporating system elements per Factor List is documented in Tables 8, 9, 10, 11.

Throughout this conceptual analysis process there has been the progressive identification and listing of foci of classification, critical parameters and subsequently key domains of interest and associated systems elements that subsequently are used in Chapter 6 to formulate the proposed planning framework.

Chapter 6.

Proposed Taxonomy & Structural Components

6.1 Introduction to Taxonomy Structural Components

This chapter outlines the essential structure and components of the proposed Taxonomy or Planning Framework and discusses a range of related issues and approaches to visualizing the Taxonomy and its application.

This chapter now takes the proposed Domains, Factor Lists and System Elements as developed in Chapter 5 and builds a structure around them. It also further develops the paradigm thematic to propose a Paradigmatic Planning Framework as an integral part of the taxonomy. In this regard, the conceptual analysis and proposed conceptual models developed through Chapter 5 and assembled into a proposed structure in this chapter, further represent the 5^{th} and 6^{th} SSM stages of the research methodology as expressed in Chapter 3 Figure 27: Adaptive Grounded Soft Systems Methodology, and Table 1: AGSSM Research Activity as Adaptation of SSM Approach.

6.2 Structural Components of the Taxonomy

6.2.1 Tetradic Structure

As per the preceding thematic development and conceptual analysis chapters the proposed taxonomy and planning framework as a ‘knowledge organization system or knowledge organization structure’ (Hedden, 2010, p.1) addresses an organization’s preparedness and capability to undertake the development or implementation of advanced visualization tools utilising new media VR-based products or services, whether based on technical research and development activities using immersive 3-D CAD techniques, or the more socially oriented use of new media virtual reality as a means of supporting collaborative engagement (immersive or otherwise) in virtual or synthetic world environments and the use of such systems to support decision making in the management of an organization and its environment.

The proposed modelling for the taxonomy has strongly focussed on using a systems thinking approach that reflects an appreciation of the many inter-relationships that arise, acknowledges the continuing convergence of both new technologies and business systems, and the necessity of effective integration of the many influences and causal factors involved, at the very least from a management perspective and more particularly from a socio-technical perspective. It is acknowledged that there are in reality a mix of differing perspectives and interests covering a range of discipline areas, including but not limited to: visual media; digital assets (both hardware and software oriented); data (in many different forms); information and knowledge management; human resources, specifically in relation to skills, expertise, ergonomics and occupational health and safety issues; organizational context, behaviour and culture; strategic planning and strategic management; innovation and change management; performance management; and management of technology.

In developing a workable model for the taxonomy or planning framework, the underlying philosophy has been that of taking an holistic view of what constitutes an engineering or technology based organization including in particular the many influencing perspectives as listed above. This philosophical positioning and methodological approach implies a strong degree of connectedness between and within the many influencing factors and systems elements as identified in Chapter 5. The taxonomy's structure itself then represents a new way of looking at and identifying an organization's preparedness for and capability to implement the use of advanced visualization tools utilising new media VR-based products or services. Accordingly, the structure must necessarily reflect the dominant features of the proposed taxonomy that impact on or reflect the performance of a potential 'user' organization.

Collating, sorting and assembling the many identified factors and proposed systems elements (See Chapter 5.2.9 Tables 6(a,b,c), Chapter 5.7 Tables 7, 8, 9, 10, 11) has led to identifying four clearly dominant and significant areas of interest, hereafter referred to as four core 'domains' of influence. Each of these domains has been identified as being characteristically influenced by a specific set or short list of key 'factors' that specifically apply within the relevant domain of interest, these are identified in Chapter 5.7 Table 7. Further analysis through Chapter 5 in turn indicates an extensive listing of 'systems elements' specifically relevant to each of the factor lists and in turn the related key domains. In assembling these formulations, an hierarchical tetradic structure consisting of four key 'Domains' of influence each containing three core Factor segments and a range of definable System Elements has been proposed. As discussed in Chapter 5.7 and listed in Table 7 the tetrad of four Domains of interest, each with three core Factor Lists, is proposed as follows:

1. Organizational Domain: Representing corporate or institutional perspectives
Factor List: Human Factors; Operational Factors; Strategic Factors
2. Technological Domain: Representing key issues associated with the core technologies proposed
Factor List: Product Specific Factors; Enabling Technology; Necessary Technology
3. Sociological Domain: Representing individual social and the broader societal perspectives
Factor List: The Individual; Group Factors; Broader Societal Factors
4. Phenomenal Media Domain: Representing the key characteristics of phenomenal media.
Factor List: Sensory Factors; Engagement Factors; Virtuality Factors

A further extensive breakdown incorporating System Elements per Factor List is documented in Chapter 5.7 in Tables 8, 9, 10, 11.

It should be recalled that the proposed taxonomy and planning framework is primarily focused on addressing the potentialities for the application of advanced visualization and virtual reality technology and systems in engineering and technology based organizations, it has also been ascertained from the preceding

Content Analysis and subsequent discussion and analysis, that such organizations are not to be considered as simple phenomena. Rather, multiple internal and external factors directly or indirectly influence or impact on an organization, influencing in turn both its operations, procedures, processes and behaviours, and its technological stance, particularly with regard to its products and/or services and its capability to initiate or respond to innovation and change (whether technological innovation or otherwise). The impact of the introduction of new media as both 'social media' and as an instrument for enabling and facilitating communication across and between organizations, has been significant and continues to grow as both the volume of such communication messages increases along with rising levels of critical reliance on such communication systems. This raises concerns over growing ITC infrastructure requirements, data and message security issues, and related critical issues in areas such as rising digital asset values and an increasingly inherent corporate dependency on such systems. Engineering and technology based organizations in the twenty first century must necessarily address these issues as central to their very existence, a condition that significantly differs from earlier dependencies almost entirely based on the pragmatics of production being on time, on budget, and compliant with technical specifications. Increasingly, issues in collaboration with partner organizations (often global) real time adaptations in supply chain, and shifting requirements in internal competencies, skills and technological capabilities, are central and driving conditions for success. The twenty first century world is increasingly reliant on global, ubiquitous and effective communications, a world no longer stable in any one paradigm of design approach, technological base, process or product, for any length of time compared to previous eras.

Again, such performance related influences and inherent or otherwise corporate capabilities and competencies vary from industry sector to industry sector and from organization to organization. Thus a wide range of related issues arise when considering the structural components of the proposed taxonomy and planning framework (see Chapter 5) with many such issues interconnected and/or interdependent. The above approach to structuring a common 'base' of four key domains of interest has been taken to provide a framework model capable of being applied across a wide range of organizations, albeit in this instance largely focused on those engaged in or strongly influenced by engineering disciplines such as in manufacturing, construction, mining, automotive, aerospace, energy, communications, and related science and technology based disciplines, and in particular those organizations with an orientation toward the use of new media and ICT related systems.

6.2.2 Visualization Approach

It is proposed that the taxonomy should be readily comprehensible and relatively straightforward to use and understand, in terms of both its embodied structure and its application. Visually representing the structure of the taxonomy in a way that both reflects the central tenets and core attributes of the taxonomy such that they can be readily understood and utilised by its practitioners and users, then forms a critical formative aspect of the taxonomy itself.

Whilst taxonomies are inherently hierarchical in nature, some existing taxonometric systems are known only by virtue of particular or popular aspects of their structure. For example: Bloom's Taxonomy of Learning is readily described by referring to its three domains of learning: the Affective, the Cognitive, and the Psychomotor domains (Bloom, 1956) and is generally illustrated in a tabular form; whereas Maslow's taxonomy or Hierarchy of Needs is commonly known by its layered two dimensional pyramidal form structured from the base upwards as: Physiological Needs, Safety needs, Social Needs, Esteem Needs, and Self-actualisation Needs (Massie, 1979).

In this regard, it is proposed to assemble the proposed taxonomy to focus user's attention on addressing the concerns implicit in the four identified key Domains of: Organizational Perspectives; Technological Perspectives; Sociological Perspectives; Phenomenal Media Perspectives; and their embedded hierarchy of influencing Factors. One such approach to visualizing these Domains and their internal structures of Factor Lists is by considering them to collectively form a three-dimensional idealised square right pyramid, each side triangular and of equal dimensions with a common vertex forming an apex where the axis is perpendicular to the centre of the square base. Each side of the assembled pyramid representing one of the four prospective Domains, with each side in turn structured as three integrated horizontal layers. The three layers of each side (or Domain) of the pyramid are designated as representing the three Factor Lists in each of the Domains. Potentially, building blocks or segments within each layer would in turn represent the various Systems Elements that constitute or influence each of the Factors in the Domain Factor Lists. This proposed visualization structure is illustrated in Figures 39 and 40.

This simple structural approach provides an easily visualized three-dimensional physical model, which is common in structure to many management related modelling approaches used to explain or illustrate complex processes and problem solving strategies. For example, Johnson *et al* (2008, 2011) use at least 15 different forms of graphical representations throughout their wide-ranging discussions to illustrate, highlight, model, explain, and reflect on key issues and areas of interest or concern. Similarly, whilst essentially hierarchical in nature, this pyramidal graphic form is not intended to absolutely define a level of pre-potency between the structural layers, rather it provides a visualization technique that emphasizes a desirable hierarchy or order of significance and suggests a significant level of inter-relatedness and dependency between its elements.

6.3 Domains of Influence

6.3.1 Organizational Domain

The Organizational Perspective Domain is illustrated in Figure 39 as one face of a square right pyramid. The face of the pyramid is in turn divided into three component layers, each layer representing one of the proposed key Factor Lists as follows: Strategic Factors; Operational factors; Human Factors. The layering of each Factor List is hierarchically ordered in the form shown to illustrate both the importance of Strategic planning and thinking (positioned at the top of the pyramid) and the criticality of having Human Factors issues resolved as a fundamental means for building on a solid foundation (the base of the pyramid). Operational factors are represented as the means of connecting the essential human factors/resources base with the driving force of strategic planning/strategic thinking. System elements used to configure each of the three Factor List layers in the Organizational Domain are documented in Chapter 5.7 Table 8.

This form of hierarchical assembly as shown in Figure 39 strongly suggests that organizational factors influencing the potential capability of an organization to undertake the introduction of new media VR is dominated by and is foundational on Human Factors related issues and concerns. Historically, the role of human factors in ICT systems and products were factored on human skills sets and in particular the inevitability of subsequent training and up-skilling processes. The array of Human Factors systems elements identified in Chapter 5 indicate that here the emphasis is more on addressing physiological and higher level cognitive processes. Virtual world and virtual reality engagement is largely driven through sensory interaction with a strong component of visualization that requires for example an advanced level of visual acuity, a strong sense of disciplined imagination and a highly developed level of skilled perception relative to identifying and extracting meaning from visual images. These are not specific skills that can be addressed through a defined set of simple training tasks. Rather, they are a complex set of characteristics that characterise successful 'users' of virtual world and virtual reality environments. Interestingly, they are also characteristic of the growing array of 'on-line' user communication skills that typify the GenY sector of the population for whom the use of new media in its many different forms is a growing normality.

In the suggested hierarchy, Operational Factors is placed as building on the performance related capabilities of identified Human Factors. In the twenty first century, the characteristics of operational performance are changing dramatically from the earlier Taylorist structured environment of stable, planned processes and practices. This is particularly so in contemporary engineering and technology based environments. Significant turbulence in operational practice is apparent across many engineering and technology oriented firms and enterprises, particularly so in the area of manufacturing. Increasingly, there is pressure for substantive re-engineering of business processes, shifts and fundamental changes in corporate core competencies, developing a capacity for rapid change, alongside developing and actioning significant potential for collaboration between multiple organizations and enterprises and associated cross-disciplinary information sharing (European Commission *et al*, 2010). Developing effective cross organizational communications skills and at the operational level having ICT systems and technologies in place to support them, is a critical aspect to building and sustaining an organization's operational performance in an increasingly hyper-competitive environment.

Clearly, in this context the determination and actioning of strategic purpose, intent, positioning, and engagement, are at the top of the Organizational Domain. Innovation, leadership, globalisation, change management, knowledge management, and understanding of the many sectoral transformations and adaptations either occurring or identified as future factors in 'leadershifts' in the future, are all key systems elements building this level of the hierarchy. The very determination and selection of new media virtual reality systems as a potential application within the organization is in itself a significant strategic choice, requiring an in-depth understanding of the many shifts and changes occurring within and across industry sectors and impacting on the very technology base and core competencies of an organization.

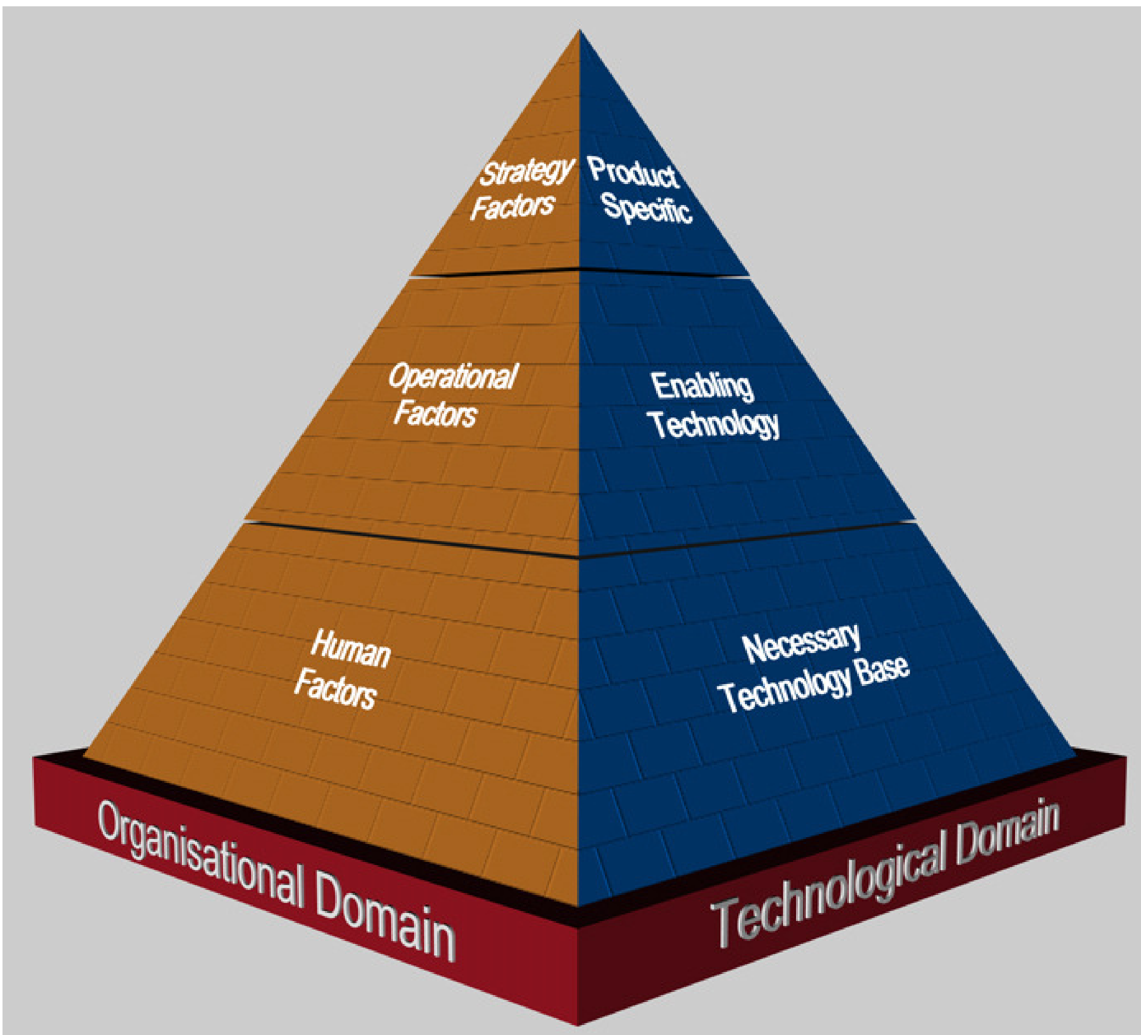


Figure 39. Organizational & Technological Perspective Domains

6.3.2 Technological Domain

The Technological Perspective Domain is illustrated in Figure 39 as an adjacent face of the pyramid to that of the Organizational Domain. The face of the pyramid is in turn divided into three component layers, each layer representing one of the proposed key Factor Lists as follows: Product Specific Factors; Enabling Technology Factors; Necessary Technology Base Factors. The layering of each Factor List is ordered in the form shown to illustrate both the importance of Product specific factors (positioned at the top of the pyramid) and the criticality of having a Necessary Technology Base (the base of the pyramid). Enabling Technology factors are represented as an integrating means and connecting the necessary technology base with the needs of the product/services factors. System elements used to configure each of the three Factor List layers in the Technological Domain are documented in Chapter 5.7 Table 9.

The broad layer at the base of the domain face is indicative of the significant role that the technology base has to play for engineering and technology based organizations. Achieving and sustaining this substantive base represents a significant task with both capital and recurring cost implications. It constitutes an essential structural and technological capability base for the organization, whether it is manufacturing technology, ICT systems and technology, transportation systems and technology, science and medical systems and technologies, avionics, energy systems, audio or vision systems. Without this essential technological base such organizations would be incapable of operating in their chosen area of interest. With regard to the introduction and use of new media virtual reality systems, the base technology requirements must include the essential resources for both the ICT base systems as required for the organization's business and technological operations, plus the additional requirements to support IT intensive data, graphics and vision processing, along with communications network platform systems and related technologies.

The Enabling Technology Factors layer is positioned above the broad technology base and represents the array of ICT specific technologies and systems required to implement intensive data, graphics and vision processing, and the requisite network communications systems required to implement effective virtual world and virtual reality systems. In effect, these provide a technological sub-platform on which the more processing intense systems required for VR implementation can be built. Systems integration, human interface systems, display systems, and an array of robotic and haptic systems may also be relevant System Elements at this level.

At the top of the Technological Domain are the Product Specific Factors, at this level specificity of technology and systems is at its highest. This requires a clear focus on the organization's functional requirements for its technology, system and applications compliance with user and customer expectations and requirements, and a strong focus on an array of product and service Quality parameters. With specific regard to the introduction of new media virtual reality, there is the need for clarity on role and purpose of the new systems and an understanding of exactly how and where they fit in the organizations technological tool-kit. This requires a high level of technological specificity and task identification, product differentiation, and an advanced capacity for data collection, collation, processing, and technological aspects of information and knowledge management.

6.3.3 Sociological Domain

The Sociological Perspective Domain is illustrated in Figure 40 as the third face of the pyramid, adjacent to the Technological Domain. Its face is in turn divided into three component layers, each layer representing one of the proposed key Factor Lists as follows: The Individual Factors; Group Factors; Broader Societal Factors. The layering of each Factor List is ordered in the form shown to illustrate both the importance of the Individual (positioned at the top of the pyramid) and the necessity of establishing coherent relationships with the Broader Societal factors (as the base of the pyramid). Group factors are represented as the means of embracing the interests, needs and competencies of the individual to achieve organizational objectives in the context of and in association with Broader Societal factors. System elements used to configure each of the three Factor List layers in the Sociological Domain are documented in Chapter 5.7 Table 10.

Broader Societal Factors are positioned as the base of this face of the pyramid representing the Sociological Domain of influence. It reflects the wide range of societal issues that impact on an organization, and through which in turn the organization may have an impact or influence on broader society. In the case of engineering and technology based organizations there is the inevitable technological impact that the company's very existence has on the society within which it operates, or through which it provides its goods and services, and from which it acquires goods, services and its people. The external economic environment in which it operates, whether locally or at a global level, in turn influences and constrains the organization. Industry sector ethnographics, sectoral transformations, political regimes and changes in the nature and organization of work, all influence the organization and in turn are influenced by the operations of an organization. With regard to the introduction of new media virtual reality systems, the expanding user base for new media social systems in the broader society both raises opportunities for organizations to gain personnel already experienced in the use of new media, whilst raising the challenges of redirecting that expertise in external social media to more industry focussed applications within the organization. Organizations attuned to these issues and opportunities are likely to be well positioned to move quickly into effective implementation of new collaborative virtual environments.

The second layer of the Sociological Domain factors addresses Group Factors and in particular the social organization of work and recognition that the management of change and technological innovation is largely a social process. The development and acknowledgement of corporate core competencies and the importance of internal organizational culture as critical areas of engagement for both staff and management, is a significant area of influence on the performance of an organization. Given the inevitable shifts and changes in requisite competencies and system capabilities required to effectively implement new technology applications, it is critical that the internal social structures, organizational culture and value systems are supported and in effect, owned by staff and management. Effective 'team' orientation at the work group and collective organizational level can provide a work atmosphere in which the extension into 'virtual team' engagement is a relatively easy step.

At the top of the Sociological Domain are the Individual Factors, a category that reflects the value that the organization places on the capabilities, competencies, skills, and performance factors of the individual. Many identified Systems Elements address this Factor including: specialist technology skills and competencies, imagination and creativity, team participation and communication skills, strategic attitude, interpersonal skills and leadership capabilities. There are also the many aspects that the use of new media VR require the individual to become competent in, these can include: operating in a virtual workspace (as opposed to the actual real-world office or workshop environment), development of skills in interactivity in virtual world space, and a capability to work with a range of virtual reality attributes such as immersion, tele-presence, and illusion.

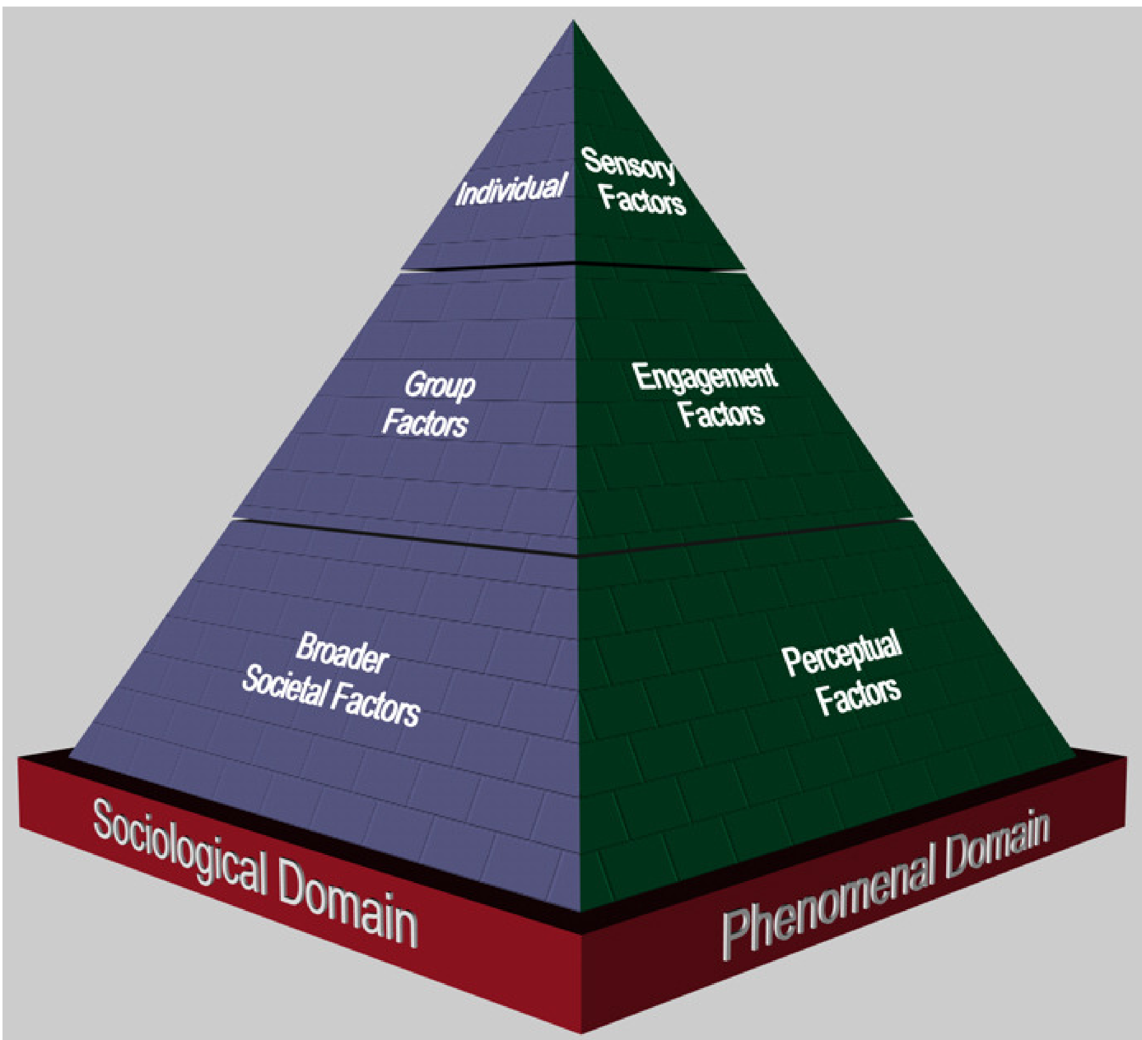


Figure 40. Sociological & Phenomenal Media Domains

6.3.4 Phenomenal Domain

The Phenomenal Media Perspective Domain is illustrated in Figure 40 as the fourth face of the pyramid. Its face is in turn divided into three component layers, each layer representing one of the proposed key Factor Lists as follows: Sensory Factors; Engagement Factors; Perceptual Factors. The layering of each Factor List is ordered in the form shown to illustrate the significance of sensory interface in phenomenal media (positioned at the top of the pyramid) and the unique role of perception and cognition (as the base of the pyramid). Engagement factors are represented as the means used to connect sensory input with perceptual/cognition processing and responses. System elements used to configure each of the three Factor List layers in the Phenomenal Domain are documented in Chapter 5.7 Table 11.

The positioning of perception and cognition as the base layer in this face of the pyramid is a recognition of the fundamental role these factors play in the introduction and effective application of virtual world and virtual reality systems as phenomenal media. Without significant development and competency in these areas, VR systems are merely amusement arcade applications of no real relevance to industry or commerce. Critical to this layer of factors is the capability for engaging in a 'new way to think', a new way of approaching and using information rich environments and data fields. The ability to shift discussion, argument, design, planning, and decision–making activities between real and virtual work-space environments requires significant flexibility and capacity for mediated coherence at both the individual user and organizational level. It is at this level that there is significant potential for radical and disruptive change in the way in which problems, opportunities and established practices are perceived and approached.

Engagement Factors as the second layer in the Phenomenal Media Domain, relates to the connection between theory and the practice of using new media virtual reality. Its system elements are dominated by the mechanisms through which virtual world and virtual reality is enacted. Engagement through interactivity, the use of tele-presence, immersion, the potential use of tele-robotics and haptic systems, sound, vision, all these are reflected in the mechanisms of effective engagement. In turn there are the potentials for real-time engagement with data sets and information in mediated virtual environments.

The third and top layer in the Phenomenal Media Domain is that of Sensory Factors. Virtual reality systems are largely about the stimulation of multiple senses, as in vision, sound, and touch. Cognition and perception in turn play critical roles in enabling the extraction of information and meaning from the engagement of such sensory stimulation. There are significant connections here to the 'Individual' top layer in the Sociological Domain as in the acknowledgement of individual aptitude, perception and interpretation of sense stimulation. Similarly there are connections to the 'Strategic' top layer of the Organizational Domain where disciplined imagination and creativity are key elements, and again to the 'Product Specific' top layer in the Technological Domain where the use of information rich 3D visualization and connection to the realism of the real-world are related elements.

6.4 Paradigmatic Planning Framework

In further addressing the organizational issues, a Paradigmatic Planning Framework is proposed to assist in identifying existent or desirable paradigms relative to epistemological, ontological, technological, and market related perceptiveness and orientation of organizations (as discussed in Chapter 5.8). In developing a particular focus on the potential for paradigmatic change it is proposed to position the influences coming from the identified system elements and associated domains of influence within a planning framework focused on determining an organization's background and current level of engagement in relation to four key areas reflecting differentiated paradigms of engagement. It addresses these as follows:

1. **Behaviourist Paradigm:** Related to the ontology of the organization, the way it is, in terms of its demonstrated behaviours, core capabilities, and performance characteristics.
2. **Cognitive Paradigm:** Related to the epistemology of the organization, its level of intellectual capital, core competencies, skills and expertise, and strategic attitude or orientation.
3. **Technological Orientation Paradigm:** Related to the technological orientation of the organization, the scope of its technology base, extent of dependence on technological services, and its capability to exploit technological advantage.
4. **Product Characterisation Paradigm:** Related to the perceptions of product/services of the organization, low-tech versus high-tech, stable versus changing profile, leading edge versus follower, competitive status and market-share.

It is further proposed that the overall Taxonomy with its associated Domains of Interest and Paradigmatic Framework be focused on developing an VR-Organizational Index as a possible measure of threshold capabilities or organizational readiness to effectively utilise virtual reality technology and systems, or in an alternative configuration, to establish the appropriateness or viability of a given virtual reality product or system to a particular organization, or to establish what 'system elements' an organization will most likely need to address and improve or enhance corporate capabilities and competencies in, before attempting to introduce new media virtual reality systems and technologies.

It must be clearly stated that it is not intended that the proposed taxonomy or its elements be seen as mechanisms for cybernetic determinism. Rather, they are intended as a means of aiding organizations to identify potential areas where new-media virtual reality systems may be used to advantage and the organization's preparedness or potential adaptability to meet, manage and use to optimal effect, significant and inevitably potentially disruptive innovation and technological change. The approach taken throughout this whole research program, the analysis phase and the development of the proposed taxonomy, has been strongly influenced by the tenets of systems thinking, the use of soft systems methodologies, related strategic planning mechanisms, and socio-technical perspectives. All focused on managing the introduction of innovative new-media based technologies and the affective influences of technological change on organizations, particularly those organizations with a strong orientation toward and active engagement in the use of technology and in particular ICT.

Following the work of Thomas Kuhn, circa 1962, the general concept of paradigm has usually been applied to describing a singular approach or common theme of perception that is strongly identified with by its proponents. Kuhn's model or approach to thinking of paradigm change in particular specifically requires a radical change or transition between competing paradigms, which he describes as involving a Gestalt switch or significant transition in world view or percept (Chen, 2006; Kuhn, 1962, 1996). However, in this case the term paradigm is being used to describe particular Gestalt-like phenomena or world-view orientations or perceptions apparent within and holistically integrated across an organization. Specifically in this Planning Framework context, the concept of paradigm is applied in relation to recognising the array of human perceptions, orientations and thus organizational experiences that collectively form the pattern and fabric of organizational culture, tradition, process and practice, and their impact on the introduction of newly emerging technologies (Gutting, 1984).

Whilst in this specific instance the outcomes of the planning framework are essentially formulaic (and thus not strictly in keeping with Kuhn's earlier references to Gestalt approaches) the core purpose of the planning framework is to reflect the reality of the many influences, functional and dysfunctional, that are inevitably integrated within organizations. As skills and corporate competencies and required strategic capabilities change to meet changing demands in the market place and the challenge of achieving some degree or form of sustainable competitive advantage, so also the dominant orientation or focus of the organization will shift. This in turn may be seen as an adjustment to the core paradigm or paradigms acting within the organization and/or impacting on the organization from its surrounding environment or technological ecology within which the organization operates.

The proposed Paradigmatic Planning Framework thus provides a further tool for understanding how well organizations are prepared for, how they are likely to respond to, and are influenced by, the introduction of radical innovation and potentially disruptive new technologies such as virtual reality systems. These perspectives are in turn developed to construct a framework of four paradigms as follows:

1. Behaviourist Paradigm

- Related to the ontology of the organization, the way it is, in terms of its demonstrated behaviours, performance, and corporate capabilities.
- Characterised by:
  - i. Specific product or service orientation
  - ii. Defined skills and expertise orientation
  - iii. Quality management/performance orientation
  - iv. Normative approach or 'hyper-competitive'

2. Cognitive Paradigm

- Related to the epistemology of the organization, its level of intellectual capital, skills and expertise, and core corporate competencies.
- Characterised by:
  - i. Mature systems approach

ii. Active engagement in strategic planning and strategic management
iii. Active engagement in innovation and high levels of creativity
iv. Mission focused

3. Technological Orientation Paradigm

- Related to the technological orientation of the organization, the scope of its technology base, dependence on technology, extent of internal or external reliance for technological services.
- Characterised by:
  i. Technology user or developer
  ii. Technology push or technology pull environment
  iii. Stable or changing technology environment
  iv. Dependent on specific technology or independent

4. Product Characterisation Paradigm

- Related to the perceptions of product/services of the organization, low-tech versus high-tech, stable versus changing profile.
  i. Supply or demand driven product or service
  ii. High or low added value and the organization's value chain
  iii. Market segmentation or across market sectors
  iv. High or low competition (in the market place)

The nature of each paradigm is in turn characterized by the organization's response to its past, present and prospective future orientation and engagement and in relation to the particular areas being addressed by the proposed domains of the taxonomy. In applying the taxonomy, the specific input details for the Planning Framework are to be derived from data collected from the client or target organization and from determining the organization's position in relation to the above domains of interest.

6.5 Virtual Reality – Organizational Index

Finally, it is proposed that the overall taxonometric framework be used to develop a VR-Organizational Index as a measure of organizational readiness to effectively utilise virtual reality technology and systems, or in an alternative configuration, to establish the appropriateness or viability of a given virtual reality product or system to a particular organization. The systems element analysis approach used to formulate the foregoing Domains of Interest and Paradigmatic Planning Framework (see Chapter 5.7) resulted in the final assembly of 114 key systems elements. The need for a structured analysis approach to analysing these 114 systems elements further invoked the development of a tabular analysis instrument based on an approach to survey design and analysis developed by educational psychologist Klaus Mallendar (1993). Subsequently, the analysis instrument has been further developed as a structured means of collecting and analysing data about organizations and their capacity and preparedness to introduce and implement VR systems and technology. The analysis instrument and its further application as a survey analysis instrument is further described in detail throughout Chapter 7, and documented in Appendix 2.

In summary, the relevance of systems elements to a particular company are firstly entered into the table as a graded score. The graded/scored elements are in turn collected together in the analysis table according to their perceived relationship with each of the proposed paradigms. That is, they are collated together down the y-axis according to their most strongly related paradigm. The scores for each element entry into each of the domain columns in the analysis table are summed and entered into the final row of each relevant domain column. These represent the domain scores. The scores for each of the element entries in each of the domain columns are summed across each element row and entered in the relevant paradigm column or columns (where more than one paradigm is being represented as being influenced). The scores for each paradigm column are summed and entered as final scores for each relevant paradigm column. These represent the paradigm scores. These scores are again summed; this is then the final virtual reality Organizational 'Index' score.

When used as a survey instrument across multiple organizations (as is the case detailed in Chapter 7) the individual system element scores from multiple survey forms are averaged, meaning that the collective VR Organizational Index score is further structured as the result of a sum of sums of means, where the means have been distributed or mapped across multiple paradigms whose scores are those being summed. The result is that it takes a significant shift in a significant number of related systems elements to make any appreciable shift in the final Index score. By collating respondent surveys according to a set of common categories (VR User; Prospective User; Non-User) it is possible to establish a nominal level of the Index value for that category of respondent surveys. Individual variations within categories can thus be expected to produce marginal variations around the nominal value for that category. Similarly, respondent surveys from individual organizations non-compliant with any of the defined categories will produce Index values that are incompatible with the defined categories, and could be expected to lie between or completely outside of defined category index values.

6.6 Assembling the Proposed Taxonomy & Planning Framework

Bringing the various components of the taxonomy together presents a significant challenge in terms of achieving both coherent processes and an effective visualization strategy for representing the taxonomy and planning framework as a whole. In effect, it involves bringing together a collection of disparate things:

- Collation of empirical measurements (quantitative and qualitatively based);
- Determination of affective relationships between conceptual categories of measurements;
- Calculation of combinational weightings and values;

All of which need to be assembled within a coherent overall framework capable of producing reliable results that can be readily understood and interpreted by executive management.

Figure 41 provides a simplified form to illustrate the proposed structure and associated relationships. This structural form in turn is that used in the testing and evaluation stage of this research using Virtual Reality User Surveys to collect data from organizations about their organizational behaviours and attitudes, and their use or otherwise of virtual reality systems and technologies. The format used to illustrate the structure of the taxonomy is again in an approximate pyramidal form, with a large base of system elements covering a wide range of issues within an organization, condensed through a mapping process to some 12 key factors leading in turn to 4 core domains of interest (3 key factors per domain). These are in turn mapped to establish 4 related paradigms representing organizational behaviour or attitudes towards technological innovations such as virtual reality. Finally, these are in turn used to establish a VR-Organizational Index as a means of indicating an organization's perceptiveness and potential readiness to make effective use of virtual reality systems and technology.

It is expected that in actual use the range of systems elements to be used would need to be selected or engineered toward reflecting the particular characteristics of various types of organization, thus the notation in Figure 41 against the System Elements as being: 'Defined by Users'. As can be seen from Figure 41 there can be a considerable number of defined relationships involved in establishing the key factors (to a maximum of 12 x 114 = 1368 in the current configuration). Some of which may have negligible affect, whilst others, for a given type of organization, may have significant effects across multiple factors, domains and paradigms.

The Taxonomy testing process involving the analysis of the Virtual Reality User Surveys as documented in Chapter 7 made use of some 150 scored question responses per survey, mapped against 114 systems elements, with 312 identified relationships between systems elements and the 12 key domain factors. Even so, many of the organizations surveyed or interviewed throughout the research program showed little understanding or use of such relationships in their management.

In effect, the responses of some organizations may be best served through analysis of a limited set of significant systems elements and related relationships to key domain factors. Determining these sub-sets of systems elements for defined organizational types or specific industry sectors will require further research and investigation to identify key threshold capabilities relevant to those particular types of organizations or industry sectors.

On the other hand, enabling an organization to identify weaknesses in its understanding, use and application of organizational theory and established practices (at least in relation to its use of technology and preparedness for technological innovation) may well prove to be the most valuable outcome of the application of the taxonomy.

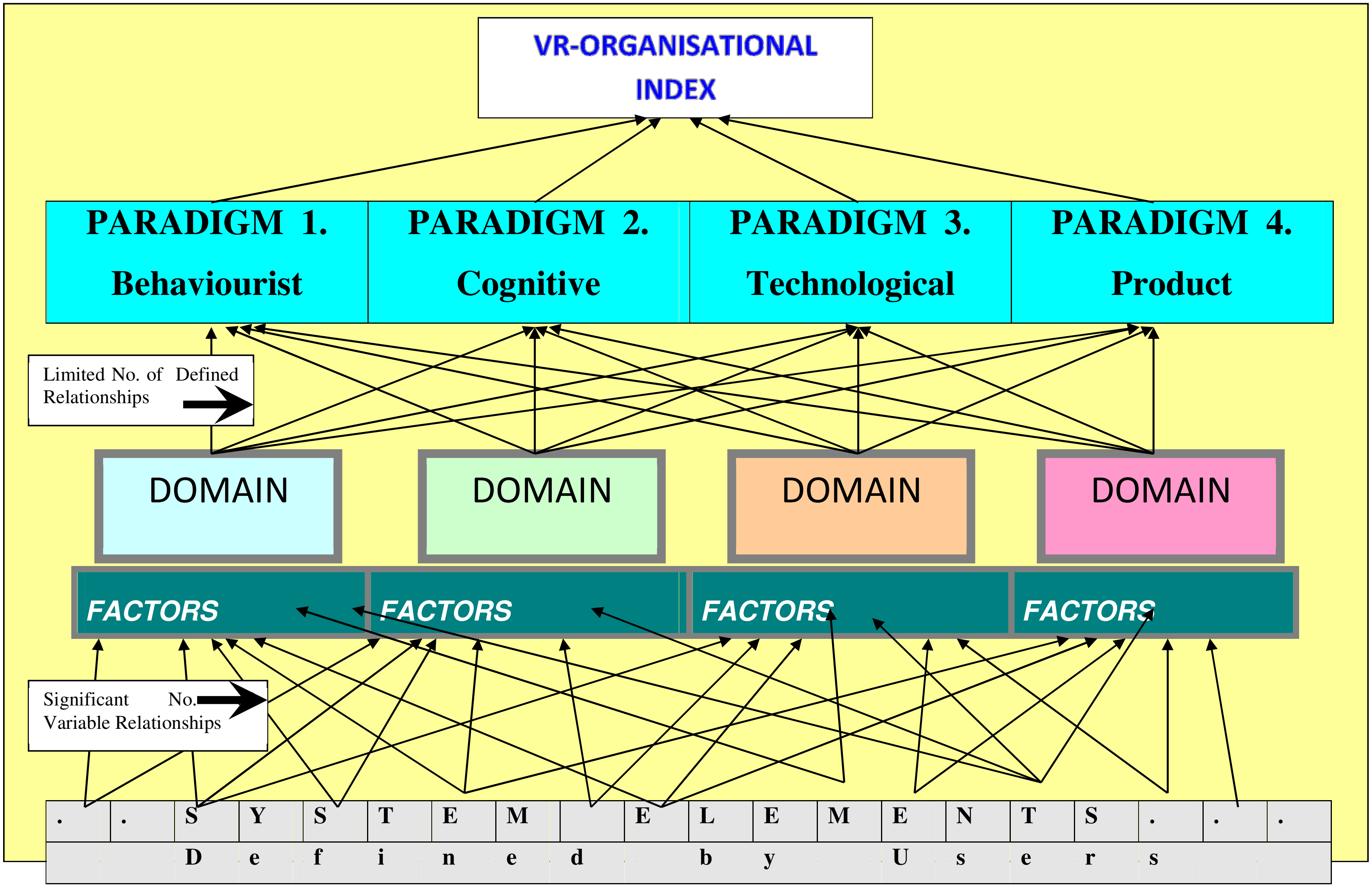


Figure 41. Taxonomy & Framework Structure

6.7 Proposed Taxonomy and Structural Components Summary

This chapter has assembled the various components previously developed through Chapters 4 and 5 into the proposed Taxonomy or planning framework and has discussed a range of related issues and possible approaches to visualizing the proposed Taxonomy and its application.

It has taken the proposed Domains, Factor Lists and System Elements as developed in Chapter 5 (see Chapter 5.7 and Tables 7, 8, 9, 10, 11) and built a structure around them in the form of a hierarchical tetradic framework that can be visualized as being pyramidal in form. In effect, providing a multi-layered tetradic analysis tool for organizations seeking to introduce new-media virtual reality as both technological innovation and business innovation. (See Figures 39, 40)

It also further develops the paradigm thematic introduced in Chapter 4 and Chapter 5 to propose a Paradigmatic Planning Framework as an integral part of the proposed taxonomy. This includes the development of a VR-Organizational Index as a possible measure of organizational readiness to introduce and effectively use new-media virtual reality technology and systems.

Finally, the proposed taxonomy and planning framework is assembled and its relationships structure illustrated in Figure 41.

The functioning of the analysis instrument developed through this process and used in the subsequent VR User Survey is described in detail in Chapter 7.

Chapter 7.
Testing and Review Processes and Findings

7.1 Introduction to Testing & Review Processes

This chapter details the approaches taken in the collection, collation and analysis of data relative to the testing and review of the proposed taxonomy. It outlines the two stages of data collection used throughout the research program: Pre-theory Building Stage and Post-theory Building Stage. It further describes the use of the 'VR Centre User Survey' data collection instrument as the primary means of testing the validity of the proposed taxonomy and planning framework as developed through Chapters 5 and 6 and provides detail on the review and analysis of collected data, including examples of final data sets. Detailed findings from the survey analysis are documented and explained using relevant graphs and charts.

The chapter represents further levels of engagement through the 5th and 6th stages of the AGSSM research methodology.

7.2 Approach

A two-stage approach to data collection has been used throughout the research program: Pre-theory Building Stage; Post-theory Building Stage.

7.2.1. Pre-theory building stage

1. <u>Extensive literature review and content analysis</u>

This involved appraisal of a wide range of research findings and publications covering the broad spectrum of: views; opinions; experiments; findings; technologies; applications; suppliers; users; and experiences of a great many individual researchers and organizations involved in simulation, visualization and the application of new-media virtual reality technology and systems. As well, it reviewed and analysed relevant issues in organisational theory and practice; technological innovation; strategic planning and strategic management practices; the related theory and practice of developing and applying systems thinking approaches to organizational change; the management of engineering and technology based organizations; conceptualisation and the development of synthetic or virtual worlds (See Chapters 2, 4 and 5). This extensive review and analysis of the literature has been used to establish the overall body of theory and practice upon which the proposed taxonomy and paradigmatic planning framework for virtual reality has been grounded and built. It has covered the broad spectrum of systems thinking and strategic management approaches to managing engineering and technology based enterprises through focussing largely on examples and argument built around the key issues of innovation and associated technological change management strategies.

2. Personal experiential engagement

This has involved extensive exposure to and use of virtual reality systems and various simulation and visualisation systems including:

- Virtual Reality Centre facilities and hemispherical displays systems in the Interactive Information Institute (I^3) Reality Centre, RMIT University.
- Demonstration systems as made available through Silicon Graphics Inc. Melbourne office, including: mobile Virtual Reality Centre, 'boom' mounted display, I-wall display, stereo-vision systems, and various virtual reality related software products and systems.
- Demonstration systems as made available through I^3 and various systems and technology suppliers, including hemispherical displays and various stereovision workbench systems.
- Multiple virtual reality related research and development projects including the non-immersive: 'Web Based Scenario Simulation Modelling Project' for jet-fire and explosion modelling of highly flammable materials, an Australian Government funded AusIndustry Graduate START Research Grant with the author as Academic Supervisor and advisor to the risk management consultancy company engaged in the research.

These initial approaches to data collection, largely undertaken concurrently, were used to select and structure the proposed systems elements, establish the concept and build the initial theoretical structure for the proposed taxonomy and paradigmatic framework.

7.2.2. Post-theory building stage

This second stage of data collection was used to test the validity of assumptions made in the formulation of the initial taxonomy and to establish the presence or otherwise of assumed relationships in the proposed taxonomy. The processes applied throughout this stage particularly involved observation of and access to users of the RMIT I^3 Reality Centre. Additionally, a survey instrument (See Appendix 1) was developed and administered to representatives of organizations currently actively involved in the use and application of advanced visualization and/or virtual reality technology and systems. Similarly, senior staff and management of such organizations were interviewed. Overall, the surveys and interviews provided a means of collecting data about the causal influences and drivers on the use of advanced simulation systems such as virtual reality, the expectations of users, the extent to which such expectations are met or potentially exceeded and the conditions which facilitate or hinder such achievements. The same survey instrument and analysis tools were also used to collect data from organizations not directly involved in the use of virtual reality or advanced visualization systems, as well as organizations that could readily be described as prospective future users. Thus the collected data-sets were collated and analysed as per the following three categories: Active VR Users; Prospective VR Users; Non-VR Users. All organizations involved in the survey process are either engineering companies or technology-based organizations, that is, organizations with a strong technology orientation and history of technology use.

Respondents are asked to provide up to a total of 164 responses to questions addressed on the survey instrument (see Appendix 1). Effective completion of the survey requires considerable insight into the target organization and its operations. On average, it was found to take 40-45 minutes for an executive staffer to fill in, sometimes more where supplementary information was required. In this regard, respondents were encouraged to discuss or review questions and answers in consultation with colleagues prior to submission of survey responses. This in turn reflects both the complexity of issues being addressed and the level of detail sought and provided by the respondents.

7.3 VR User Surveys Review

7.3.1 Review approach

Altogether, 30 User Surveys from a range of organizations were collated and analysed. Key elements in the design and administration of the survey were designed to identify those aspects of organizational theory and practice, including corporate core competencies and related matters, directly impinging on the specific design and application of the proposed taxonomy. Accordingly, respondents were encouraged to respond to the specific survey questions and then to add their own perceptions and insights in free text. This provided a body of targeted information as well as supporting commentary and rationale.

The process of category allocation and subsequent collation was undertaken prior to any further processing and mapping of survey data:

Category 1. Active VR Users

Category 2. Prospective VR Users

Category 3. Non-VR Users.

Allocation to category 1 was a case of noting responses to Question 5 in the survey: “Does your organization currently use Virtual Reality systems?” A ‘yes’ response to this question provides a clear allocation to category 1. - Active VR User.

Open-text responses in embedded text response boxes provided further allocation details. For example the following response to Question 5 (see above) provided an allocation to category 2 - Prospective VR User:

- *NO. We do have the technology but we don’t actually use it yet.* (From a survey from a radiological laboratory with an interest in using virtual colonoscopy virtual reality techniques)

Similarly, Non-VR Users could be readily identified from embedded comments such as:

- *No experience*. (From a survey from an agricultural products manufacturer)
- *Project focussed, output and milestones are the goal. New technology, staff development and other ‘non-core’ activities are viewed as an overhead not as a long-term profit centre.* (From a survey from a Defence contractor)

The following is also typical of several such responses from both prospective and non-user respondents:

  - *Definition of VR terms would have been appreciated.* (From a survey of an IT department in a large local government organization)

Overall there was a strong diversity in open text responses as demonstrated above. Collectively, these reflected a wide range and diversity of experience and understandings of virtual reality technologies, systems and available applications. Most responses indicated an awareness of virtual systems and associated technologies, some in great detail as in those from organizations categorized as existing Active VR Users. However, commonly most open text responses exhibited limited comprehension or level of understandings of 'theoretical' aspects of virtual systems and applications. Of the 10 identified VR User organizations, 9 responded positively as to the effectiveness of their VR use, a 90% approval rating. The remaining organization indicated it needed more experience in the use of VR to be able to make the determination.

Specific terms and expressions (both in relation to organisational theory and virtual reality) were deliberately not elaborated on in the survey instrument. This was intended to ensure that respondents reflected actual current knowledge and understandings of their organization, unbiased by external prompting or advice from the researcher. The use of somewhat academic language throughout the survey also by default provided indications of whether or not respondents had any exposure to the theoretical constructs being explored. The above comment for example potentially reflects a lack of knowledge or expertise in relation to various aspects of virtual reality systems, technology and applications, and (typically) produced a series of non-answers to questions focussed on virtual reality (subsequently coded as a neutral '0' in the analysis stage).

In addition to questions directed at identifying exposure to specific virtual reality technology and systems and the technology base of the organization, the survey addressed a range of issues related to identifying corporate core competencies and related matters, including: Skills and expertise base; Strategic planning approaches; Risk taking; Innovation; Creativity; Economic structures; Business plan approaches; Technology competence; Technology push-pull perceptions. The key purpose for these questions was to gain data that could assist in identifying possible connections between an emerging new technology such as virtual reality/virtual world building and the presence or otherwise of key competencies, strategic attitudes, and social structures or responses deemed desirable or possibly essential. It also probed the awareness and understandings of respondents about phenomenal media (such as virtual reality) and its capabilities.

Anonymity was a strong characteristic requirement of almost all respondents. Whilst the 'industry sector' of respondents has been identified no actual organization can be explicitly identified. The level of respondents in their respective organizations is as follows: 1x Chief Executive Officer (CEO); 3 x General Managers; 10 x Divisional Managers; 6 x Departmental/Section Managers; 10 Senior Technologists.

Organizations involved in the survey included:

- Large automotive manufacturer;
- Medical radiations laboratory;
- Large hospital;
- Pharmaceutical manufacturer;
- Logistics transport company;

- Local government city councils;
- Medical research centre;
- University medical science related faculty;
- University virtual reality center;
- CAD design centre;
- IT consultancy company;
- Telecommunications company;
- Multimedia production companies;
- Real-estate company;
- Agricultural supplies company;
- Agricultural equipment manufacturing company;
- Defence contractor;
- Oil & gas exploration and mining companies;
- Large (national) Law firm with significant ITC services
- Telecommunications equipment manufacturers
- Asset management group

The following is the distribution of the 30 returns from the 100+ surveys originally distributed and their classification against VR-user, non-user, and prospective-user:

VR-User 10

Prospective VR-User . . . 14

Non VR-User 6

7.3.2 Survey evaluation structure

The analysis approach used on the survey responses involved a mapping exercise to establish firstly the presence or otherwise of key parameters, and secondly the weighting or importance given to such parameters by respondents. In developing the analysis tool, the Domains, Factor Lists, and Element Lists (as per Table 6 (a) (b) (c) in Chapter 5) have been organized into a common table format in order to map the survey data across various combinations of factors and elements. Free text responses were also mapped against the core factors and listed elements using the same Likert type scaling process. Example completed tables illustrating this process are documented in Appendix 2.

The analysis instrument used is based on the use of tabulated scored entries summed across the rows (representing system elements) and divided by the number of entries to obtain an averaged score (statistical 'mean' value) across the number of organizations for each system element. As well, the system element scores are summed down the columns (covering all system elements) to obtain an overall system elements score specific to each individual organization. As such, it is an adaptation of the survey analysis approach developed and utilised by educational psychologist Klas Mallendar (1993) using a series of mediated data transformations. The analysis is structured in three stages. The first stage involves the entry into an Excel spreadsheet and subsequent calculation of system element and organization specific scores. The second stage involves the mapping of scores across proposed domains and paradigms. The same process, calculations and mapping is used for each of the three categories of organization: VR-User; Prospective VR-User; Non VR-User. The third stage involves the further

Surveys are labelled as A through N and allocated to whichever category of user they represent. Raw data from the 150 scorable survey questions are entered in the data entry stage of the analysis instrument. Entry data for each survey is then mapped against 114 system elements (as derived in chapter 5.7) and entered into a matching column for each survey in the Stage 1 analysis instrument. The 114 system elements identified in the systems analysis stage (see chapter 5.7) are entered as the rows in the Stage 1 analysis instrument. The value for each systems element is summed across all surveys and the resulting sum averaged for the number of surveys entered.

The 12 Domains/Factors Lists and 4 proposed Paradigms are listed at the head of the 16 columns in the Stage 2 analysis instrument. The 114 system elements identified in the Stage 1 analysis stage are entered as the rows in the instrument.

7.3.3 Evaluation of Virtual Reality User Surveys: Stage 1.

The following provides a detailed explanation of the processes used in setting up the Stage 1 analysis. The associated data-tables are attached as follows:

- ‘Survey Questions to Systems Element Mapping’ is attached in Appendix 2.1.
- ‘Stage 1. Analysis Instrument VR Users’ is attached as Appendix 2.2.

Step 1. Data collected in the surveys in the form of 5 element Likert scale responses are defined and collated as follows:

- Likert ‘3’ is defined as neutral and coded as ‘0’.
- Likert 1-2 are identified as negative, with ‘2’ defined as negative (–1) and ‘1’ defined as strongly negative (–2).
- Likert 4-5 are identified as positive, with ‘4’ defined as positive (+1) and ‘5’ defined as strongly positive (+2).

Step 2. Open text responses are analysed and a determination made as to whether or not they can be classified against any of the Systems Elements. Where this is the case they are defined according to the above Likert scale classifications.

Step 3. Question 14 tick the box responses (where entered) are defined as: +1 against the relevant Likert response elements.

Step 4. Survey questions are mapped against the Systems Elements in the table: ‘Survey Questions to Systems Element Mapping’ (See data table in Appendix 2.1).

Step 5. Survey responses are entered into the ‘Stage 1. Analysis Instrument for VR Users’ according to the Step 4 mapping exercise (see data table in Appendix 2.2). Where multiple questions are mapped against a particular system element the scores are summed and the average calculated and entered.

Step 6. Text response Likert values are mapped and entered against relevant Systems Elements.
Step 7. Scores for clustered survey questions are also summed and averaged and entered into relevant elements as per map. For example: Sum Q1 entered into Organizational Culture systems element.
Step 8. Likert responses entered into the Systems Elements rows of the analysis table are summed across the N columns A-N and divided by the number of surveys entered. The result is entered into the **SEMSS** column as **System Element Mediated Sum Scores**. ($SUM_{a\text{-}n}$)/Number of surveys.
Step 9. Likert responses entered into the analysis table are summed down the survey columns and entered into the **ISMSS** row at the base of each of the survey columns as **Individual Survey Sum Scores**. ($SUM_{1\text{-}114}$)
Step 10. The mediated values for each system element in the **SEMSS** column are summed down the column and entered into the **OSEMS** box. This is now the **Overall System Element Mediated Score** (SUM($SUM_{a\text{-}n}$) (**OSEMS**) for the set of system elements derived from the surveys collected.

The 'Stage 1. Analysis Instrument' (see data table in Appendix 2.2) provides Stage 1. data, illustrating mapping from raw survey format to Systems Elements, prior to their being mapped to Domains or Paradigms. Data illustrated in Appendix 2.2 is from the category of: **VR-Users**.
The presence of a numeric character in a cell of the spreadsheet represents a mapping to that Systems Element (row) for that survey/respondent (column) (See data table 'Survey Questions to Systems Elements Mapping' in Appendix 2.1). A zero (0) entry may represent either no relevant data entered by the respondent, or a net sum of zero resulting from equal positive and negative scores being mapped to that cell.

7.3.4 Evaluation of Virtual Reality User Surveys: Stage 2.

The 4 Domains and associated 12 Factors Lists are listed at the head of the columns in the Stage 2 analysis instrument: 'Stage 2. Systems Elements to Domains Mapping: Analysis Instrument for VR-Users' (see data table in Appendix 2.3). The 114 Systems Elements identified in the Stage 1 analysis stage are entered as the rows in the Stage 2 analysis instrument.

Step 1. The **SEMSS** value for each of the system element rows as derived in Stage 1 are entered into the relevant Domain Factor List columns (as identified in Chapter 5.7). Where Systems Elements have been mapped against multiple Domain Factor Lists, the same **SEMSS** value is used for each relevant Domain Factor List.
Step 2. The **SEMSS** values entered into the columns for the Domain Factor Lists are summed down each column and entered in the **DFLS** row as **Domain Factor List Sums**.
Step 3. The 3 **DFLS** values are summed for each of the 4 Domains and entered as the **Final Domain Scores** (**FDS**) for each Domain.

The Stage 2 Analysis Instrument (see Appendix 2.3) provides Stage 2 data, illustrating mapping from the System Element Sum Scores (SEMMS) for Systems Elements to the Domains. Data illustrated in Appendix 2.3 is from the category of: **VR-Users**.

The presence of a numeric character in a cell of the spreadsheet represents a mapping to that Domain Factor List (column) for that Systems Element (row). A zero (0) entry may represent either no relevant data entered by respondents, or a net sum of zero resulting from equal positive and negative scores being mapped to that cell.

7.3.5 Evaluation of Virtual Reality User Survey: Stage 3.

The Domains to Paradigm Mapping process is wherein the Systems Elements Sums for each Domain for a given Systems Element is entered into the relevant Paradigm column as per the following mapping process.

Step 1. The selection of domains to be mapped against given Paradigm columns is informed from the earlier content analysis and discussion incorporated in Chapters 4, 5, and 6, and is documented in the 'Domain to Paradigm Mapping' data table in Appendix 2.4.
Step 2. The **SEMSS** values entered into the 12 columns for the Domain Factor Lists (See Appendix 2.3) are summed across the rows for each Domain (each 'sum' incorporating the three Factors within a given Domain) and according to the Domain-Paradigm Map (see Appendix 2.4) are entered into the relevant Paradigm column in data table: 'Stage 3. Domains to Paradigm Mapping: Analysis Instrument for VR-Users and Final VR-Index Scores' (see Appendix 2.5) as **System Element Paradigm Sums** (**SEPS**).
Step 3. The **SEPS** values in each of the 4 Paradigm columns are summed down the columns and entered as **Final Paradigm Scores** (**FPS**).
Step 4. The 4 **FDS** values and the 4 **FPS** values are summed resulting in a final overall **Index** value.

7.4 Summary of Testing & Review Approaches & Findings

7.4.1 Summary Data

Summary analysis scores derived from the mapping analysis instrument are listed in the following Table 12 and are in turn illustrated in the following diagrams Figures 42 to 51. Again, note that all categories of user data were analysed using the same data transformation, mapping and analysis processes.

As documented in Table 12 all scores for active VR Users are strongly positive in value for all Domains and Paradigms and subsequently in final VR Index value. Similarly, all scores except 'Phenomenal Media Senses' are positive for Prospective Users. In contrast, all scores in all Domains and Paradigms, and thus in VR Index value, are negative for Non-Users. Given that the data mapping processes used in the analysis instrument are essentially focussed on identifying the presence or otherwise of positively oriented attributes for VR-Users and Prospective-Users, the negative results for Non-Users are not surprising.

From the data collected, it can be seen that under the data mapping process used and the wide range of organizations surveyed, the active VR-User organizations involved produced an overall VR Index score for the collection of VR-User surveys in the order of 700. The collection of Prospective-Users achieved a VR Index score in the order of 260+, whilst Non-User organizations produced a negative VR Index score in the order of –300.

The following Figures 52-57 provide exemplar sets of Domain, Paradigm and VR-Index score results for the respective three categories of respondents: VR-Users; Prospective-Users; Non-Users. The selected surveys shown are typical within their particular category and thus indicative of responses.

From the evidence it is clear that virtual reality-active organizations, or organizations with a definite commitment to engage with the introduction and use of virtual reality systems and technology, produce high positive scores in response to the VR Survey instrument and associated analysis instrument. In the context of this research program this is taken as strong support for, and empirical evidence of, a clear correlation with the proposed taxonomy and its core elements.

It remains a matter of supposition at this stage (although strongly supported by this research) that individual organizations with a positive oriented VR Index score in the order of 100<300+ may be classified as potentially prospective users of virtual reality systems and visualization technology.

Similarly, that scores of 0>-300 represent classically Non-User category organizations. However, it is unclear at this stage of research what status or classification could be given to VR Index scores of 0<100, other than noting that such scores may reflect organizations undergoing some form of transition (although it is not at all clear in which direction or why).

From these scores it can be seen that organizations scoring in the order of 40+ in the Taxonomy's scoring regime for the Organisational Factor Domain Sums (FDS) and 20+ in the Technological FDS, are likely to be either current users or prospective users of virtual reality. It is however, quite puzzling that the attributes of these domain factors, whilst widely and publicly argued over (and also appearing very commonly as core content in typical MBA and related management studies) also scored as the most negative domain characteristics for Non-VR User organizations (-39 and –25 respectively) although is must be noted again that these are all technology based organizations rather than 'commerce' based.

It is also apparent that Sociological domain scores in the order of 28+ also appear to characterise prospective or active VR User organizations, whilst the Non-VR User organizations again produced quite negative scores (-33).

Perhaps the most surprising outcome is what appears to be a low performance with regard to the knowledge and understandings of phenomenal media itself. Indeed, it is distinctly noticeable that whilst this attribute is positive for active VR Users (32) it is also the weakest attribute in currently active VR User organizations, whilst also being quite low for prospective users (6.2).

It is apparent from the Phenomenal Media Domain scores that even active VR Users demonstrate limited knowledge or understandings about the theoretical aspects of virtuality and sensory attributes of phenomenal media, although apparently more aware of or perceiving as more relevant, the role of 'engagement'. However, these phenomenal media aspects are also clearly negative characteristics for non-user organizations (-13), who generally exhibit either no knowledge at all about phenomenal media, or where they are aware of it see no use for it, or are sceptical about the use of such media and related visualization technologies.

Colour Scale by Scores			
400+			
300+			
200+			
100+			
50+			
20+			
15+			
10+			
5+			
0+			
		-5	
		-10	
		-15	
		-20	
		-30	
		-100	
		-400	

ORGANISATIONAL Domain Factor Lists	**Users**		**Prospective**		**NonUsers**	
Operational Factors	39		20		-16	
Strategic Factors	28		12		-17	
Human Factors	24		7.7		-6.8	
ORG. Final Domain Scores	91		40		-39	
TECHNOLOGICAL Domain Factor Lists	**Users**		**Prospective**		**NonUsers**	
Product	23		11		-6.3	
Enabling Tech	20		6.4		-12	
Base Tech	9.4		4.8		-5.5	
TECH. Final Domain Scores	53		22		-24	
SOCIOLOGICAL Domain Factor Lists	**Users**		**Prospective**		**NonUsers**	
Individual	34		11		-12	
Group	29		13		-14	
Society	10		4.2		-7.2	
SOC. Final Domain Scores	73		28		-33	
PHENOMENOLOGICAL Domain Factor Lists	**Users**		**Prospective**		**NonUsers**	
Engagement	11		3.1		-4.2	
Virtuality	12		3.6		-4.7	
Senses	9.1		-0.6		-4.3	
PHEN. Final Domain Scores	32		6.2		-13	
Paradigms	**Users**		**Prospective**		**NonUsers**	
Paradigm 1. Behaviourist	126		50		-70	
Paradigm 2. Cognitive	131		56		-53	
Paradigm 3. Technological	91		28		-39	
Paradigm 4. Product	109		37		-33	
	Users		**Prospective**		**Non-Users**	
VR INDEX	705		268		-304	

Table 12. Summary Scores from Analysis of VR User Surveys

The following graph in Figure 42 provides a listing of the highest scoring SEMSS (Systems Element Mediated Scores) from all categories.

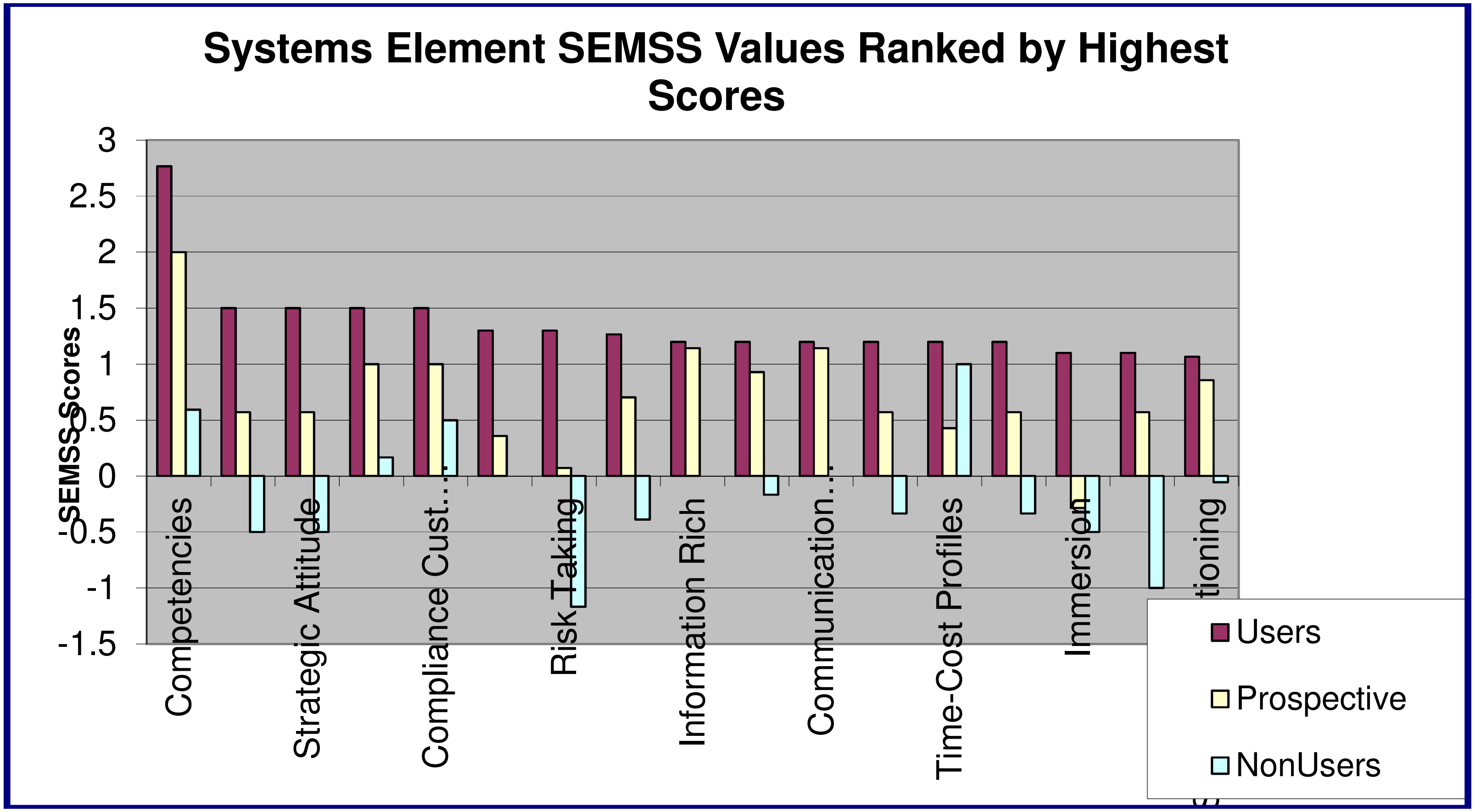


Figure 42. Highest Scoring SEMSS for all categories.

Figures 43-45 provide details of statistical analyses for: mean; median; minimum; maximum; range; variance and standard deviation for the systems element values. Tabulated data for all 114 systems elements is listed in Appendix 3. Figure 44 charts the results for the highest ranked systems element: 'Core Competencies'.

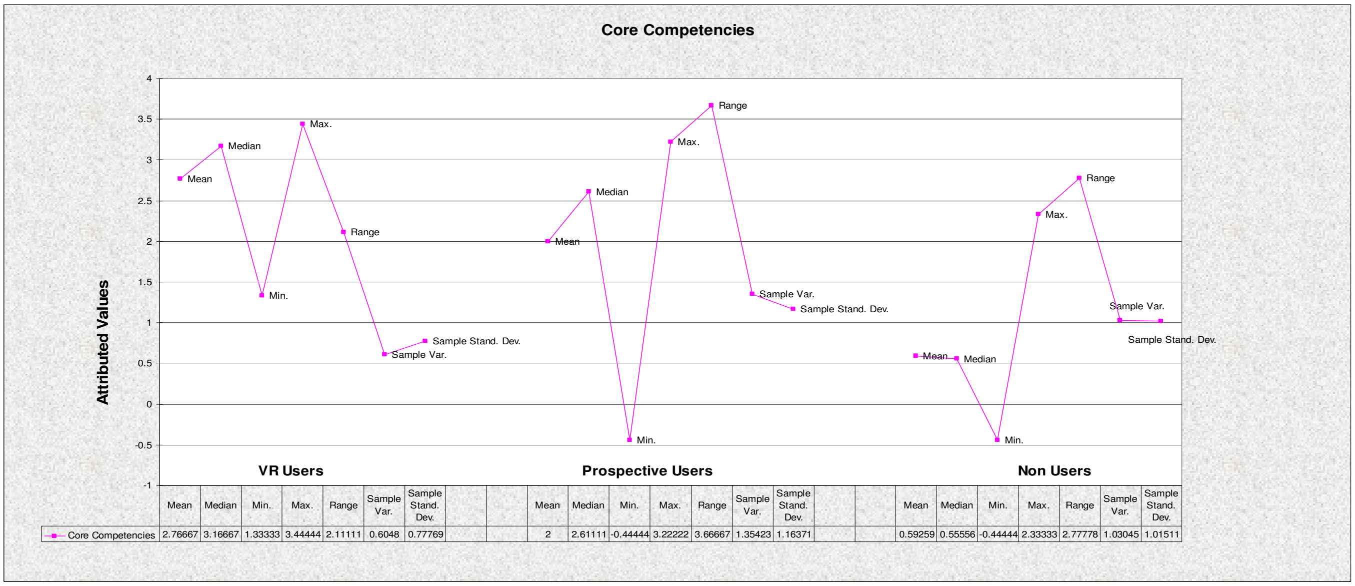


Figure 43. Statistical Measures for the Systems Element Data-set: Competencies

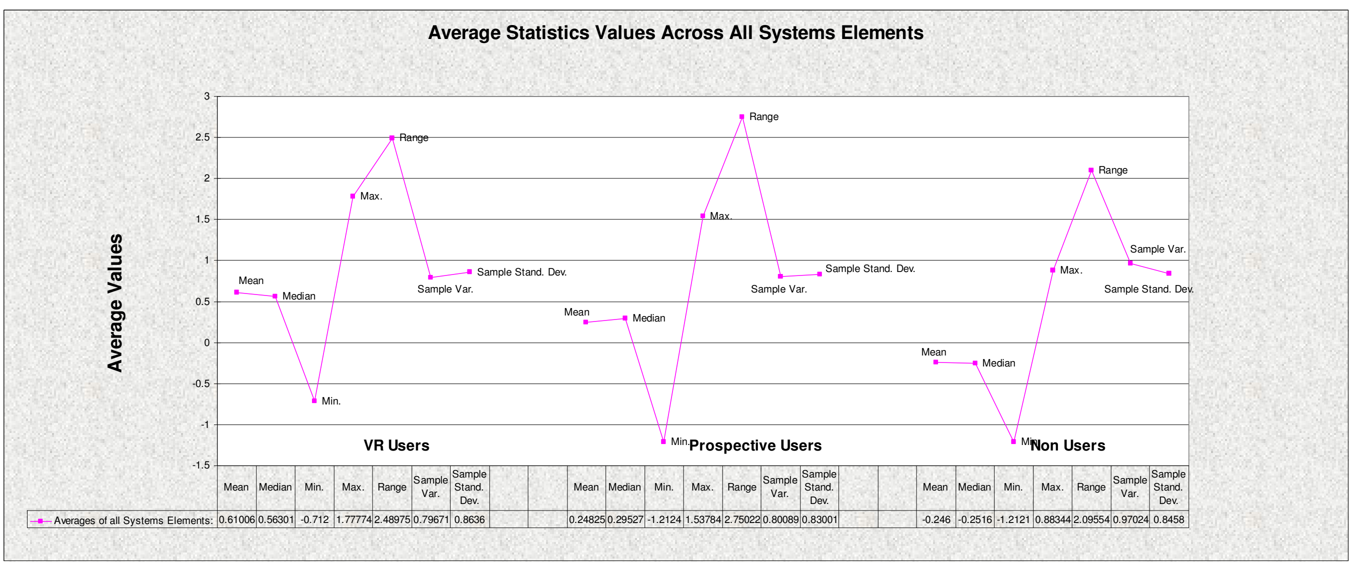
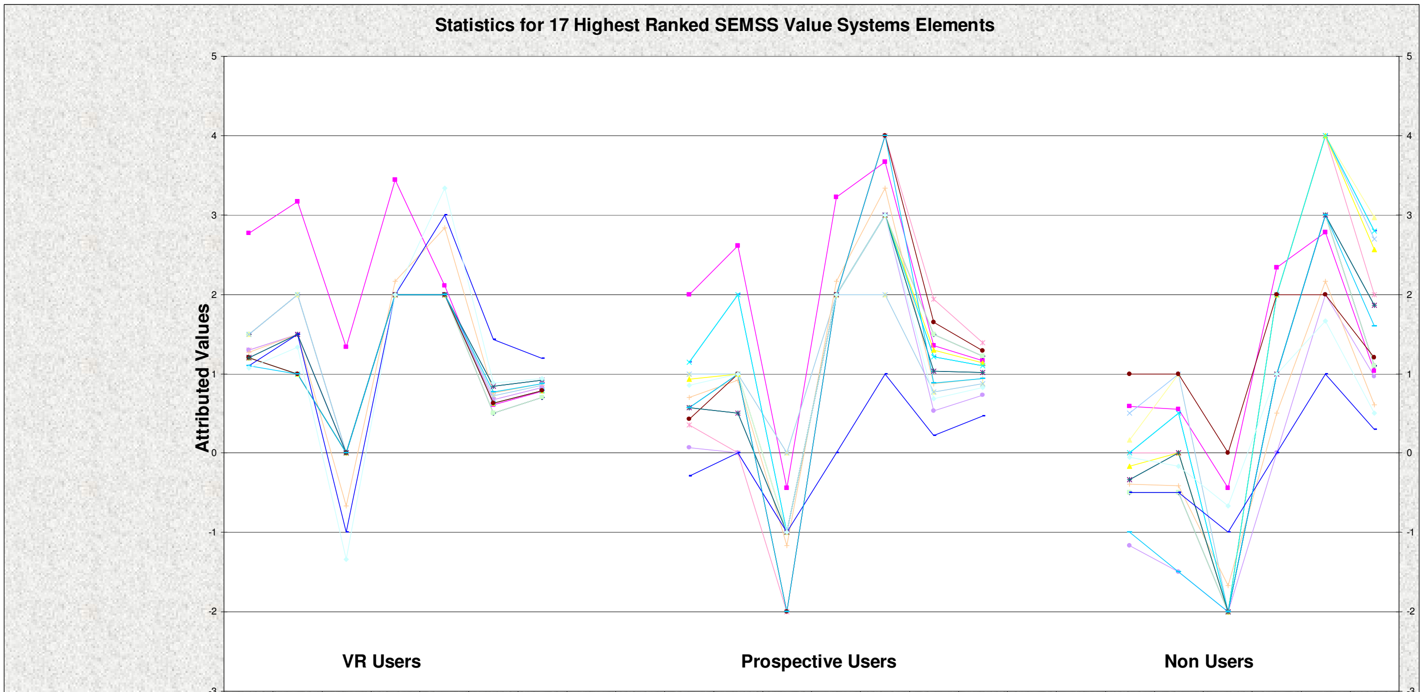


Figure 44. Average Statistics Measures across All 114 Systems Elements

Figure 44 provides a chart of the overall scores for all systems elements averaged for VR Users, Prospective Users and Non Users. A collective view of the top 17 ranked systems elements as previously illustrated in Figure 42 above is charted in Figure 45.



VR Users

	Mean	Median	Min.	Max.	Range	Sample Var.	Sample Stand. Dev.
Core Competencies	2.7666667	3.1666667	1.3333333	3.4444444	2.1111111	0.6048011	0.7776896
Innovation culture	1.5	2	0	2	2	0.5	0.7071068
Strategic attitude	1.5	2	0	2	2	0.5	0.7071068
Customer expectations	1.5	2	0	2	2	0.7222222	0.8498366
Compliance with customer requirements	1.5	2	0	2	2	0.7222222	0.8498366
Product differentiation	1.3	1.5	0	2	2	0.6777778	0.8232726
Risk taking	1.3	1.5	0	2	2	0.6777778	0.8232726
Corporate memory	1.2666667	1.5	-0.666667	2.1666667	2.8333333	0.7604938	0.872063
Information rich environments	1.2	1	0	2	2	0.6222222	0.7888106
Interpersonal skills	1.2	1	0	2	2	0.6222222	0.7888106
Communication skills	1.2	1	0	2	2	0.6222222	0.7888106
Transparent systems integration	1.2	1.5	0	2	2	0.8444444	0.9189366
Time-cost profiles	1.2	1	0	2	2	0.6222222	0.7888106
Tele-communications	1.2	1.5	0	2	2	0.8444444	0.9189366
Immersion	1.1	1.5	-1	2	3	1.4333333	1.197219
Longevity	1.1	1	0	2	2	0.7666667	0.875595
Strategic Positioning	1.0666667	1.3333333	-1.333333	2	3.3333333	0.8839506	0.9401865

Prospective Users

	Mean	Median	Min.	Max.	Range	Sample Var.	Sample Stand. Dev.
Core Competencies	2	2.6111111	-0.444444	3.2222222	3.6666667	1.354226	1.1637122
Innovation culture	0.5714286	1	-1	2	3	1.4945055	1.2224997
Strategic attitude	0.5714286	1	-1	2	3	1.4945055	1.2224997
Customer expectations	1	1	0	2	2	0.7692308	0.877058
Compliance with customer requirements	1	1	0	2	2	0.7692308	0.877058
Product differentiation	0.3571429	0	-2	2	4	1.9395604	1.392681
Risk taking	0.0714286	0	-1	2	3	0.532967	0.7300459
Corporate memory	0.702381	0.9166667	-1.166667	2.1666667	3.3333333	0.872558	0.9341081
Information rich environments	1.1428571	2	-1	2	3	1.2087912	1.0994504
Interpersonal skills	0.9285714	1	-1	2	3	1.3021978	1.1411388
Communication skills	1.1428571	2	-1	2	3	1.2087912	1.0994504
Transparent systems integration	0.5714286	0.5	-1	2	3	1.032967	1.0163499
Time-cost profiles	0.4285714	1	-2	2	4	1.6483516	1.2838815
Tele-communications	0.5714286	0.5	-1	2	3	1.032967	1.0163499
Immersion	-0.285714	0	-1	0	1	0.2197802	0.4688072
Longevity	0.5714286	1	-2	2	4	0.8791209	0.9376145
Strategic Positioning	0.8571429	1	-1	2	3	0.6788767	0.8239397

Non Users

	Mean	Median	Min.	Max.	Range	Sample Var.
Core Competencies	0.5925926	0.5555556	-0.444444	2.3333333	2.7777778	1.0304527
Innovation culture	-0.5	-0.5	-2	1	3	1.1
Strategic attitude	-0.5	-0.5	-2	1	3	1.1
Customer expectations	0.1666667	1	-2	2	4	2.9666667
Compliance with customer requirements	0.5	1	-2	2	4	2.7
Product differentiation	0	0	-2	2	4	2
Risk taking	-1.166667	-1.5	-2	0	2	0.9666667
Corporate memory	-0.388889	-0.416667	-1.666667	0.5	2.1666667	0.6074074
Information rich environments	0	0.5	-2	2	4	2.8
Interpersonal skills	-0.166667	0	-2	2	4	2.5666667
Communication skills	0	0.5	-2	2	4	2.8
Transparent systems integration	-0.333333	0	-2	1	3	1.8666667
Time-cost profiles	1	1	0	2	2	1.2
Tele-communications	-0.333333	0	-2	1	3	1.8666667
Immersion	-0.5	-0.5	-1	0	1	0.3
Longevity	-1	-1.5	-2	1	3	1.6
Strategic Positioning	-0.055556	-0.166667	-0.666667	1	1.6666667	0.5074074

Figure 45. Statistical Measures for Top Seventeen Ranked Systems Elements

From Figures 43, 44, 45, and Appendix 3, and their data tables, it can be seen that the top ranking measures for VR Users are very tightly defined with multiple systems elements reflecting tightly distributed variance and standard deviation values compared to either Prospective or Non Users. Results for almost all systems elements become increasingly distributed through Prospective Users and Non Users with a particularly evident move toward more negative values.

Overall, VR Users data exhibits a consistent response across multiple systems elements with notably significant positive response with regard to the categories of: Core Competencies; Innovation Culture; Strategic Attitude; Customer Expectations; Compliance with Customer Requirements; Product Differentiation; Risk Taking; and Corporate Memory, compared to the overall average scores for all systems elements.

7.4.2 Organizational domain

Findings relative to the Organisational Domain are shown in Figure 46 below.

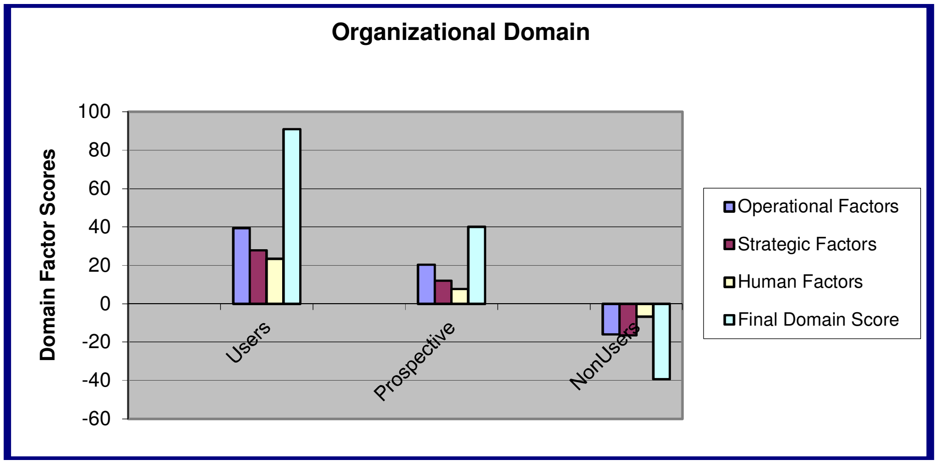


Figure 46. Domain Factor List Sums & Final Domain Scores for the Organisational Domain

7.4.3 Technological domain

Findings relative to the Technological Domain are shown in Figure 47 below.

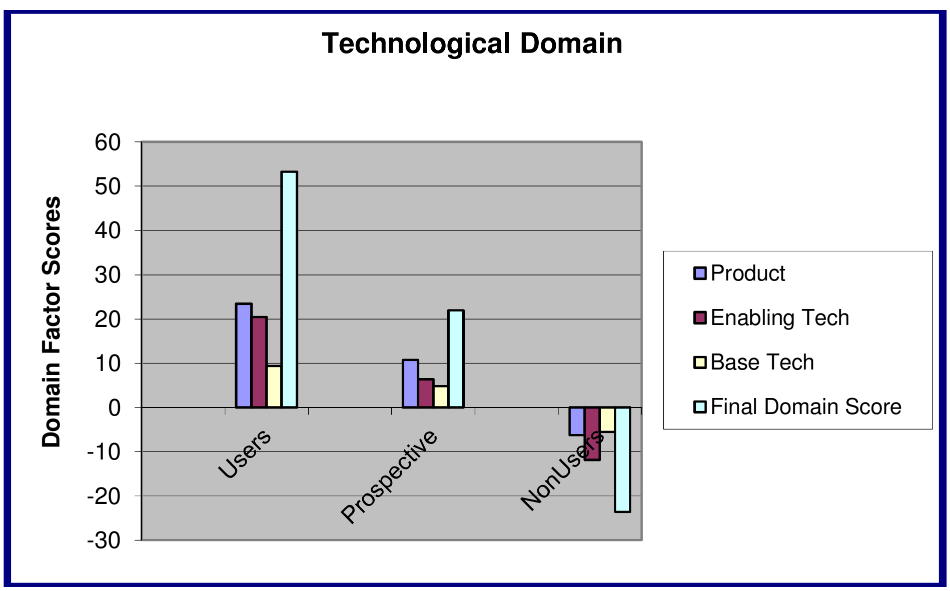


Figure 47. Domain Factor List Sums & Final Domain Scores for the Technological Domain

7.4.4 Sociological Domain

Findings relative to the Sociological Domain are shown in Figure 48 below.

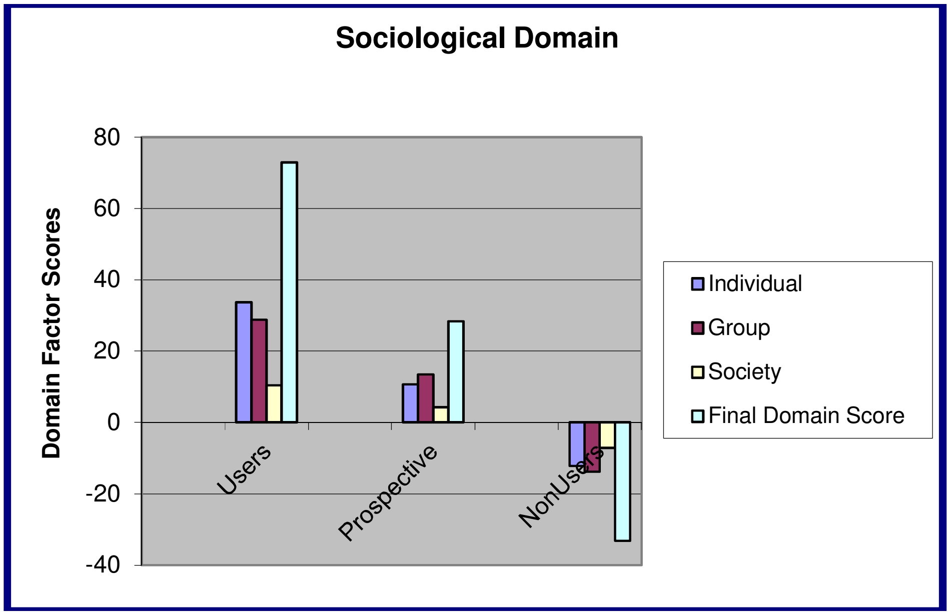


Figure 48. Domain Factor List Sums & Final Domain Scores for the Sociological Domain

7.4.5 Phenomenal Media Domain

Findings relative to the Phenomenal Media Domain are shown in Figure 49 below.

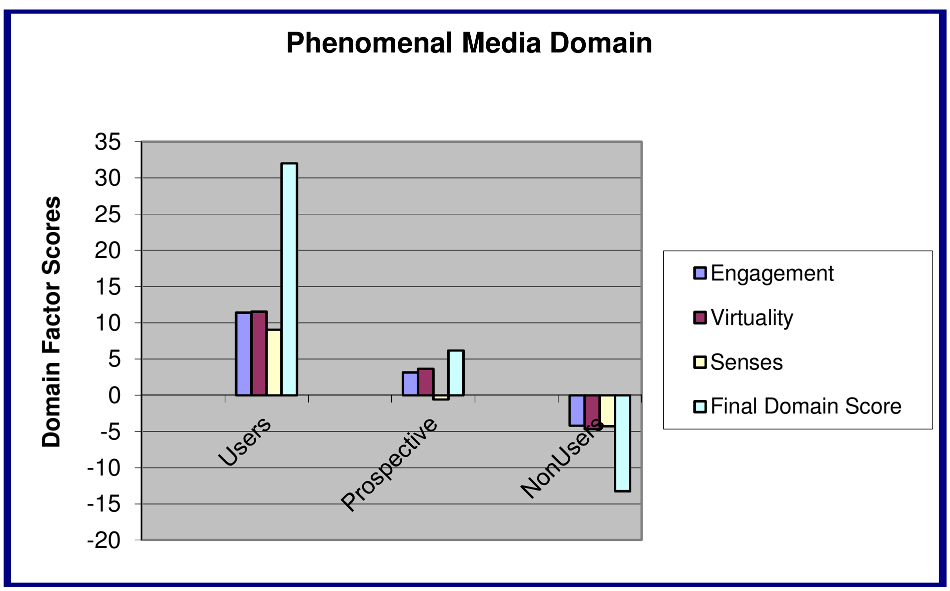


Figure 49. Domain Factor List Sums & Final Domain Scores for the Phenomenal Media Domain

7.4.6 Paradigmatic Framework

Findings relative to the four proposed Paradigms are shown in Figure 50 below.

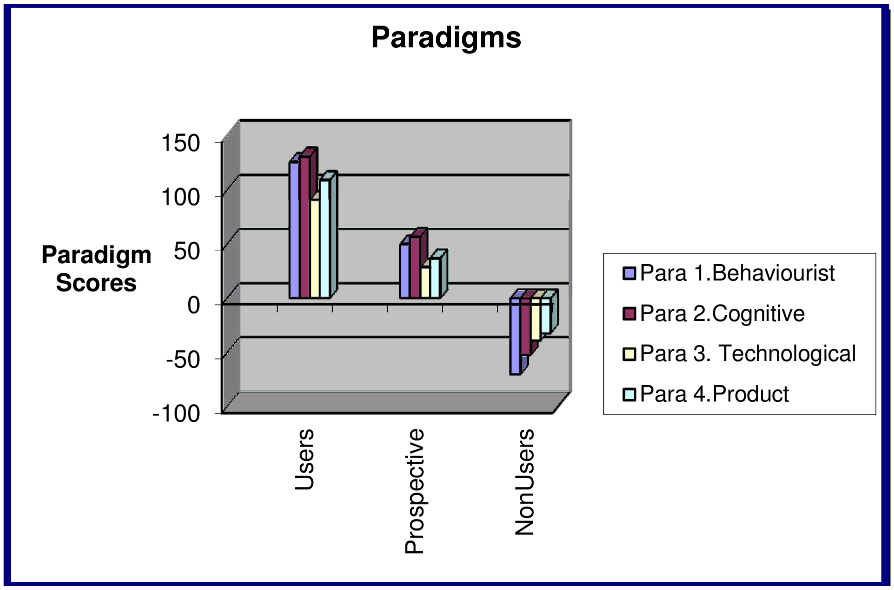


Figure 50. Final Paradigm Scores

7.4.7 Virtual Reality Organizational Index

Findings relative to the proposed VR Organisational Index are shown in Figure 51 below.

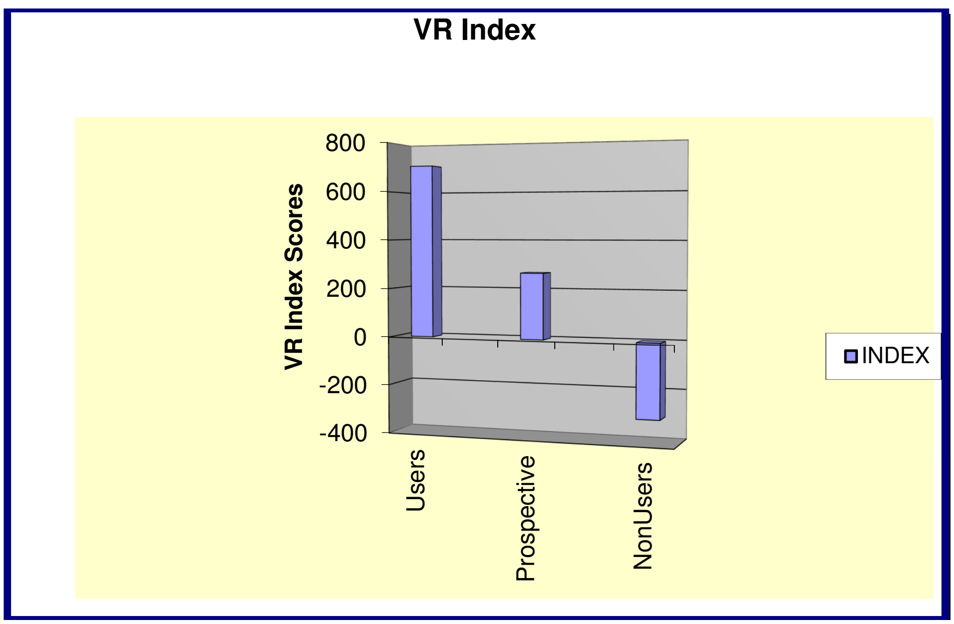


Figure 51. Virtual Reality Organizational Index Scores

	Organizational Domain			Technological Domain			Sociological Domain			Phenomenal Domain			Paradigms				INDEX
	Human Factors	Operat'nl Factors	Strategic Factors	Base Tech. Factors	Enabling Tech. Factors	Product Specific Factors	The Individual Factors	Group Factors	Broader Societal Factors	Sensory Factors	Engagement Factors	Virtuality Factors	Paradigm 1	Paradigm 2	Paradigm 3	Paradigm 4	
DFLS	17.71	54.2778	44.77	17.08	28.083	25.583	28.4921	38.33	18.944	4.8333	7.333	7.83333					
FDS		116.762			70.75			85.76			20						
FPS													171.623	145.623	108.889	108.083	
INDEX																	827.5

Figure 52. **Domain, Paradigm and VR-Index Scores for High-range VR-User (Large Telecommunications Company)**

	Organizational Domain			Technological Domain			Sociological Domain			Phenomenal Domain			Paradigms				INDEX
	Human Factors	Operat'nl Factors	Strategic Factors	Base Tech. Factors	Enabling Tech. Factors	Product Specific Factors	The Individual Factors	Group Factors	Broader Societal Factors	Sensory Factors	Engagement Factors	Virtuality Factors	Paradigm 1	Paradigm 2	Paradigm 3	Paradigm 4	
DFLS	25.12	40.6111	26.016	4.833	15.286	25.833	31.0635	25.9	10.167	5.3333	14.83	10.3333					
FDS		91.746			45.952			67.13			30.5						
FPS													115.246	143.516	56.7937	107.833	
INDEX																	658.7

Figure 53. **Domain, Paradigm and VR-Index Scores for Mid-range VR-User (Architectural Consultancy)**

	Organizational Domain			Technological Domain			Sociological Domain			Phenomenal Domain			Paradigms				INDEX
	Human Factors	Operat'nl Factors	Strategic Factors	Base Tech. Factors	Enabling Tech. Factors	Product Specific Factors	The Individual Factors	Group Factors	Broader Societal Factors	Sensory Factors	Engagement Factors	Virtuality Factors	Paradigm 1	Paradigm 2	Paradigm 3	Paradigm 4	
DFLS	5.261905	31.59722	12.12698	5.875	12.68452	21.20833	17.65079	24.81746	17.5	-1	5.5	7.5					
FDS		48.98611			39.76786			59.96825			12						
FPS													94.44444	91.24603	37.68849	65.5	
INDEX																	449.6012

Figure 54. Domain, Paradigm and VR-Index Scores for High-range Prospective User (Large City Council)

	Organizational Domain			Technological Domain			Sociological Domain			Phenomenal Domain			Paradigms				INDEX
	Human Factors	Operat'nl Factors	Strategic Factors	Base Tech. Factors	Enabling Tech. Factors	Product Specific Factors	The Individual Factors	Group Factors	Broader Societal Factors	Sensory Factors	Engagement Factors	Virtuality Factors	Paradigm 1	Paradigm 2	Paradigm 3	Paradigm 4	
DFLS	16.59524	12.86111	14.9127	8.916667	10.09524	13	19.03968	3.539683	-0.22222	7.166667	4.1666667	5.166667					
FDS		44.36905			32.0119			22.35714			16.5						
FPS													58.56349	54.21825	25.6627	64.41667	
INDEX																	318.0992

Figure 55. Domain, Paradigm and VR-Index Scores for Mid-Range Prospective User (Medical Radiations Laboratory in Large Hospital)

	Organizational Domain			Technological Domain			Sociological Domain			Phenomenal Domain			Paradigms				INDEX
Elements	Human Factors	Operat'nl Factors	Strategic Factors	Base Tech. Factors	Enabling Tech. Factors	Product Specific Factors	The Individual Factors	Group Factors	Broader Societal Factors	Sensory Factors	Engagement Factors	Virtuality Factors	Paradigm 1	Paradigm 2	Paradigm 3	Paradigm 4	
DFLS	-7.7381	-14.4028	-18.873	-6.125	-16.3155	0.208333	-16.3492	-8.18254	-5.5	-8	-3.5	-4.5					
FDS		-41.0139			-22.2321			-30.0317			-16						
FPS													-66.5556	-66.754	-54.3115	-29.5	
INDEX																	-326.399

Figure 56. Domain, Paradigm and VR-Index Scores for Low-range Non-User (Defence Equipment Contractor)

	Organizational Domain			Technological Domain			Sociological Domain			Phenomenal Domain			Paradigms				INDEX
	Human Factors	Operat'nl Factors	Strategic Factors	Base Tech. Factors	Enabling Tech. Factors	Product Specific Factors	The Individual Factors	Group Factors	Broader Societal Factors	Sensory Factors	Engagement Factors	Virtuality Factors	Paradigm 1	Paradigm 2	Paradigm 3	Paradigm 4	
DFLS	-3.45238	0.236111	-1.60317	1.208333	-0.55357	1.208333	-3.34127	1.15873	1.166667	-3.16667	-2.66667	-2.16667					
FDS		-4.81944			1.863095			-1.01587			-8						
FPS													-6.69444	8.123016	-11.2599	-4.75	
INDEX																	-26.5536

Figure 57. Domain, Paradigm and VR-Index Scores for Non-User (Agricultural Supplies Company)

7.5 Testing and Review Summary

This chapter has outlined the approaches taken in the collection, collation and analysis of data relative to the testing and review of the proposed taxonomy. In particular, it has focussed on the 'Post-theory Building Stage' data collection process involving the use of the 'VR Centre User Survey' data collection instrument as the primary means of testing the validity of the proposed taxonomy/planning- framework.

In summary, the testing process has identified a strong correlation between the core attributes of the proposed taxonomy/planning framework and the VR Centre User Survey responses from organizations actively engaged in the use of virtual reality technology and systems. Organizations classified as prospective VR Users also show partial alignment with the core attributes of the taxonomy/planning framework. Organizations classified as clearly non-users show a weak alignment with the taxonomy/planning framework.

This distribution of alignment is taken as an initial confirmation that the current form of the taxonomy/planning framework is sufficiently cohesive to allow that it may be used as a planning tool for identifying organizations with the potential to successfully introduce virtual reality technology and systems, and to assist such organizations to identify those key areas or categories of knowledge, skills and expertise, and resources that they need to develop further.

The mode of analysis used in the survey analysis instrument provides a series of graphical outputs and a quantitative tabulation of scores that clearly differentiates User and Prospective organizations from Non User organizations. As a consequence of the structure and format of the taxonometric approach used in the analysis instrument, it also provides a summary of significant areas or domains of interest that organizations can address to improve their likelihood of success and performance in the application of virtual reality technology and systems.

The analysis instrument similarly enables the identification of the dominant paradigm or paradigms affecting organisational performance.

Discussion with both respondents and other prospective respondents, but who had declined to be involved in the survey activity, also elicited that most users of virtual reality systems and technology perceive it to have a significant influence on establishing and sustaining their competitive advantage. This was particularly evident in companies associated with the film and video (no respondents) automotive, aerospace, and defence industries.

The relatively low scores apparent in the Phenomenal Media domain (relative to the other domains) is of particular interest with regard to interpreting the levels of understanding of the complexities and underlying philosophy of media, new media in particular. Interestingly it reflects the following earlier perspective of

Marshal McLuhan: *The transforming power of media is easy to explain, but the ignoring of this power is not at all easy to explain.* (McLuhan, 1994, p. 304)

This was highlighted when detailed analysis of ‘active’ VR User survey returns showed surprisingly low levels of understandings of theoretical attributes of virtual reality and virtual world environments, their interdependencies and relationships. Prospective Users showed very little understanding and Non-users showed virtually no understandings at all of these aspects.

In effect, the survey has highlighted a long established profile of early adopters of a new technology or innovation: a focus on quick and effective pragmatic outcomes focussed on achieving competitive advantage. Subsequent adopters and users (often including the initial users) tend to refine and further develop the technology/innovation through a more detailed level of understandings, this would also appear to be evidenced in the dominance of core ‘competencies’ as the highest scoring systems element as illustrated in Figure 42. This can also be seen in the continuing evolution of virtual-reality/virtual-world based techniques in the film and video industry where extremely sophisticated and complex digital imagery is now very much *de rigour*.

Chapter 8.
Conclusions

8.1 Objectives of this Chapter

This chapter outlines the key findings of the research program, discusses potential applications for the Taxonomy and planning-framework and identifies opportunities for and areas in which, additional related research may be undertaken in future. As such it represents the 7th and final stage of the AGSSM research methodology used throughout the program.

8.2 Overview of Research Program

This research program has analysed a wide range of selected research and development projects and published works addressing the theory, culture and practices of contemporary technology oriented organizations and their preparedness for and approaches to technological innovation. In particular it addresses the introduction and management of radical innovation and potentially disruptive new and emerging technology. In doing so, it has developed a theoretical basis for a taxonometric classification based planning framework for analysing technology oriented organizations. Application of the framework will help organizations to determine their preparedness to introduce and make effective use of advanced visualization technology. New media based virtual reality systems have been used as an exemplar of such new and continually emerging set of technologies. The focus has thus been on the potential application of such a taxonomy in engineering and technology-based organizations. Such organizations are typified by a strong connection with the practice of developing, introducing and using new technology. As a consequence, decision making in such organizations is strongly connected to both epistemological and ontological reasoning and understandings and use of their technology base, and its application in the real world, both internally and externally to the organization. Thus, the potential interface between real-world conditions and decision making relative to extracting 'meaning' from complex data based visualization has necessarily been an issue addressed both throughout the research. It has also been specifically identified as an area for further research.

An extensive Literature Review and associated Content Analysis (addressed in Chapters 2 and 4 respectively) provides thematic development through reflections on the historical and contemporary development of new media and the philosophical evolution of: systems approaches and systems thinking; the development of strategically focused management practices; the progressive establishment of strategic information and communication technology and related systems; and the evolution of theory and practice of organizations and organizational behaviour. These thematic areas and schools of thought and practice all provide essential theory-based building blocks for what may now be considered as a new and more coherent viewpoint for considering the impact of innovative, and potentially disruptive, technological change on engineering and technology based organizations. Whilst the research activity initially focussed on the potential use of visual projection technologies and systems in virtual reality Centre contexts, recent and continuing new media developments particularly in: desktop workstation capability; image capture devices; extended broadband access (including to WiFi environments); and enhancements to multi-user conferencing software; have now extended the range of visualization and virtual tools and applications to a significantly wider user-base.

This increasing user-base with potentially decreasing costs of entry into the use of virtual reality systems, raises an even wider scope for future applications including moving from highly structured collaboration restricted to being between designated company officiates (complete with high-cost technical support) through to the concept of 'mass collaboration' involving a wide range of individual potential users with a mixed array of technology skills, primarily honed in the 'blog', 'Facebook', and 'Twitter' communities of practice. This essentially loose association of basic skills and expertise in the use of often visually predicated communications raises very interesting and challenging issues for corporate and organizational management. In particular, it challenges the status and form of corporate knowledge and competencies, and the containment of their associated influence on assumed corporate competitive advantage for any real time-space artifice, previously deemed the property of and effectively (and indeed usually rigorously) contained within the corporate body or commercial entity. In effect, what was previously considered as essentially intellectual property and the virtual world of Facebook and Twitter, are seriously at logical odds.

Whilst appearing at first glance to nullify the relevance of the proposed taxonomy, in reality the current almost exponential growth in new media capabilities can be seen to introduce a significant element of additional chaos into an already complex organizational management – policy – expertise mix. A mix that potentially delivers increased risk factors to organizations struggling to establish and maintain competitive advantage through corporate competencies, skills, expertise and advanced knowledge-base involving the use of new media as a mechanism for competitive advantage. Strategically positioning the contemporary technology-based enterprise to take advantage of this, at times chaotic state of knowledge and skills, is not only essential for success but also subject to continuous pressure and conceptual movement. From a socio-technical perspective, this ensuing chaos reflects a 'normal' state of knowledge development, moving from recognition of 'need' for a new or at least better way of resolving an identified issue (not necessarily as a problem, quite possibly as a opportunity) through the 'straits of uncertainty' and vague idea evolution, through conceptual development, eventually to statement of, or possibly definition of, a new form or shape of solution building. These challenging aspects of twenty first century management and the associated pressures and influences on engineering and technology based enterprises is acknowledged throughout the research program, specifically in the development of the 114 Systems Elements and identification of Domains of Influence and associated Factor Lists as developed and assembled throughout Chapters 5 and 6.

This condition of working through uncertainty to an evolving and potentially workable strategy reflects an environment in which ideas can be fluid, adaptable, and transformative in their conceptualisation, without necessarily having first a fixed physical form or technologically derived artefact. In the world of twenty first century management, such flexibility and potential for adaptation is a characteristic that differentiates the knowledge focussed 'learning organization' from the 'corporate dinosaurs' of Alvin Toffler's pre dot-com world (Toffler, 1985). For such transformative organizations, the use of telematics and new media has increasingly become ubiquitous, a work-in-progress that continually adapts, adopts, and renews, as and when required. This reflects a very different notion of 'paradigm' over the earlier construct of one-size-fits-all with a fixed technology-base that changes only under duress, an inherently power-dominated model wherein a paradigm is born, grows, becomes dominant, is challenged, and subsequently overturned, invariably dramatically. Against this Kuhnian old-school dominant paradigm model we can now see at least the semblance of a new form of 'pluralist' paradigmatic framework based on cross-relational connections between multiple paradigmatic formularisms (as developed and discussed in Chapters 5 and 6). A paradigm model wherein the formal structures, processes, and thematics are in a state of constant change, or at least readiness to respond to the influence of change drivers such as the continuing growth in capabilities and adaptations of new media technology and its use as a set of technological platforms on which new applications are continually being built and distributed.

8.3 Research Framework Model

The formal approach to and structure of research activity throughout the research program has involved the application of systematically and inherently integrated processes, reflecting the 'emergent' tradition in research strategy. The following Figure 58 provides a graphical overview of the research framework as applied throughout the program.

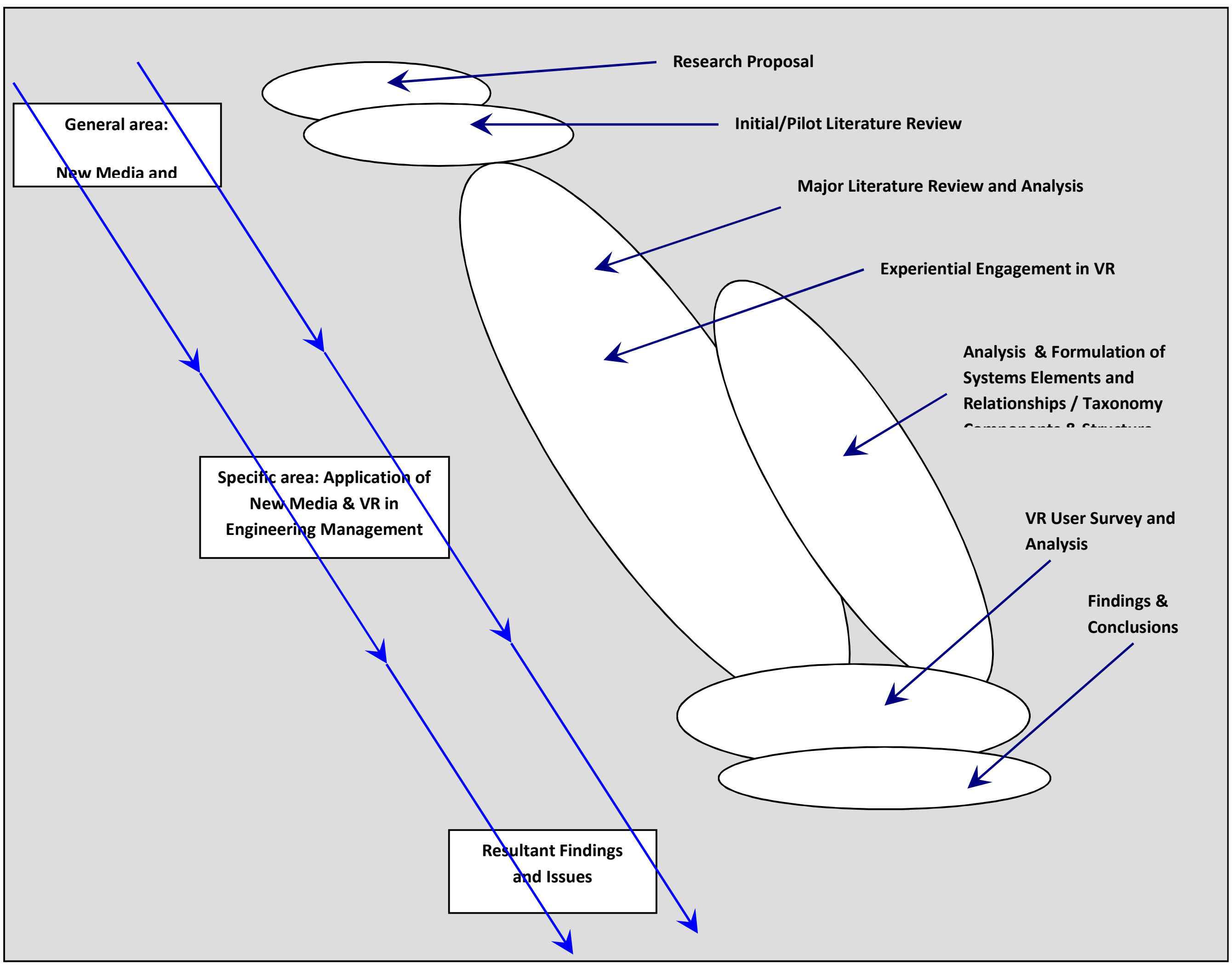


Figure 58. Applied Research Framework Model

8.4 Major Research Findings

This research has demonstrated a new way of looking at and thinking about organizations with a dependence and reliance on contemporary information and communications technology and related technology and knowledge based systems, products and processes. This viewpoint in turn takes cognisance of the technological, economic, environmental and sociological aspects of contemporary twenty first century technology-oriented organizations and the potential impact of radical or disruptive new technology, capable of inducing Kuhnian paradigmatic change, or Gestalt switch like shifts, or Constant's style technological revolution, in an enterprise's underlying technology and applications base.

The research program has identified the potential for strategically inducing such shifts through the introduction of advanced visualization technology. It has also identified that organizations that have successfully introduced such technology have typically developed related intellectual capital and core corporate competencies, not only in relation to the new technology itself, but to a wide range of related organizational and sociological issues within the enterprise that in turn reflect significant changes occurring across and within industry sectors. Such preparation and development can lead to an organizational paradigmatic switch from being a potential VR User with a distant perception of virtual reality systems and technologies and their application, to being a committed VR User organization, with an informed perception of and active investment in the continually developing and changing technology of advanced visualization systems supporting information rich and visually intense virtual reality applications (as discussed throughout Chapters 4, 5 and 6).

Overall, the research has been driven by considering cross-disciplinary interactions between five core areas of related theory and practice: organizational theory; systems theory; strategic planning/management; innovation and change management; engineering and technology management (See Chapters 2, 4 and 5). It has also been supplemented in turn by aspects of quality management, communications theory, communications media, human-factors/ergonomics, and substantial input from a philosophy of science viewpoint.

At its simplest, the proposed taxonomy or planning-framework may be thought of, or visualized as, a four-sided or square right pyramid, or four-pillar, or quadruple bottom-line model. Any of these commonly used analogies for visualising the interaction of related issues or new approaches may readily be used to describe the proposed new framework and its related taxonometric structures (See Figures 39, 40 and 41 in Chapter 6). At the core of the taxonomy and its under-pinning theory base, is the concept that the contemporary technology based organization, whether a manufacturing plant, communications company, or logistics transport company, consists of a connected set of policies, technologies, practices and attitudes, which collectively help form the organizational core competencies, behaviours, attributes, capabilities and corporate culture (See Chapter 5 Sections 5.3, 5.4, 5.5). These can in turn be described as being derived from or relating to a wide range of related factors (or systems elements as per Chapter 5 Section 5.7) and their causal and often widely cross-disciplinary influences. Understanding the influence of these factors and their relationships in a given company or organization provides an opportunity to better understand the potentialities for that entity. In turn, there is the possibility of being able to better identify significant areas of potential weakness in organizational competencies, skills or attitudes that could inhibit how, when and where new technological developments (such as virtual reality and associated advanced visualization systems) may be deployed and their potential benefits amplified.

As can be readily seen from the choice of the four key domains of interest, three of these are essential constructs for any organization: Organizational Domain; Technological Domain; Sociological Domain. Whilst the fourth key domain reflects the specific area of new innovative product or services of interest, in this case involving the use of advanced visualization systems and associated processes required to implement virtual reality applications. In this particular case, that of the: Phenomenal Media Domain.

It may be hypothesised that further research may well establish alternative fourth domains relative to other new innovative technological developments. For example: Small-scale technology or Nano-media Domain. In such a case a whole new set of factor lists relative to nano-technology developments in molecular physics, chemistry and materials science would be needed. This particular area of interest is notably topical, given recent research findings and increasing investments in nano-technology and related small-scale technology developments. Similarly, the growing potential offered by new techniques and applications in high resolution 3D print technology in advanced manufacturing systems for complex components, is of particular relevance given its inherent use of sophisticated 3D imagery. It may be conjectured that such an alternative structure for the fourth Domain may well extend the application of the taxonomy to a new and innovative way of thinking about a range of other contemporary new technology developments.

The findings from the testing phase of the research have in turn provided evidence of significant differences between organizations categorised as: VR-Users; Prospective VR-Users; or Non-VR Users. The most dramatic differentiation, in terms of apparent non-congruent attitudes or factor values, is the considerable shift in value placed on basic theoretical constructs in all three core domains relating to: organizational theory and practice; technological factors; and sociological perspectives. With regard to the significant differences identified between VR-Users and Non-VR Users, it should be noted that all 30 organizations participating in the survey are reliant on and are directly involved in the active use of a range of technologies and all make particular use of IT systems. All 30 may be classified as technology-based or technology-oriented organizations.

In the case of active VR Users there is a demonstrated heightened awareness and strong degree of value placed on the Organizational and Technological Domains, with a lesser degree of value, although still positive, with regard to the Sociological Domain. Similarly with prospective users, there is a strong degree of value placed on the Organizational and Technological Domains but less than the active VR Users, and again a lesser degree of value with regard to the Sociological Domain. By contrast, Non-VR Users (although still technology oriented organizations) ascribed little interest or value to all three domains. This dichotomous response is also reflected in a wide diversity of comments in ‘open text’ responses from respondents and is a significant outcome of the research. It is also likely to lead to more intense investigation, particularly with regard to identifying relevant indicators of causal influences on Non-VR user technology-oriented organizations and how to affect an increased awareness and involvement by such organizations in Organizational and Technological Domain issues.

The survey response characteristics for the fourth, Phenomenal Media Domain, show by far the weakest levels of knowledge and understandings by all three categories of respondents and provided particular insights into the extent or lack of industry awareness about both theoretical and practical aspects of phenomenal media such as virtual reality. It is apparent that the virtual reality and simulation industry sectors face a considerable knowledge drought and associated information dissemination task ahead, if they are to develop increased industry-wide knowledge and understandings about phenomenal media, to a level where enterprises can make informed decisions about prospective use and application of such media in their organizations.

It is the author's contention that the proposed taxonomy can be used as a management and decision support tool, for assisting organizations to identify the relevance of such technologies to their operations and how best to develop their organization to make optimal use of such technology. As such, the use of the taxonomy and its systems elements appraisal tool-set may be seen as an example of how an organization can better engage in 'planning to learn', in this case through focussing on the organization's performance relative to the key requirements of the very media itself in order to better understand its potentialities and benefits (Ettlie, 2006).

In operation, the proposed taxonomy may well be used in a number of different ways by different organizations and for multiple purposes. For example:

- At the proposal development stage, to enable program managers to build and better understand the 'profile' of their new virtual reality proposals and how they fit the capabilities of their organization (or their client's organization). Specifically, this could involve using the taxonomy approach to determine what related areas of organizational core competencies and other areas identified as significant indicators of virtual reality active organizations, could require development in order to make effective use of a proposed new virtual reality application. (See Chapter 7)

- At the executive decision stage, the taxonomy and planning framework could be used to enable management to better understand the ramifications of approving a new proposal, or formulating enquiry into whether or not the organization is capable of, or should be making use of virtual reality systems and approaches to improve their products, processes, or services. Or similarly, whether the organization is capable of extending or enhancing its competitive advantage through improving decision support systems through the introduction of virtual reality-based applications.

- In the simulation and virtual reality technology industry systems and technology supplier sector, to substantially enhance market intelligence and marketing strategies to grow market-share and establish viability of virtual reality development services and products, whether to existing or committed VR Users or new entrants and prospective users. The latter would be an area of particular interest for considering how best to help strategically position an organization to make the most effective use of investments in virtual reality and simulation related new technology.

This area is potentially of particular interest to the education and training sector as it could well be of significant use in identifying potential for new core competency areas within organizations, or indeed whole industry sectors, thus identifying where specific new training services opportunities exist or may develop in the near future.

- At the general management stage, as a knowledge management and strategic planning tool to assist managers to gain detailed insight into their organizational structures and capabilities, and planning for handling complex projects or issues. Of particular value would be the use of the taxonomy to aid managers to identify areas of need in relation to establishing and building company strategic and core competencies.

The author proposes that a modified form of the 'VR User Survey' instrument could be developed for use as a consulting tool to assist in identifying key areas of relevant strength or weakness in a client company and/or areas to be developed prior to or as part of a company strategy to shift into the use of advanced simulation/visualization tools and applications.

Assembling a complete evaluation of prospects for application of virtual reality in an enterprise using the full taxonomy and planning framework clearly involves a considerable degree of complex data collection, collation and analysis. It is thus most likely that a full analysis approach is only feasible in the case of large organizations or at least those with prospects of engaging in large and potentially complex and high cost simulation activities. In practice, such organizations are very likely to be already actively directing their attention to the strategic issue of either becoming or enhancing their performance as a Digital Factory/Organization. (With regard to 'global' organizations this would be at the very least in terms of current policy and intent, as expressed and strongly supported by the European Commission/European Union and associated governments, to encourage and support industry to expand and effectively integrate its ITC systems and related product design, manufacturing, distribution, and management decision support systems) However, a much-simplified version could also be applied to smaller less complex environments.

This research program has also established new understandings in relation to identifying relationships between strategic management approaches, systems thinking, innovation and technological change management, simulation and visualization technology and systems, particularly as they apply in engineering and technology oriented organizations. In this regard the research has found that both active users of virtual reality as well as prospective users have a positive viewpoint towards the application and use of visualization tools in support of management practice. However, few are prepared to categorically state that at this point in time they are committed to widening their application of such tools into more broadly based management applications. In most cases, particularly prospective users, they express the need to see better integration of existing management-data collection tools, before committing further resources toward advanced visualization applications. This indicates a demonstrated need and opportunity for both the ICT visualization industry and the education sector to develop new management training programs (targeting for example 'prospective virtual reality users') focussed on the application of new media virtual reality management support systems capable of utilising the growing quanta of knowledge and information collection and storage systems. This view is strongly supported by the weighting evidenced by the systems elements analysis in the VR User Survey results (see Figure 42) in which the highest ranked systems element (out of 114) as derived from the analysis of the VR Users and Prospective VR Users, is identified as 'competencies', scoring significantly above all other systems elements.

This reflects a range of serious concerns expressed by many managers interviewed throughout the research program, over the reliability and validity of much so-called management-data, and a perceived need to first establish reliable and accurate data collection and collation techniques company-wide. Clearly this implies a widely held view that the future of virtual reality/new-media/visualization tools for use in management may well be as an effective human-computer interface system on the front-end of effective management-data processing systems, providing sophisticated report generation and data visualization for executive managers. Few companies have yet to address the use of virtual reality /new-media/simulation/visualization systems as integrated within their real-time data collection and processing systems, as an approach to monitoring and managing company performance in real-time rather than the normal report-based and thus time-displaced approach. Manufacturing engineering and related technology-based companies currently engaged in lean-manufacturing, just-in-time and modular production planning techniques, with already finely honed data collection strategies in place and possibly already holding significant digital assets, may well be best placed to implement such real-time virtual reality/new-media-based visualization systems with a minimum of lead-time.

8.5 Addition to the Body of Knowledge

A range of new insights and additions to the body of knowledge have been made throughout this research program and thesis with regard to virtual reality styled new media and its application as a management 'tool', with a specific focus on the management of contemporary technology-based organizations. Such insights and additions range from cognition-based positioning of virtual reality styled new media based systems, technology and applications, relative to Philosophy and Philosophy of Science, new/creative-media theoretical constructs, the expanding research field of neuro-science, innovation and technological change theory and practice, management of technology, organizational theory, and both systems-based and socio-technical approaches to the management of contemporary organizations.

Specific areas of original contribution and new additions or adaptations to the body of knowledge include:

- Development of a tetradic taxonomy and strategic planning framework for describing organizations potentially capable of implementing virtual reality styled new media, structured and visualized as a pyramid (as addressed in Chapters 5 and 6).
- Development of a pluralist paradigm model within the overall taxonomy planning framework.
- Association of existing bodies of theory and practice in a new format involving extraction of new meanings from existing theory and practice and identification of new opportunities. Specifically: the visual representation of a taxonomy representing a new construct of : layered association between the theory and practice of multiple theoretical perspectives; and the orthogonal association between multiple disciple bases representing the cross-disciplinary basis of the taxonomy and strategic planning framework.
- Development of a complex strategic analysis instrument (Excel spreadsheet based) for analysis of organizational systems element data derived from a comprehensive VR/New-media User Survey instrument, providing a capacity for identifying organizations with a capability to successfully implement virtual reality new-media, and/or identifying areas of potential weakness in such organizations (as addressed in Chapters 6, 7)
- Adaptation of Checkland's Soft Systems Methodology as 'Adaptive Grounded SSM'.
  (Chapters: 3, 5, 6)
- An interpretation of McLuhan's media tetrad as applied to virtual reality/new-media.
  (Chapter 2.4.5)
- Extension of Boyer's Scholarship model to a corporate strategic technology context.
  (Chapter: 5.2.8 and Table 5)
- Identification of taxonomy systems elements and fields (Chapter 5.7 Tables 7, 8, 9, 10, 11)
- Identification of 1st 2nd and 3rd order effects from virtual reality styled new-media introduction influencing potential organizational paradigmatic change (Chapter 5.8)

The above additions and adaptations have built on and are underpinned by the established work and findings of a wide range of researchers and theorists working in multiple cross-discipline areas, as reflected in the following References and Bibliography Chapters.

8.6 Identified Areas for Future Research

The framework approach developed through the research has further provided a useful basis for future virtual reality related research projects, specifically those involving the development of virtual reality applications intended as decision support tools for management. Typical of such research opportunities would be research into both human-virtual reality system performance appraisal techniques and measurement approaches, and the development of more intuitive human-virtual reality system interfaces.

Of particular interest would the development of office environment virtual reality systems, using the taxonomy approach and systems element tools sets to work through identifying key required attributes of the new systems and related areas for development in the user enterprise. There is in turn a need for continuing research into the nature of system Domains, Factors, and Elements and their role in representing behaviours, practices and activities and their impact on organizations, and the way an organization's core competencies and competitive advantage can in turn be interpreted through them.

A strongly related area for new information technology research is that of developing new techniques for the structuring of and intelligent content analysis and retrieval from meta-media and multi-media databases. Similarly, the integration of such content analysis and retrieval systems with virtual environments and virtual reality display and visualization systems is an area for further investigation. Expanding use and capabilities of new 'social media' and new IT based 'collaborative' support systems using new media, is now creating opportunities to empirically investigate and test the effectiveness of decision-making support systems utilising new media VR and associated 'user' related issues. It is very clear that as new media-based VR technologies and associated systems continue to evolve, so also will specific VR type 'management applications' become more attractive to software system developers. As yet, very few such applications are readily available outside of the design environment.

This research also raises an entirely new area of opportunity in the possible development of a new virtual-world semiotics and iconography associated with extracting and visualizing 'meaning' from large bodies of meta and multi-media data. In particular, the visualizing in virtual reality environments of patterns of behaviours and practice in organizations, especially those that are largely engineering or technology based (just as communities of practice within industries, and indeed in the broader society, use defined visual language, or iconography, to represent specific messages such as: stop, go, wrong-way, one-way, hazard, temperature, flammable, pedestrians, train-lines, fuel, and many others). It is apparent from the author's involvement with active VR Users, Prospective Users and Non-Users, that very few have any serious concept of the potential for and role of such iconography and its application in actualising or supporting the language and grammar of new media in visually intense simulation environments. Similarly, there is a need for further research in the related evolving field of visual sociology, with a specific focus on identifying relationships between the impact of continuing growth in ICT capabilities for advanced visualisation and the mechanisms (such as new iconographic symbolisms) for interfacing visual data with management decision-making.

Similarly, few VR-Users, Prospective-Users, or Non-Users, have any detailed knowledge or comprehension about theoretical constructs of virtuality and how to effectively explore real-world concepts through virtual means. Again, there is considerable opportunity for the virtual reality and simulation industry to develop greater awareness of cognitive processing support tools using visualization systems and associated virtual reality toolsets, particularly in relation to the application of such tools in management contexts.

There is a need for sociological/ethnographic discipline based research in various related areas of concern, including the potential for conflict or clash in role definition and comprehension of role boundaries between operatives in virtual world work environments. Such areas of conflict could occur for example, between 'participant' operatives (with responsibility for organizational functions being simulated or represented in virtual environments) and 'observer' operatives (such as executive management viewing virtual world simulations for decision making purposes). Incipient blurring of the separation between the 'real' and the 'virtual' is the primary area of concern in such instances, particularly in organizations with high levels of digital assets directly or otherwise interfaced to virtual world modelling tools.

There is considerable scope for further research to explore these areas of uncertainty in the evolving ethnography of virtual world/synthetic environments and their impact on employees, whether technologists, administrators or executive management, whose work experience may largely involve operating within virtual communities in largely synthetic environments such as virtual reality. Failure to understand or to address issues arising from such work environments could potentially lead to substantive risks of fragile competencies being subsumed by the unachievable dreamworlds of digital utopias.

Such new research will most likely be strongly informed by continuing research into elements of Critical Social Theory, the Sociology of Technology, human cognition elements in information systems, and related management approaches to the continuing development and implementation of advanced ICT.

Yet another area highlighted in the research program as requiring further investigation is that of Risk Factors. This can be with regard to both ergonomics and associated occupational health and safety issues relative to human operators functioning in virtual environments, as well as risk factors relative to the commercial risks associated with the introduction of potentially disruptive innovation and change.

8.7 In Summary

In reflecting on the status, or existing position of current VR technology on an innovation style technology 'S' curve (Martin, 1994; Ettlie, 2000) or in considering the prospects for further developments in virtual reality systems and technologies, it could well be that the next significant innovation in virtual reality is not about further design or enhanced technological performance in the underpinning technology (assuming that existing virtual reality technology 'S' curve parameters are primarily premised on opportunities offered by capabilities supporting design applications and understanding science-based simulations). Rather, the next significant innovation relative to virtual reality systems and technologies may well be about the introduction and dissemination of new and innovative visualization-based virtual-world products and applications (as per example: 'Second Life') specifically focussed on providing or enhancing decision support services for corporate management. The introduction and diffusion of such applications would in turn have significant ramifications in related areas of theory and practice in the disciplines of management science, management of technology, and engineering management.

Clearly, the day-to-day office environment of executive management is not about to become that of a full-scale wrap-around virtual reality centre. Although, under a more liberal view of virtual reality systems in management, it is very likely that in the near future executive management teams or Boards of Management may well conduct formal data-intensive decision-making in such environments (refer examples in Figures: 5 and 6). However, desktop wrap-around screens and systems (Refer examples in Figures 15 and 16) and wide-angle lightweight LCD eyewear (refer example in Figure: 14) may well become commonplace in executive management offices of 'digital-assets-intense' enterprises and 'digital factory' environments in the very near future.

Effectively preparing organizations for transition to such innovative decision-making environments is an essential condition for success. The seriousness with which the European Commission of the European Union has taken up the challenge of moving European manufacturing industries into the 'Digital Factories' futures environment as a matter of urgency, underwrites the necessity of addressing the many issues identified throughout this research program and reflected in its proposed taxonometric/planning framework.

Fundamental among these issues is the need to develop corporate core competencies in the areas of knowledge, skills and expertise related to the introduction of advanced visualization tools; information and knowledge management strategies and processes; the characterization of visual data; the assembly of coherent company-wide data-sets; and the detailed modelling of enterprise functions and related activities, resources and supply-chains.

As a radical and potentially disruptive innovation, virtual reality also has the significant advantage of providing the prepared and competent user/organization with insights into the enterprise's information and knowledge management assets not hitherto easily available. The scale and success of virtual reality's impact on the 'design and development' environment across multiple industry sectors over the past 10-15 years can be seen as a pre-cursor to its potentially even greater impact as an integrative information and knowledge management instrument for change in future decision-making.

A particular aspect of this research program has been its strongly interdisciplinary approach to exploring the potentialities for and impact of virtual reality systems and technologies on the management of technology-based organizations. The ultimate aim of the research has been to develop further understandings of the dynamics of complex technology-based organizations and the various transformations that can occur with the introduction of potentially disruptive or transformative technology, in this particular case virtual reality. The proposed taxonomy identifies areas of organizational engagement within which such transformations are likely to and do occur. With respect to the findings associated with the VR-User survey analysis, it can be argued that the identified key combinations of influences on and within an organization can add to the transformative effect of a radical–revolutionary/disruptive technology, or at least be catalytic to producing such transformation.

In effect, the resultant influence of a mix of a select multiplicity of influences on an organization may exceed the sum of any individual influences, to create ‘meta-influence’ and conditions leading to paradigmatic switch, or as in the proposed taxonomy framework, the establishment of a pluralist paradigmatic environment in which multiple technological and user communities of practice both co-exist and support organizational-progression. The identification and testing of such catalytic or meta-influence effects on the introduction of various new technological developments into contemporary technology-based organizations is clearly an area for further research and study, particularly with respect to identifying appropriate mechanisms for controlling the rate of such catalysis within an organization and thus controlled ‘disruption’. The proposed taxonomy or planning framework provides a mechanism for identifying organizations with significant combinations of such key areas of influence.

8.8 Epilogue

The manufacturing and technology-based industry sectors across the European Union (EU) has over recent years suffered serious and continuing aggressive competition from Asia and South Asia based manufacturers able to source low-cost labour and production technology. In May 2006 the European Commission (EC) initiated major research projects to identify the future directions for EU manufacturing and technology-based industry.

One such project, titled 'DiFac' (Digital Factory for Human-oriented Production System) was specifically targeted at developing strategies for the future application of advanced ICT including a particular focus on the extensive use of collaborative virtual reality style technology and systems (as addressed throughout this research program). By late 2008 it was clear that such strategies would form a significant component in what had by then become a major 'European Economic Recovery Plan 2010-2013' package proposed under the Framework 7 Program to be implemented by the European Commission across all member States in the European Union commencing in 2010.

In April 2009 the European Commission announced the establishment of its proposed three significant Public-Private Partnership (PPP) projects, collectively valued at ~€7.2Billion (~12.6A$Billion) over the next three years, targeted at addressing technological innovation and change in the three dominant industrial sectors in the European Union: automotive; construction; and manufacturing.

1. 'Factories of the Future' focused on the manufacturing sector and specifically including the DiFac advanced ICT and collaborative virtual reality strategies, to be funded at €1.2 billion
2. 'Energy-efficient Buildings' focused on the construction industry, funded at €1 billion
3. 'Green Cars' focused on the automotive industry to be funded at €5 billion.

   (European Commission:
http://ec.europa.eu/research/index.cfm?pg=newsalert&lg=en&year=2009&na=ppp-310309 , 2009)

The current position of the European Commission with regard to the three PPP projects as core components in its Economic Recovery Plan is clearly that of a technological deterministic technology-driven approach or 'technology push'. The EC's PPP documentation released April 2009 outlines a clear intention to restructure and re-enervate manufacturing industries across the European Union through targeted research at producing a mix of new technological fixes to long-standing problems with an expectation of re-establishing European economic competitiveness.

The relevance of the findings and outcomes of this research program are of particular relevance to the proposed Digital Factories component of the Factories of the Future PPP projects (as above) as a means of identifying companies and enterprises with core competencies and strategically relevant capabilities to enable them to actively and effectively engage in the proposed PPP projects approach.

Whilst a long overdue and necessarily long-term strategic planning approach focussed on utilising the latest advances in science and technology, it appears that European Commission researchers have also made, at least in part, the essential connection identified and outlined in this research between the technological imperative paradigm and the critical causal and affective influences of the social structures and related human elements of technology-based organizations.

Four core critical domains of influence on technology-based organizations were identified in this research program along with extensive influencing Factor lists. (See Chapters 5 and 6)

1. **Organizational Domain** Representing corporate or institutional perspectives
2. **Technological Domain** Representing key issues associated with the core technologies proposed
3. **Sociological Domain** Representing the broader societal perspectives both internal and external
4. **Phenomenal Media Domain** Representing the key characteristics of phenomenal media.

It is apparent from the various EU project reports published through 2008-2009 that, at least with regard to the DiFac related strategies, the research focus and approach taken thus far has paid considerable attention to the above Technological and Phenomenal Media domains and the more obvious human-technology-interface oriented issues and related ergonomics driven human factors embedded in the internal aspects of the Sociological domain. However, it is as yet far from clear that other pressing issues in the Organizational and Sociological domains have received anything more than cursory attention thus far.

It would appear that a significant case could be made for an urgent appraisal of the Factories of the Future/DiFac project to determine strategies focussed on identifying current levels of knowledge, skills (constituting overall corporate competencies) relevant strategically oriented capabilities and change-management performance, against the above domains of influence in EU manufacturing and technology-based organizations. Failure to do so prior to actioning the introduction of what can best be described as radical approach to the widespread diffusion of a disruptive innovation, may well lead to inherently embedded risks of potentially calamitous outcomes at the level of individual organizations

It is not so much that the new science and subsequent applied ‘technologies’ proposed to be developed and/or introduced will fail, rather that many of the organizations attempting to implement them may effectively implode, or their internal social structures collapse in disarray. Such is the potential outcome for unsuccessful transition from an old and established technology base to a new radical and disruptive technology, driven by technology-pull-focused paradigmatic change. It is essential that such transitioning strategies take account of the need to maintain balance between the four ‘domains’ of influence reflecting organizational theory and practice as identified in this research.

References

Listing of all materials directly referenced in the body of the Thesis.

Achenbach, J. (2003) Dinosaurs Come Alive, in *National Geographic* March 2003, New York: National Geographic Society.

Afuah, A. (2003) *Innovation Management, 2nd Ed.,* New York: Oxford University Press.

Ahmed, P. K. & Shepherd, C.D. (2010) *Innovation Management: Context, Strategies, Systems and Processes*, Harlow, Essex: Pearson Education Ltd.

Aldrich, A.W. (2010) Universities and Libraries Move to the Mobile Web, in *Educause Quarterly Magazine, Vol 33, No 2, 2010*, Boulder, Col: EDUCAUSE. http://www.educause.edu/EDUCAUSE%2BQuarterly/EDUCAUSEQuarterlyMagazineVolum/UniversitiesandLibrariesMoveto/206531 (20-02-2011)

Alford, L.P. (1940) *Principles of Industrial Management*, New York: The Ronald Press.

Alford, L.P. & Beatty, R.H. (1951) *Principles of Industrial Management, Revised Edition,* New York: The Ronald Press.

American Society of Mechanical Engineers (2010) *Guide to the Engineering Management Body of Knowledge*, New York: ASME Press.

Amidon, D. (2003) *The Innovation Superhighway: Harnessing Intellectual Capital for Sustainable Collaborative Advantage*, Woburn, MA : Butterworth-Heinemann.

Andriessen, J. H. E. (2006) Managing Knowledge Processes, chapter 14 in Verburg, R. M. Ortt, J. R. & Dicke, W. M. (2006) *Managing Technology and Innovation: An Introduction*, Abingdon, Oxon: Routledge.

Andriole, S. (2005) *The 2nd Digital Revolution*, Hershey, PA: IRM Press,

Antill, J. & Farmer, B. (1991) *Engineering Management. 3rd Ed.*., Roseville, NSW: McGraw-Hill.

Applegate, L.M., Austin, R.D. & McFarlan, F.W. (2003) *Corporate Information Strategy and Management. 6th Ed.*., New York:.McGraw-Hill.

Armitage, M. (2003) *Discovery & Innovation in the 21st Century*, Keynote Presentation to SimTecT 2003, Simulation Industry Association of Australia. www.siaa.asn.au/simtect/2003/simprog.html (7-1-2004)

Arnold, H.M. (2003) *Technology Shocks: Origins, Managerial Responses, and Firm Performance*, Heidelberg: Physica-Verlag.

ASTEC (1983) *Technological Change and Employment: A Report to the Prime Minister by ASTEC prepared by the Technological Change Committee*, Canberra: Australian Science and Technology Council.

Babcock, D. L. & Morse, L. C. (2002) *Managing Engineering and Technology 3rd Ed.*, Upper Saddle River, NJ: Prentice Hall.

Baguley, D. (2011) Big Data, in *Management Today, April 2011, Australian Institute of Management*, Eveleigh, NSW: Pacific.

Balogun, J. & Hailey, V. H. (2008) *Exploring Strategic Change 3rd Ed..,* Harlow: Pearson Education Limited.

Barnatt, C. (1997) *Challenging Reality: In Search of the Future Organization*, Chichester:.John Wiley & Sons.

Bartol, K., Tein, M., Mathews, G., & Martin, D. (2005) *Management a Pacific Rim Focus. 4th Ed*., North Ryde, NSW: McGraw-Hill Irwin.

Bartol, K., Tein, M., Mathews, G., & Sharma, B. (2008) *Management a Pacific Rim Focus. 5th Ed.,*, North Ryde, NSW:.McGraw-Hill Irwin.

Battersby, M. (1969) *Art Nouveau*, Feltham, Middlesex: Paul Hamlyn.

Baudrillard, J. (translated Turner, C.)(1990) *Cool Memories*, New York: Verso.

Beasley, G. & Burwell, J. (2002) *Geospecific Databases for Battlespace Visualization*, White Paper for Silicon Graphics Inc., Mountain View, CA: SGI. www.sgi.com/pdfs/3279.pdf (19-4-2004)

Beckford, J. (2002) *Quality, 2nd Ed*. London: Routledge.

Beerli, A., Falk, S. & Diemers, D., Eds. (2003) *Knowledge Management and Networked Environments*, New York: AMACOM.

Bell, D. (2007) *Cyberculture Theorists: Manuel Castells and Donna Haraway*, Abingdon, Oxon: Routledge.

Betz, F. (1993) *Strategic Technology Management*, Singapore:.McGraw-Hill.

Betz, F. (2001) *Executive Strategy: Strategic Management and Information Technology*, New York: John Wiley & Sons.

Betz, F. (2003) *Managing Technological Innovation: Competitive Advantage from Change, 2nd Ed..,* Hoboken, NJ:.John Wiley & Sons.

Bijker, W.E., Hughes, T.P. & Pinch, T.J. (1987) *The Social Construction of Technological Systems: New Directions in the Sociological History of Technology*, Cambridge, Mass:.MIT Press.

Blakie, N. (1993) *Approaches to Social Enquiry*, Cambridge: Polity Press.

Blanchard, B.S. & Fabrycky, W..J. (1990) *Systems Engineering and Analysis 2nd Ed*.., Upper Saddle River, NJ:.Prentice Hall.

Blanchard, B.S. & Fabrycky, W..J. (2006) *Systems Engineering and Analysis 4th Ed*., Upper Saddle River, NJ:.Prentice Hall.

Blecker, T. (2005) *Information and Management Systems for Product Customization*, Boston, MA: Springer Science.

Bloom, B. (Ed.) (1956) *Taxonomy of Educational Objectives: The Classification of Educational Goals,* London: Longmans.

Boatright, J.R. (2003) *Ethics and the Conduct of Business, 4th Ed*., Upper Saddle River, NJ:.Prentice Hall.

Boczkowski, P. & Lievrouw, L.A. (2008) Bridging STS and Communication Studies: Scholarship on Media and Information Technologies, in Hackett, E.J. Amaterdamska, O. Lynch, M. & Wajcman, J. (2008) *The Handbook of Science and Technology Studies 3rd Ed*., Cambridge, Mass: MIT Press.

Boellstorff, T. (2008) *Coming of Age in Second Life: An Anthropologist Explores the Virtually Human*, Princeton: Princeton University Press.

Bouzereau, L. & Duncan, J. (1999) *Star Wars: The Making of Episode 1 The Phantom Menace*, New York: Random House.

Bower, J.L. & Christensen, C.M. (1995) Disruptive Technologies: Catching the Wave, in *Harvard Business Review Jan-Feb* 1995 pp. 43-53, Greenwich, CT: Harvard University.

Bowker, G.C. & Star, S.L.(1999) *Sorting Things Out: Classification and its Consequences,* Cambridge Mass: The MIT Press.

Boyer, E.L. (1990) *Scholarship Reconsidered: Priorities of the Professoriate*, The Carnegie Foundation for the Advancement of Teaching.

Bricken, W. (1991) Definitions, in *Virtual Reality Report*, Westport, CT: Meckler Corporation.

Bryant, A. & Charmaz, K. (Eds) (2007) *The SAGE Handbook of Grounded Theory*, London: SAGE Publications.

Burdea, G.C. & Coiffet, P. (2003) *Virtual Reality Technology, 2nd Ed.*, Hoboken, NJ: John Wiley.

Burgelman, R.A., Madique, M.A. and Wheelwright, S.C. (Eds.) (1996) *Strategic Management of Technology and Innovation, 2nd Ed..,* New York: McGraw-Hill.

Burgelman, R.A. & Doz, Y.L. (2001) The Power of Strategic Integration in *MIT Sloan Management Review (Spring)* 2001 pp. 28-38.

Burke, W.W. (2008) *Organization Change: Theory and Practice 2nd Ed..*, Thousand Oaks, Ca.: SAGE Publications.

Burrell, G. & Morgan, G. (1979) *Sociological Paradigms and Organizational Analysis: Elements of the Sociology of Corporate Life,* London: Heinemann.

Caldine, R. (1994) *An Introduction to Educational Television and Video*, Centre for Staff Development, Wollongong: University of Wollongong.

Camara, A. S. & Raper, J. Edts. (1999) *Spatial Multimedia and Virtual Reality*, London: Taylor & Francis.

Camarinha-Matos, L.M. Afsarmanesh, H. & Ollus, M. (2008) *Methods and Tools for Collaborative Networked Organizations*, New York: Springer Science.

Cao, C.G.L. & Rogers, G. (2004) Robot-assisted minimally invasive surgery: The Importance of Human Factors Analysis and Design, in *Surgical Technology International,* Vol. 12: pp.73-86.

Card, S.K., Mackinlay, J. D. & Shneiderman, B. (1999) *Readings in Information Visualization: Using Vision to Think*, San Francisco: Morgan Kaufmann Publishers Inc.

Carlopio, J. (2003) *Changing Gears: The Strategic Implementation of Technology,* Basingstoke: Palgrave MacMillan.

Castells, M. (Ed.) (2004) *The Networked Society: A Cross-cultural Perspective*, Northampton, MA: Edward Elgar.

Cavaleri, S. & Obloj, K. (1993) *Management Systems: A Global Perspective*, Belmont: Wadsworth Publishing Company.

Cavusoglu, M.C. Sherman, A. & Tendick, F. (2002) Design of Bilateral Teleoperation Controllers for Haptic Exploration and Telemanipulation of Soft Environments, in *IEEE Transactions on Robotics and Automation, Vol. 18, No.4, August 2002*, pp. 641-647.

Champy, J. (1995) *Reengineering Management: The Mandate for New Leadership*, London: HarperCollins Publishers.

Chandy, R.K. Prabhu, J.C. & Antia, K.D. (2003) What Will the Future Bring? Dominance, Technology Expectations, and Radical Innovation, in Millson, M.R. & Wilemon, D. (2008) *The Strategy of Managing Innovation and Technology*, Upper Saddle River, NJ: Prentice Hall.

Charmaz, K. (2006) *Constructing Grounded Theory: A Practical Guide Through Qualitative Analysis*, London: SAGE.

Checkland, P. (1993) *Systems Thinking, Systems Practice*, Chichester: John Wiley & Sons.

Checkland, P. & Scholes, J. (1990) *Soft Systems Methodology in Action*, Chichester: John Wiley & Sons.

Chen, C. (2006) *Information Visualization: Beyond the Horizon 2nd Ed.*, London: Springer-Verlag.

Chesbrough, H.W. (2003) *Open Innovation: The new Imperative for Creating and Profiting from Technology*, Boston, Mass: Harvard Business School.

Child, J. (2005) *Organization: Contemporary Principles and Practice*, Oxford: Blackwell Publishing.

Christensen, C.M. (1997) *The Innovator's Dilemma: When New Technologies Cause Great Firms to Fall*, Boston, Mass: Harvard Business School Press.

Christensen, C. M. (1999) The Evolution of Innovation, in *The Technology Management Handbook* edited by Richard C. Dorf, Boca Raton, FL: CRC Press and IEEE Press.

Christensen, C.M. & Raynor, M.E. (2003) *The Innovator's Solution: Creating and Sustaining Successful Growth*, Boston, Mass: Harvard Business School Press.

Christensen, C.M. Horn, M.B. & Johnson, C.W. (2008) *Disrupting Class: How Disruptive Innovation Will Change the Way the World Learns*, New York: McGraw-Hill.

Christensen, M. & Lamm, B. (2003) Morgana: From Vision to Visualisation, in *Production Methods: Behind the Scenes of Virtual Inhabited 3D Worlds*, 2003, edited by Kim Halskov Madsen, London: Springer-Verlag.

Clarke, A. E. & Star, S. L. (2008) The Social Worlds Framework: A Theory/Methods Package, in Hackett, E.J. Amaterdamska, O. Lynch, M. & Wajcman, J. (2008) *The Handbook of Science and Technology Studies 3rd Ed.*, Cambridge, Mass: MIT Press.

Clarke, S. (2001) *Information Systems Strategic Management: An Integrated Approach*, London: Routledge.

Clarke, S. Coakes, E. Hunter, M.G. & Wenn, A. (2003) *Socio-Technical and Human Cognition Elements of Information Systems*, London: Information Science Publishing.

Clarke, S. & Drake, P. (2003) A Social Perspective on Information Security: Theoretically Grounding the Domain, chapter 12 in Clarke, S. Coakes, E. Hunter, M.G. & Wenn, A. (2003) *Socio-Technical and Human Cognition Elements of Information Systems*, London: Information Science Publishing.

Clayton, A. M. H. & Radcliffe, N. J. (1996) *Sustainability: A Systems Approach*, London: Earthscan Publications Limited/Kogan Page.

Clegg, S. (2002) *Central Currents in Organizational Studies: Contemporary Trends*, London: SAGE Publications.

Clegg, S. Kornberger, M. & Pitsis, T. (2008) *Managing and Organizations: An Introduction to Theory and Practice 2nd Ed.*, London: SAGE Publications.

Coakes, E. (2003) Socio-Technical Thinking: A Holistic Viewpoint, in Clarke, S. Coakes, E. Hunter, M.G. & Wenn, A. (2003) *Socio-Technical and Human Cognition Elements of Information Systems,* London: Information Science Publishing.

Coakes, E. Willis, D. and Clarke, S. (2002) *Knowledge Management in the SocioTechnical World,* London: Springer-Verlag.

Collins English Dictionary (1998) *Collins English Dictionary, 4th Australian Edition*, Glasgow: HarperCollins.

Collins, B. M. (1993) Data Visualisation – Has it all been seen before? in *Animation and Scientific Visualisation: Tools and Applications*, Earnshaw, R A. & Watson D. Editors, 1993, London: Academic Press.

Constant, E.W. (1984) as attributed in Gutting, G. (1984) Paradigms, Revolutions, and Technology, chapter in *The Nature of Technological Knowledge: Are Models of Scientific Change Relevant?* Lauden, R. Ed., (1984) Dordrecht: D. Reidel Publishing Company.

Constant, E.W. (1987) The Social Locus of Technological Practice: Community, Systems, or Organization? Chapter in Bijker *et al* (1987) *The Social Construction of Technological Systems*, Cambridge, Mass: MIT Press.

Constantinescu, C. Runde, C. Volkmann, J. Lalas, C. Sacco, M. Liu, D. Pavlopoulous, C. & Papas, M. (2007) *Definition of a VR Based Collaborative Digital Manufacturing Environment*, DiFac Consortium, European Commission. www.difac.net/Downloads (15-06-2009)

Corbin, J. & Strauss, A. (2008) *Basics of Qualitative Research, 3rd Ed.*, Thousand Oaks, Ca: Sage Publications Inc.

Costigan, J. (2000) *Visualisation of Large Datasets*, Presentation at Asia Pacific Visualisation Summit2000, Melbourne: RMIT University.

Coulter, M.K. (2005) *Strategic Management in Action, 3rd Ed.*, Upper Saddle River, NJ: Pearson Prentice Hall.

Coveny, P. & Highfield, R. (1990) *The Arrow of Time*, London: W.H.Allen.

Coyne, R. (1999) *Technoromanticism: Digital Narrative, Holism, and the Romance of the Real*, Cambridge, Mass: The MIT Press.

Craig, M. (2000) *Thinking Visually: Business Applications of 14 Core Diagrams*, London: Continuum.

Creeber, G. & Martin, R. (2009) *Digital Cultures: Understanding New Media*, Maidenhead, Berks: Open University Press.

Crison, F., Lecuyer, D., Mellet d'Huart, D., Burkhardt, J., Michel, G. & Dautin, J. (2005) Virtual Technical Trainer: Learning How to Use Milling Machines with Multi-Sensory Feedback in Virtual Reality, chapter in Frohlich, B., Julier, S. & Takemura, H., Eds. (2005) *IEEE Virtual Reality 2005 Conference Proceedings*, Danvers MA: IEEE Inc.

Cruz-Neira, C., Sandin, D.J., DeFanti, T.A., Kenyon, R.V. & Hart, J.C. (1992) The CAVE: Audio Visual Experience Automatic Virtual Environment, in *Communications of ACM* 1992, Vol 35 (6), pp.64-72.

Cruz-Neira, C. (2002) Immersed in Engineering, in *Eye on Innovation: Vol. 2: Summer 2002: Guest Commentary*, Silicon Graphics Inc.

www.sgi.com/industries/manufacturing/eoi/vol2/summer/guest.html (11-4-2003)

Daft, R. (2007) *Organization Theory and Design 10th Ed.*, Mason: South-Western Cengage Learning..

Danesi, M. (2002) *Understanding Media Semiotics*, London: Arnold.

D'Aveni, R. A. (1994) *Hyper-competition: Managing the Dynamics of Strategic Manoeuvring*, New York: The Free Press.

Davis, R. (1928) *The Principles of Factory Organization & Management*, New York: Harper & Row.

Davis, R. (1951) *The Fundamentals of Top Management,* New York: Harper Brothers.

Defense Modeling & Simulation Office (2002) United States Department of Defense. www.dmso.mil/public/ (18-7-2002)

Del Favero, D., Shaw, J., Gibson, R., and Howard, I. (2002) *The Reformulation of Narrative within Digital Cinema as the Integration of Three Models of Interactivity*, ARC Discovery Research Project Outline, iCinema, Sydney: University of New South Wales.

Denzin, N. K. (1989) *The Research Act: A Theoretical Introduction to Sociological Methods*, Engelwood Cliffs, NJ: Prentice Hall.

Descartes, R. (1642) Meditations as cited in Warburton, N. (Ed.) (1999) *Philosophy: Basic Readings*, London: Routledge.

Desouza, K.C. & Hensgen, T. (2004) *Managing Information in Complex Organizations: Semiotics and Signals, Complexity and Chaos*, New York: M.E. Sharpe.

Devlin, K. (1997) *Goodbye Descartes: The End of Logic and the Search for a New Cosmology of the Mind*, New York: John Wiley & Sons.

Dewey, J. (1938) Logic: The Theory of Enquiry, Henry Holt & Co., as cited in Betz, F. (2003) *Managing Technological Innovation: Competitive Advantage from Change, 2nd Ed.,* Hoboken, NJ: John Wiley & Sons.

Dey, I. (2007) Grounding Categories, in Bryant, A. & Charmaz, K. (2007) *The SAGE Handbook of Grounded Theory*, London: SAGE Publications.

Dorf, R. C. Editor in Chief (1999) *The Technology Management Handbook*, Boca Raton, FL: CRC Press & IEEE Press.

Doubleday & Company Inc. (1975) *The World Book Dictionary*, Clarence L. Barnhart Ed., Chicago: Doubleday & Company Inc.

Douglas, M. (1975) Humans Speak, a critical essay in: *Implicit Meanings - Essays in Anthropology,* Routledge & Kegan Paul.

Downes, D. (2005) *Interactive Realism: The Poetics of Cyberspace*, Montreal: McGill-Queens University Press.

Drucker, P. (1999) *Management Challenges for the 21st Century*, Oxford: Elsevier Butterworth-Heinemann.

Duarte, D.L. & Snyder, N.T. (2006) *Mastering Virtual Teams: Strategies, Tools, and Techniques That Succeed*, San Francisco: John Wiley & Sons.

Durlach, N. I. & Mavor, A. S. (1995) *Virtual Reality: Scientific and Technological Challenges*, Washington DC: National Academy Press.

Earley & Associates (2011) Digital Asset management, Stow, MA: Earley & Associates. www.earley.com/consulting-services/digital-asset-management

Edison, T. (1913) as attributed by Gould & Mason, (1985) in: *TAFE Board Telematics Program,* Melbourne: Office of the TAFE Board.

Einstein, A. as attributed by Hawken, P., Lovins. A. & Hunter, L. (1999) *Natural Capitalism: Creating the Next Industrial Revolution*, Boston: Little Brown and Co.

Eisner, H. (2002) *Essentials of Project and Systems Engineering Management, 2nd Ed.,* New York: John Wiley & Sons.

Ettlie, J.E. (2000) *Managing Technological Innovation*, New York: John Wiley & Sons.

Ettlie, J.E. (2006) *Managing Innovation 2nd Ed.* Burlington, MA: Elsevier Butterworth-Heinemann.

Ezzy, D. (2002) *Qualitative Analysis: Practice and Innovation*, Crows Nest, NSW: Allen & Unwin.

Fassbender, E. & Richards, D. (2008) Using a Dance Pad to Navigate through the Virtual Heritage Environment of Macquarie Lighthouse, Sydney, in Wyeld, T.G., Kenderdine, S. & Docherty, M. (Eds.) (2008) *Virtual Systems and Multimedia*, Berlin: Springer-Verlag.

European Commission Ad-hoc Industrial Advisory Group (2010) *Factories of the Future PPP: Strategic Multi-annual Roadmap*, Brussels: European Union.

Fayol, H. (1916) *Administration Industrielle et Generale*, Paris: Dunod.

Fayyad, U., Grinstein, G. & Wierse, A. Eds. (2002) *Information Visualization in Data mining and Knowledge Discovery*, San Francisco, CA: Morgan Kaufmann Publishers.

Flew, T. (2002) *New Media: An Introduction*, South Melbourne: Oxford University Press.

Flew, T. (2005) *New Media: An Introduction 2nd Ed.*, South Melbourne: Oxford University Press.

Flew, T. (2007) *Understanding Global Media*, Basingstoke, Hamps: Palgrave Macmillan.

Flood, R. L. & Jackson, M. (1991) *Creative Problem Solving: Total Systems Intervention*, Chichester: John Wiley & Sons.

Forster, J. & Browne, M. (1996) *Principles of Strategic Management*, Melbourne: Macmillan Education Australia.

Fortune, J. & Peters, G. (2005) *Information Systems: Achieving Success by Avoiding Failure*, Chichester: John Wiley & Sons.

Franke, U..J. (2002) *Managing Virtual Web Organizations in the 21st Century: Issues and Challenges*, Hershey, PA.

Fraser, M. & Dutta, S. (2008) *Throwing Sheep in the Boardroom*, Chichester: John Wiley & Sons.

Fraunhofer IAO (2005) Fraunhofer Institut fur Arbeitswissenschaft und Organization (IAO) www.vr.iao.fhg.de/index.en.php

Friedhoff, R.M. & Peercy, M.S. (2000) *Visual Computing*, New York: Scientific American Library.

Frohlich, B., Julier, S. & Takemura, H., Eds. (2005) *IEEE Virtual Reality 2005 Conference Proceedings*, Danvers, MA: IEEE Inc.

Gardner, H. (2004) *Frames of Mind: The Theory of Multiple Intelligences, 20th Anniversary Ed.*, New York: Basic Books.

Gardner, H. (2006) *Multiple Intelligences: New Horizons*, New York: Basic Books.

Gayeski, D. M. (2005) *Managing Learning and Communication Systems as Business Assets*, Upper Saddle River, NJ: Pearson Education.

Gaynor, G. H. (1996) *Handbook of Technology Management*, New York: McGraw-Hill.

Gibson, R. Ed., (1998) *Rethinking the Future, Revised Ed.,* London: Nicholas Brealey Publishing.

Gibson, W. (1986) *Neuromancer*, West Bloomfield, Mich: Phantasia Press.

Glaser, B. (2001) *The Grounded Theory Perspective: Conceptualization Contrasted with Description*, Mill Valley, CA: Sociology Press.

Glaser, B. & Strauss, A. (1967) *The Discovery of Grounded Theory: Strategies for Qualitative Research*, Chicago: Aldine.

Godau, R. (2001) *Introduction to Systems Thinking and Approaches: Study Guide for Module 1 of EM540 Industrial Systems & Environment,* Department of Mechanical & Manufacturing Engineering, Melbourne: RMIT University.

Goodwin, P. & Wright, G. (1998) *Decision Analysis for Management Judgment, 2nd Ed.,* Chichester: John Wiley & Sons.

Gordon, I. (1996) *Theories of Visual Perception 2nd Ed.*, Chichester: John Wiley & Sons Ltd.

Gosling, J. (2004) *The War of the Worlds Invasion: An Historical Perspective,* www.btinternet.com/~jd.gosling/wotw/radio.htm (19-4-2004)

Gould & Mason, (1985) *TAFE Board Telematics Program*, Melbourne: Office of the TAFE Board.

Goulding, C. (2002) *Grounded Theory: A Practical Guide for Management, Business and Market Researchers,* London: SAGE Publications.

Grau, O. (2003) *Virtual Art: from Illusion to Immersion*, Cambridge, MA: MIT Press.

Graubar, S.R. (1980) Preface to Modern Technology: Problem or Opportunity*?* Daedalus 109(1), as attributed in *Managing Innovation and Entrepreneurship in Technology Based Firms*, Martin, M. J. C. (1994) New York: John Wiley & Sons.

Gutiérrez, M.A., Vexo, F. & Thalmann, D. (2008) *Stepping into Virtual Reality*, London: Springer-Verlag.

Gutting, G. (1984) Paradigms, Revolutions, and Technology, chapter in *The Nature of Technological Knowledge: Are Models of Scientific Change Relevant?* Lauden, R. Ed., (1984) Dordrecht:.D. Reidel Publishing Company.

Hacking, I (1983) *Representing & Intervening: Introductory Topics in the Philosophy of Natural Science*, Cambridge: Cambridge University Press.

Hackett, E.J. Amaterdamska, O. Lynch, M. & Wajcman, J. (2008) *The Handbook of Science and Technology Studies 3rd Ed.*, Cambridge, Mass: MIT Press.

Hagel, J. Brown, J.S. & Davison, L. (2009) *Managing Resources in an Uncertain World*, Harvard Business School, http://blogs.harvardbusiness.org/bigshift/2009/02/the-potential-of-pull.html (02-07-2009)

Haltiner, J. & Surz, R. (2004) Using Virtual Reality to Assess Performance Under Uncertainty: Portfolio Management, in *Journal of Investing: Winter, v13 i4*, p. 37, Euromoney Institutional Investor PLC.

Hamel, G. (2000) *Leading the Revolution*, Boston Mass: Harvard Business School Press.

Hammer, M. (1993) *Re-engineering the Corporation: A Manifesto for Business Revolution*, London: Nicholas Brealey.

Handzic, M. (2004) *Knowledge Management: Through the Technology Glass*, Singapore: World Scientific Publishing Co.

Hanrahan, P. (2000) Illuminating a Revolution, in Friedhoff, R.M. & Peercy, M.S. (2000) *Visual Computing*, New York: Scientific American Library, p.xiii.

Hansen, M. (2004) *New Philosophy for New Media,* Cambridge Mass: MIT Press.

Hanson, D. Dowling, P. J. Hitt, M. A. Ireland, R. D. & Hoskisson, R. E. (2008) *Strategic Management: Competitiveness and Globalisation, Asia Pacific 3rd Ed.,* Melbourne: Cengage Learning Australia.

Hargadon, A. B. (1999) Diffusion of Innovations, in *The Technology Management Handbook* edited by Richard C. Dorf, Boca Raton, FL: CRC Press and IEEE Press.

Härtel, C.J. & Fujimoto, Y. (2010) *Human Resource Management 2nd Ed.,* Frenchs Forest, NSW: Pearson Australia.

Hawken, P. Lovins, A.B. & Lovins, L.H. (1999) *Natural Capitalism: Creating the Next Industrial Revolution*, Boston: Little Brown and Co.

Hedden, H. (2010) *The Accidental Taxonomist*, Medford, NJ: Information Today Inc.

Heim, M. (1993) *The Metaphysics of Virtual Reality*, New York: Oxford University Press.

Heim, M. (1998) *Virtual Realism*, New York: Oxford University Press.

Henczel, Susan (2001) *The Information Audit: A Practical Guide*, Munchen: K.G.Saur Verlag GmbH.

Hill, C. W. L. & Jones, G. R. (2004) *Strategic Management Theory: An Integrated Approach, 6th Ed.,* Boston: Houghton Mifflin Co.

Hinz, B. (1979) *Art in the Third Reich*, Translated from the German by Robert and Rita Kimber, New York: Pantheon Books.

Hitchins, D. (2000) *Basic Models for Systems Thinking,* www.hitchins.co.uk/SysMods.html (29-05-2003)

Hitt, M.A., Ireland, R.D. & Hoskisson, R.E. (2005) *Strategic Management: Competitiveness and Globalization, 6th Ed.,* Mason: Thomson South-Western.

Hood, J.C. (2007) Orthodoxy vs. Power: The Defining Traits of Grounded Theory, in Bryant, A. & Charmaz, K. (2007) *The SAGE Handbook of Grounded Theory*, London: SAGE Publications.

Hubbard, G. (2004) *Strategic Management: Thinking, Analysis & Action, 2nd Ed.,* Frenchs Forest, NSW: Pearson Prentice Hall.

Institute of Human & Computer Cognition (2003) *Tactile Situation Awareness System,* University of West Florida, www.coginst.uwf.edu/projects/tsas/description_main.html (05-05-2005)

Ito,M., Davidson, C., Jenkins, H., Lee, C., Eisenberg, M., & Weiss, J. (2008) Foreword, in Salen, K. (Ed.) (2008) *The Ecology of Games: Connecting Youth, Games, and Learning*, Cambridge, Mass: MIT Press.

Jackson, M. (2003) *Systems Thinking: Creative Holism for Managers*, Chichester: John Wiley & Sons.

Jacobson, L. (1992) *CyberArts: Exploring Art & Technology***,** Miller Freeman Inc.

Jenkins, H. (2006) *Convergence Culture: Where Old and New Media Collide*, New York: New York University Press.

Jenkins, H. (2008) *Convergence Culture: Where Old and New Media Collide, Updated Ed.,* New York: New York University Press.

Jenkins, H. (2009) *Confronting the Challenges of Participatory Culture: Media Education for the 21st Century*, Cambridge, MA: The MIT Press.

Johnson, G. & Scholes, K. (2002) *Exploring Corporate Strategy, 6th Ed.*, Harlow ,UK: Prentice Hall.

Johnson, G. Scholes, K. & Whittington, R (2008) *Exploring Corporate Strategy, 8th Ed.*., Harlow, UK: Prentice Hall.

Johnson, G. Scholes, K. & Whittington, R (2009) *Fundamentals of Strategy,,* Harlow UK: Prentice Hall.

Johnson, G. Whittington, R. & Scholes, K. (2011) *Exploring Strategy, 9th Ed.*, Harlow, UK: Prentice Hall.

Jones, C. & Munro, R. (2005) *Contemporary Organization Theory*, Oxford: Blackwell Publishing.

Jones, C. V. (1996) *Visualization and Optimization*, Norwell, Mass:.Kluwer Academic Publishers.

Jones, S. (2003) *Encyclopedia of New Media*, Thousand Oaks, Ca: Sage Publications.

Kalowsky, R.S. (2000) *Exploiting Virtual Reality Techniques in Education and Training: Technological Issues,* A Report prepared for the Advisory Group on Computer Graphics, Loughborough: Loughborough University of Technology.

Kalawsky, R.S. (2000) *Human Factors Aspects of Virtual Design Environments in Education,* Project Report for JTAP Project 305 for Joint Information Systems Committee of the Higher Education Funding Councils, UK.

Kaplan, D. (Ed.) (2004) *Readings in the Philosophy of Technology,* Maryland: Rowman & LittleField Publishers.

Katz, R. Ed., (2003) *Managing Creativity and Innovation*, Boston: Harvard Business School Press.

Katz, R. Ed., (2004) *The Human Side of Managing Technological Innovation: A Collection of Readings 2nd Ed.*, New York: Oxford University Press.

Katzy, B. R. (2006) Design of Technological Firms, chapter 2 in Verburg, R. M. Ortt, J. R. & Dicke, W. M. (2006) *Managing Technology and Innovation: An Introduction*, Abingdon, Oxon: Routledge.

Kelly, K. (1996) The New Biology of Business, chapter in *Rethinking the Future*, edited by R. Gibson, 1998, London: Nicholas Brealey.

Kenderdine, S. & Hart, T. (2004) *This is not a Peep Show! The Virtual Room at Melbourne Museum (VROOM)*, Melbourne: Melbourne Museum.

Keys, Paul (1991) *Operational Research and Systems: The Systematic nature of Operational Research*, New York: Plenum Press.

Kjeldskov, J. & Stage, J. (2003) Interaction Styles in Development Tools for Virtual Reality Applications, chapter in *Production Methods: Behind the Scenes of Virtual Inhabited 3D Worlds*, 2003, edited by Kim Halskov Madsen, London: Springer-Verlag.

Knights, D. Noble, F. Vurdubakis, T. & Willmott, H. (2002) Allegories of Creative Destruction: Technology and Organization in Narratives of the e-Economy, chapter in Woolgar, S. (2002) *Virtual Society? Technology, Cyberbole, Reality*, Oxford: Oxford University Press.

Kolstrup, S. (2003) The Making of a Pedagogical Tool for Picture Analysis and Picture Construction, chapter in *Production Methods: Behind the Scenes of Virtual Inhabited 3D Worlds*, 2003, edited by Kim Halskov Madsen, London: Springer-Verlag.

Kreps, D. (2008) Virtuality: Time, Space, Consciousness, and a Second Life, in Panteli, N. & Chiasson, M. (2008) *Exploring Virtuality Within and Beyond Organizations*, Basingstoke, Hamps: Palgrave Macmillan.

Kuhn, T. (1962) *The Structure of Scientific Revolutions,* Chicago: University of Chicago Press.

Kuhn, T. (1996) *The Structure of Scientific Revolutions, 3rd Ed.*, Chicago: University of Chicago Press.

Lacy, N. (2009) *Image and Representation: Key Concepts in Media Studies 2nd Ed.*, Basingstoke Hamps: Palgrave Macmillian.

Lauden, R. Ed., (1984) *The Nature of Technological Knowledge: Are Models of Scientific Change Relevant?* Dordrecht: D. Reidel Publishing Company.

Lawrence, J. A. & Pasternack, B. A. (2002) *Applied Management Science, 2nd Ed.*, New York: John Wiley & Sons.

Lawson, G. (2006) *DiFac: Digital Factory for Human-Oriented production System*, VIRART, Human Factors Research Group, University of Nottingham. www.virart.nottingham.ac.uk/projects/DiFac.htm (22-01-2007)

Lee, Y. G. Lyons, K. W. & LeBrun, T. W. (2003) Virtual Environment for Manipulating Microscopic Particles with Optical Tweezers, in the *Journal of Research of the National Institute of Standards and Technology, Vol. 108, Iss. 4*, p.275, National Institute of Standards and Technology, Gaithersburg.

Legge, J. & Hindle, K. (1997) *Entrepreneurship: How Innovators Create the Future*, Melbourne: Macmillan Education Australia.

Lester, P. (2006) *Visual Communication: Images with Messages, 4th Ed.,* Belmont Ca: Thomson Wadsworth.

Levinson, P. (2001) *Digital McLuhan: A Guide to the Information Millennium,* London: Routledge.

Lievrouw, L. & Livingstone, S. (Eds) (2008) *Handbook of New Media*, London: Sage.

Liikanen, E. as attributed in Probert *et al* (2004) *Bringing Technology and Innovation into the Boardroom*, Basingstoke: Palgrave MacMillan.

Linden Lab (2009) *How Corporations Use Virtual Worlds*, http//:secondlifegrid.net/slfe/corporations-use-virtual-worlds (18-02-2009)

Lister, M. Dovey, J. Giddings, S. Grant, I. & Kelly, K. (2003) *New Media: A Critical Introduction*, Abingdon, Oxon, Routledge.

Lister, M. Dovey, J. Giddings, S. Grant, I. & Kelly, K. (2009) *New Media: A Critical Introduction 2nd Ed.*, Abingdon, Oxon, Routledge.

Locke, K. (2001) *Grounded Theory in Management Research*, London: SAGE Publications.

Loeffler, C. E. & Anderson, T. (1994) *The Virtual Reality Casebook*, New York: Van Nostrand Reinhold.

Lofts, N. (2002) *Process Visualization: An Executive Guide to Business Process Design*, Etobicoke,Ontario: John Wiley & Sons Canada.

Lorino, P. (2001) A Pragmatic Analysis of the Role of Management Systems in Organisational learning, in *Knowledge Management and Organisational Competence*, Sanchez (2001) Oxford: Oxford University Press.

Lorino,P. & Tarondeau, J. C. (2002) From Resources to Processes in Competence-based Strategic Management, in *Systems Perspectives on Resources, Capabilities, and Management Processes*, Edited by Morecroft, John., Sanchez, Ron. & Heene, Aime., (2002) Oxford: Elsevior Science Ltd.

Luciani, A. (2002) *TNS Project Abstract,* ICA Laboratory, Institut National Polytechnique de Grenoble, Grenoble. http://usenet.jyxo.cz/cz.comp.grafika/0210/post-doc-vo-francvzsku.html, (5-5-2005)

Maani, K. & Cavana, R. (2000) *Systems Thinking and Modelling: Understanding Change and Complexity*, Aukland: Pearson Education New Zealand.

Mackinlay, J. D. (2000) Opportunities for Information Visualisation, in *IEEE Computer Graphics and Applications,* Jan/Feb 2000, Vol. 20 (1) pp. 22-23, IEEE.

Madsen, K. H. Editor (2003) *Production Methods: Behind the Scenes of Virtual Inhabited 3D Worlds*, London: Springer-Verlag.

Magalhaes, R. (2004) *Organizational Knowledge and Technology*, Cheltenham: Edward Elgar.

Magee, B. (1973) *Popper*, London: Fontana/Collins.

Malhotra, Y. (2000) *Knowledge Management and Virtual Organizations*, London: Idea Group Publishing.

Malhotra, Y. (2001) *Knowledge Management and Business Model Innovation*, Hershey, PA: Idea Group Publishing.

Mallendar, K. (1993) *The Power of Learning*, Burr Ridge, Ill: Irwin.

Malone, T. W. & Crowston, K. (2003) The Interdisciplinary Study of Coordination, chapter in *Organizing Business Knowledge*, Malone, Thomas W., Crowston, Kevin. & Herman, George A. Eds. (2003) Cambridge, Mass: MIT Press.

Nankervis, A., Compton, R., Baird, M. & Coffey, J. (2011) *Human Resource Management: Strategy and Practice 7th Ed.*, South Melbourne: CENGAGE Learning Australia.

Manovich, Lev (2001) *The Language of New Media,* Cambridge, Mass: MIT Press.

Marchese, F. T. (1995) *Understanding Images: Finding Meaning in Digital Imagery*, TELOS.

Marshall, D.P. (2004) *New Media Cultures*, London: Arnold.

Martin, M. J. C., (1984) *Managing Technological Innovation and Entrepreneurship,* Reston, Virg: Reston Publishing Co. Inc.

Martin, M. J. C. (1994) *Managing Innovation and Entrepreneurship in Technology Based Firms*, New York: John Wiley & Sons.

Massie, J. (1979) *Essentials of Management 3rd Ed..*, Englewood Cliffs NJ: Prentice Hall.

Mason, J. (1996) *Qualitative Researching*, London: SAGE Publications.

Mayo, E. (1933) *The Human Problems of Industrial Civilization*, New York: Macmillan.

McCloy, Rory & Stone, Robert (2001) Virtual Reality in Surgery, in the *British Medical Journal: Clinical Review: Science, Medicine and the Future, BMJ Vol. 323 No.7318*, pp. 912-915, London: BMJ Publishing Group. www.bmj.com/cgi/content/full/323/7318/912 (22-01-2007)

McCormick, B H., DeFanti, T A., & Brown, M D. (Eds.) (1987) Visualization in Scientific Computing, *Computer Graphics-Nov. 1987, Vol. 21, No.6,* Association for Computing Machinery SIGGRAPH.

McGrath (2005) Room to Manoeuvre in *Melbourne International Motor Show Official Guide*, Melbourne: Herald-Sun.

McGregor, D. (1960) *The Human Side of Enterprise*, New York: McGraw-Hill.

McLay, A.F. (1998) *Telematic Media, Associated Computing & Communications Technologies in Education*, Melbourne: RMIT University.

McLay, A. (2003) Virtual Reality – Quality Management Integration, in *Proceedings of QUALCON Conference*, Edited by Pilli, A. (2003) Melbourne: Australian Organisation for Quality & RMIT University.

McLuhan, M. (1964) *Understanding Media: The Extensions of Man*, New York: McGraw-Hill.

McLuhan, M. & Fiore, Q. (1967) The Medium is the Message: An Inventory of Effects, as cited in Levinson, P. (2001) *Digital McLuhan: A Guide to the Information Millennium,* London: Routledge.

McLuhan, M, & Fiore, Q. (1968) *War and Peace in the Global Village*, New York: Bantam Books.

McLuhan, M. & McLuhan, E. (1988) Laws of Media: The New Science, University of Toronto Press, Toronto, as cited in Levinson, P. (2001) *Digital McLuhan: A Guide to the Information Millennium,* London: Routledge.

McLuhan, M. (1994) *Understanding Media: The Extensions of Man, MIT Press Ed.*, Cambridge Mass: MIT Press.

McNinch, Frank R. (1938) attributed comments in article: *Radio Listeners in Panic, Taking War Drama as Fact*, New York Times, October 31 1938, front page.

McNurlin, B.C., Sprague, R.H. Jr. & Bui, T. (2009) *Information Systems Management in Practice, 8th Ed.,* Upper Saddle River NJ: Prentice Hall.

McPhail, T. & McPhail, B. (1990) Communication: The Canadian Experience, Coop Clark Pitman, Toronto, as cited in Flew, T. (2002) *New Media: An Introduction*, South Melbourne: Oxford University Press.

McQuillan, F. (2000) *Challenges in the Reality Centre World*, MS-Powerpoint Presentation to Pan Pacific VR Summit at RMIT University, 16th Aug. 2000, Melbourne: Silicon Graphics Inc.

Metz, R. (2010) Cloud Computing Explained, in *Educause Quarterly Magazine, Vo l 33, No 2, 2010,* Boulder, Col: EDUCAUSE.
http://www.educause.edu/EDUCAUSE%2BQuarterly/EDUCAUSEQuarterlyMagazineVolum/CloudComputingExplained/206526 (20-02-2011)

Miller, D. (2000) *Introduction to Collective Behavior and Collective Action,* Waveland Publishing, Inc.

Mintzberg, H. (1983) *Structure in Fives: Designing Effective Organizations*, Englewood Cliffs, NJ: Prentice Hall.

Mirriam-Webster (Gove, P.B. Ed.) (1993) *Webster's Third New International Dictionary*, Springfield Mass: Mirriam-Webster Inc.

Morgan, G. (1997) *Images of Organization, 2nd Ed.*, Thousand Oaks, Ca: Sage Publications.

Morgan, G. (2006) *Images of Organization, Updated Ed.*, Thousand Oaks, Ca: Sage Publications.

Mulder, K. (2006) Managing the Dynamics of Technology in Modern Day Society, chapter 6 in Verburg, R. M. Ortt, J. R. & Dicke, W. M. (2006) *Managing Technology and Innovation: An Introduction*, Abingdon, Oxon: Routledge.

Murphy, A. & Potts, J. (2003) *Culture & Technology*, Basingstoke, Hamps: Palgrave Macmillan.

Nankervis, A. R., Compton, R. L. & Baird, M. (2005) *Human Resource Management: Strategies & Processes 5th Ed.*, Melbourne: Thomson Learning.

Nankervis, A. R., Compton, R. L. & Baird, M. (2008) *Human Resource Management: Strategies & Processes 6th Ed.*, Melbourne: Nelson Australia.

Nankervis, A. R., Compton, R. L., Baird, M. & Coffey, J. (2011) *Human Resource Management: Strategy & Practice 7th Ed.*, Melbourne: Cengage Learning Australia.

Neves, J. N., Goncalves, P., Muchaxo, J. and Silva, J. P. (1999) A Virtual GIS Room: Interfacing Spatial Information in Virtual Environments, chapter 13 in *Spatial Multimedia and Virtual Reality* edited by Antonio S. Camara & Jonathan Raper (1999) London: Taylor & Francis.

Nicholas, J. M (1990) *Managing Business and Engineering Projects*, New Jersey: Prentice Hall.

Nicholls, M.G., Clarke, S. & Lehaney, B. (2001) *Mixed-mode Modelling: Mixing Methodologies for Organizational Intervention*, Dordrecht: Kluwer Academic Publishers.

OECD (1988) *New Technologies in the 1990s: A Socio-economic Strategy,* Paris: OECD.

Ofeisch, G. (1991) *Virtual Reality Report*, Westport CT: Meckler Corporation.

Oliver, D. W., Kelliher, T. P. & Keegan, J. G. (1997) *Engineering Complex Systems: with Models and Objects*, McGraw-Hill.

Orenstein, A. (1998) Epistemology Naturalised – Nature know thyself, Ch. 30 in Warburton, N. (Ed.) (1999) *Philosophy: Basic Readings*, London: Routledge.

Orna, E (1999) *Practical Information Policies, 2nd Ed.*, Aldershot: Gower.

O'Shaughnessy, M & Stadler, J. (2002) *Media and Society: An Introduction, 2nd Ed..,* South Melbourne: Oxford University Press.

Oxford University Press (1976) *The Concise Oxford English Dictionary New Edition,* Oxford: Oxford University Press.

Oxford University Press (2006) *The Concise Oxford English Dictionary 11th Ed.*, Oxford: Oxford University Press.

Oxford University Press (Little, W., Fowler, H.W., Coulson, J. & Onions, C.T. Eds) (1972) *The Shorter Oxford English Dictionary 3rd Ed.,* Oxford: Oxford University Press.

Oxford University Press (Simpson, J.A. & Weiner, E.S.C. Eds) (1989) *Oxford English Dictionary, 2nd Ed.*, Oxford: Oxford University Press.

Oxford University Press (Brown, L. Ed.) (2002) *Shorter Oxford English Dictionary, 5th Ed.*, Oxford: Oxford University Press.

Oxford University Press (Moore, B. Ed .) (2004) *The Australian Concise Oxford English Dictionary 4th Ed.,* South Melbourne: Oxford University Press.

Pagani, M. (2003) *Multimedia and Interactive Digital TV: Managing the Opportunities Created by Digital Convergence*, Hershey, PA: IRM Press.

Panteli, N. & Chiasson, M. (2008) *Exploring Virtuality Within and Beyond Organizations*, Basingstoke, Hamps: Palgrave Macmillan.

Papineau, D. (Ed.) (2004) *Philosophy*, London: Duncan Baird Publishers.

Papargyris, A. & Poulymenakou, A. (2008) Playing Together in Cyberspace: Collective Action and Shared Meaning Constitution in Virtual Worlds, in Panteli, N. & Chiasson, M. (2008) *Exploring Virtuality Within and Beyond Organizations*, Basingstoke, Hamps: Palgrave Macmillan.

Partington, D. (2002) *Essential Skills for Management Research*, London: Sage Publications Ltd.

Pearlson, K.E. & Saunders, C.S. (2010) *Managing and Using Information Systems: A Strategic Approach 4th Ed.*, Hoboken, NJ: John Wiley & Sons.

Peirce, C. (1958) *Collected Papers, 1931-58, Vols 7-8 (Ed. Arthur Burke)* Cambridge Mass: Harvard University Press.

Petenrieder, K. Constantinescu, C. Redaelli, C. Pavlopoulous, C. Decker, F. & Lungu, R. (2007) *New Media for Collaborative Virtual Manufacturing*, DiFac Consortium, European Commission. www.difac.net/Downloads.htm (15-06-2009)

Peters, T. & Austin, N. (1985) *A Passion for Excellence: The Leadership Difference,* London: William Collins Sons & Co.

Peters, T. & Waterman, R. H. (1982) *In Search of Excellence: Lessons from America's Best-run Companies*, Sydney: Harper & Row.

Pidd, M. (1996) *Tools for Thinking: Modeling in Management Science*, Chichester: John Wiley & Sons.

Pimental, K. & Teixeira, K. (1993) *Virtual Reality: Through the New Looking Glass*, New York: McGraw-Hill.

Pimental, K. & Teixeira, K. (1995) *Virtual Reality: Through the New Looking Glass, 2nd Ed.*, New York: Windcrest –McGraw Hill.

Polonsky, M.J. & Waller, D.S. (2005) *Designing and Managing a Research Project: A Business Students Guide*, Thousand Oaks, Ca: SAGE Publications.

Popper, K. R. (1959) *The Logic of Scientific Discovery*, London: Hutchinson & Co.

Popper, K. (1972) *Conjectures and Refutations: the Growth of Scientific Knowledge, 4th Ed.,* Routledge & Keegan Paul.

Popper, K. (1974) The Problem of Demarcation, Ch. 31 in Warburton, N. Ed. (1999) *Philosophy: Basic Readings*, London: Routledge.

Popper, K. R. & Eccles, J. C. (1977) *The Self and its Brain,* London: Springer-Verlag.

Popper, K. R. (1994) *The Myth of the Framework: In Defence of Science and Rationality*, London: Routledge.

Porter, M. (1980) *Competitive Strategy,* New York: The Free Press.

Porter, M. E. (1990) *The Competitive Advantage of Nations,* London: MacMillan Press.

Porter, M. (1996) Creating Tomorrow's Advantages, chapter in *Rethinking the Future*, edited by R. Gibson, 1998, London: Nicholas Brealey.

Porter, M. E. (1998) *The Competitive Advantage of Nations: With a New Introduction*, London: MacMillan Press.

Prahalad, C. K. & Hamel, G. (1990) The Core Competence of the Corporation, in *Harvard Business Review, vol. 68, no. 3, May-June 1990*, pp. 79-91.

Prentice Hall (1992) *Websters New World Encyclopedia, 9th Edition*, New York: Prentice Hall.

Probert, D., Granstrand, O., Nagel, A., Tomlin, B., Herstatt, C., Tschirky, H. & Durand, T. (2004) *Bringing Technology and Innovation into the Boardroom*, Basingstoke: Palgrave MacMillan.

Pugh, D.S. & Hickson, D.J. (2007) *Writers on Organizations, 6th Ed.*, Thousand Oaks, Ca: Sage Publications.

Purple Insight Ltd. (2005) www.purpleinsight.com/home.html , (05-05-2005)

Ragsdale, C. (2007) *Spreadsheet Modeling and Decision Analysis: A Practical Introduction to Management Science, 5th Ed.*, Cincinnati, Ohio: South-Western College Publishing.

Rheingold, H. (1991) *Virtual Reality*, Martin Secker & Warburg Limited.

Rhyne, T. M. (2000) Scientific Visualisation in the Next Millennium, in *IEEE Computer Graphics and Applications, Jan/Feb 2000*, IEEE.

Rizun, P. & Sutherland, G. (2005) Surgical Laser Augmented with Haptic Feedback and Visible Trajectory, chapter in Frohlich, B., Julier, S. & Takemura, H., Eds. (2005) *IEEE Virtual Reality 2005 Conference Proceedings*, Danvers MA: IEEE Inc.

Robbins, S. P. & Barnwell, N. (2006) *Organization Theory: Concepts and Cases, 5th Ed.,* Frenchs Forest, NSW: Pearson Education Australia.

Robbins, S. P., Millett, B., & Waters-Marsh, T. (2004) *Organizational Behaviour, 4th Ed.*, Frenchs Forest, NSW: Pearson Education Australia.

Roberts, P. & and Webber, J. (1999) *Visual Truth in the Digital Age: Towards a Protocol for Image Ethics*, Paper presented at Australian Institute of Computer Ethics Conference, Lilydale.

Robinson, R. (2002) *Web-based Scenario Simulation Modeling: Project Final Report*, Melbourne: Risk & Reliability Associates.

Rogers, E. M. (2003) *Diffusion of Innovations, 5th Ed.*, New York: Free Press.

Rouse (1987) as attributed in Turnball, D. (1991) *Technoscience Worlds,* Geelong: Deakin University.

Rowe, C. (2000) Bechtel Collaboratory Allows Remote Research Teams to Work Together, in *Carillon Vol. 43 May 2000*, College of Engineering & Applied Science, University of Colorado. www.colorado.edu/Carillon/volume43/stories/10bechtel.html. (30-4-2004)

Russell, B. (1912) The Value of Philosophy, taken from Russell, B. (1912) The Problems of Philosophy, Ch. 4 in Warburton, N. (Ed.) (1999) *Philosophy: Basic Readings*, London: Routledge

Saaty, T. L. (2006) *Fundamentals of Decision Making and Priority Theory: With the Analytic Hierarchy Process*, Pittsburgh: RWS Publications.

Saaty, T. L. & Vargas, L. G. (2001) *Models, Methods, Concepts & Applications of the Analytic Hierarchy Process*, Norwell, Mass: Kluwer Academic Publishers Group.

Sacco, M. (2006) DiFac: *Digital Factory for Human-Oriented Production System*, DiFac Consortium, European Commission. www.difac.net/Download/DiFac_report_edited_DTC_31052006.pdf (15-06-2009)

Salen, K. (Ed.) (2008) *The Ecology of Games: Connecting Youth, Games, and Learning*, Cambridge, Mass: MIT Press.

Sanchez, R. Ed., (2001) *Knowledge Management and Organizational Competence*, Oxford: Oxford University Press.

Sandiego Museum (2002) *Toulouse-Lautrec* www.sandiegomuseum.org/lautrec/intro.html and subsequent pages. (13-04-2004)

Satava, R. (2001) *Current Trends In Surgical Simulation Using Virtual Reality*, a Seminar Presentation at RMIT I^3.

Saussure, F. (1974) *Course in General Linguistics*, London: Fontana.

Schoderbek, P. P., Schoderbek, C. G. & Kefalas, A. G. (1990) *Management Systems: Conceptual Considerations, 4th Ed.,* Boston: BPI Irwin.

Scott, C.J. Ly, K. & Biggar, M.J. (1992*) Virtual Reality as a Future Service on B-ISDN,* in *Proceedings of the Australian Broadband Switching and Services Symposium*, Melbourne: Monash University.

Shaw, J. (2003) *Navigable Cinematic Systems: The Reformulation of Cinematic Narrative and the Development of Next Generation Interactive Technology in new Media,* ARC Federation Fellowship Research Outline, iCinema, Sydney: University of New South Wales.

Sherman, B. & Judkins, P. (1993) *Glimpses of Heaven, Visions of Hell: Virtual Reality and its Implications*, London: Hodder and Stoughton Ltd.

Sherman W.R. & Craig A.B. (1995*) Literacy in Virtual Reality: A New Medium*, in ACM SIGGRAPH Computer Graphics Vol.29 Issue 4 (Nov. 1995) pp. 37-42.

Shields, R. (2003) *The Virtual*, London: Routledge.

Schultze, Q. (1988) Evangelical Radio and the Rise of the Electronic Church 1921-1948, *Journal of Broadcasting & Electronic Media*, Vol. 32, Issue 3, 1988, p. 289.

SIAC Corporate Communications (1999) *SIAC is NTSE's Technology Partner; 3-D Project Unveiled*, Securities Industry Automation Corporation, www.siac.com/in_the_news/3d_project.html(21-04-2004)

Sibley, B. (2002) *The Lord of the Rings: The Making of the Movie Trilogy,* London: Harper Collins Publishers.

Silicon Graphics Inc. (2004) *SGI Visualization Technology Drives Statoil's New Onshore Support Center*, Silicon Graphics Inc., www.sgi.com/company_info/newsroom/press_releases/2004/march/statoil.html (30-11-2007)

Silverthorne, Sean (2006) *Developing a Strategy for Digital Convergence*, Harvard Business School: Working Knowledge, (on-line journal) Boston: Harvard University. http://hbswk.hbs.edu/item/5445.html (22-01-2007)

Slouka, M. (1995) *War of the Worlds: Cyberspace and the High-Tech Assault on Reality*, London: Abacus.

Sobel Lojeski, K. & Reilly, R.R. (2008) *Uniting the Virtual Workforce: Transforming Leadership and Innovation in the Globally Integrated Enterprise*, Hoboken, NJ: John Wiley & Sons.

Sosik, J. J., Jung, D. I., Berson, Y., Dionne, S. D. & Jaussi, K. S. (2004) *The Dream Weavers: Strategy-Focused Leadership in Technology-Driven Organisations*, Greenwich Conn: Information Age Publishing.

Squire, K.D. (2008) Video Game Literacy: A Literacy of Expertise, chapter in Coiro, J. (Ed.) (2008) *Handbook of Research on New Literacies*, New York: Lawrence Earlbaum Associates/Taylor & Francis Group.

Stair, R. & Reynolds, G. (2006) *Principles of Information Systems: A Managerial Approach 7th Ed.,* Boston, MA: Thomson.

Steinweis A. E. (1993) *Art, Ideology, & Economics in Nazi Germany: The Reich Chambers of Music, Theater, and the Visual Arts*, Chapel Hill: University of North Carolina Press.

Stone, A. R. (1992) Will the Real Body Please Stand Up, chapter in *Cyberspace: First Steps*, Benedikt M. (1992) Cambridge, Mass: MIT.

Stone, R. & Connell, A. (1993) Real Applications – Virtual markets (Selling the Vision of Virtual Reality), in *Virtual Reality in Engineering*, Edited by Warwick, Kevin. Gray, John. & Roberts, David. (1993) London: The Institution of Electrical Engineers.

Strauss, A. & Corbin, J. (1990) *Basics of Qualitative Research: Grounded Theory Procedures and Techniques*, London: Sage.

Sui, D. & Goodchild, M. (2003) A Tetradic Analysis of GIS and Society Using McLuhans Law of the Media, in *The Canadian Geographer*, Vol.47, No.1. pp.5-17.

Sutherland, I.E. (1965) The Ultimate Display, in *Proceedings of IFIP Congress 1965*, pp.506-508.

Swann, G. & Watts, T. (2002) Visualization Needs Vision: The Pre-Paradigmatic Character of Virtual Reality, chapter in Woolgar, S. (2002) *Virtual Society? Technology, Cyberbole, Reality*, Oxford: Oxford University Press.

Taverna, M. A. (2004) Case Study in Virtual Reality, in *Aviation Week & Space Technology 5/10/2004, Vol.160 Issue 19*, p. 52., The McGraw-Hill Companies Inc.

Taylor, F.W. (1911) *The principles of Scientific Management*, New York: Harper & Row.

Thamhain, H. J. (1992) *Engineering Management: Managing Effectively in Technology-Based Organizations*, New York: John Wiley & Sons.

Thamhain, H.J. (2005) *Management of Technology: Managing Effectively in Technology-Intensive Organizations*, Hoboken, NJ: John Wiley & Sons.

Theall, D.F. (1971) *The Medium is the Rear View Mirror: Understanding McLuhan,* Montreal: McGill-Queen's University Press.

Thierauf, R. J. (1995) *Virtual Reality Systems for Business,* Westport, Conn: Quorum Books.

Thilmany, J. (2003) A Touching Sensation, in *Mechanical Engineering Nov.2003, Vol.125, Issue 11*, New York: American Society of Mechanical Engineers.

Thomas, N. J.T. (2003) *Imagination, Mental Imagery, Consciousness, and Cognition*, Los Angeles: California State University. www.calstatela.edu/faculty/nthomas/index.htm (30-03-2006)

Tidd, J., Bessant, J. & Pavitt, K. (2001) *Managing Innovation, 2nd Ed..,* Chichester: John Wiley & Sons.

Tidd, J., Bessant, J. & Pavitt, K. (2005) *Managing Innovation, 3rd Ed..,* Chichester: John Wiley & Sons.

Tidd, J. & Bessant, J. (2009) *Managing Innovation: Integrating Technological, Market and Organizational Change 4th Ed..,* Chichester: John Wiley & Sons.

Tiffin, J. & Rajasingham, L. (1995*) In Search of the Virtual Class: Education in an Information Society*, Routledge.

Toffler, A. (1985) *The Adaptive Corporation*, London: McGraw-Hill Book Company.

Tosi, H. L. (1990) *Organizational Behaviour and Management: A Contingency Approach*, Boston: PWS-KENT Publishing Co.

Tosi, H. L. (2009) *Theories of Organization*, Thousand Oaks,Ca: SAGE Publications.

Trist, E. & Murray, H. (1990) *The Social Engagement of Social Science: A Tavistock Anthology,* Philadelphia: The University of Pennsylvania Press.

Tsai, H. L. (2003) *Information Technology and Business Process Reengineering: New Perspectives and Strategies*, Westport, CT: Praeger.

Tschirky, H. (2004) Bringing Technology to the Boardroom: What Does it Mean? Chapter in Probert, David *et al* (2004) *Bringing Technology & Innovation into the Boardroom*, Basingstoke: Palgrave Macmillan.

Turban, E., McLean, E. & Wetherbe, J. (2002) *Information Technology for Management: Transforming Business in the Digital Economy, 3rd Ed.,* New York: John Wiley & Sons.

Turban, E., Leidner, D., McLean, E. & Wetherbe, J. (2008) *Information Technology for Management: Transforming Organizations in the Digital Economy, 6th Ed..,* New York: John Wiley & Sons.

Turban, E. & Volonino, L. (2011) *Information Technology for Management: Improving Strategic and Operational Performance 8th Ed.,* Hoboken, NJ: John Wiley & Sons.

Turnball, D. (1991) *Technoscience Worlds,* Geelong: Deakin University.

Tushman, M.L. & Anderson, P. (2004) *Managing Strategic Innovation and Change, 2nd Ed.*, New York: Oxford University Press.

Ulhoi, J. P. & Gattiker, U. E. (1999) The Nature of Technological Paradigms: A Conceptual Framework, in *The Technology Management Handbook* Edited by Richard C. Dorf, Boca Raton, FL: CRC Press & IEEE Press.

Urwick, L. (1952) Management's Debt to Engineers, in Advanced Management, December 1952, p.7, as cited in Babcock,D. L. and Morse, L. C. (2002) *Managing Engineering and Technology 3rd Ed..*, Upper Saddle River, NJ: Prentice Hall.

Verburg, R. M. Ortt, J. R. & Dicke, W. M. (2006) *Managing Technology and Innovation: An Introduction*, Abingdon, Oxon: Routledge.

Vince, J. (2004) *Introduction to Virtual Reality*, London: Springer Verlag.

Virtalis (2005) Homepage: virtual reality and simulation consultancy. www.virtalis.com (24-04-2005)

VREfresh (2005) *VREfresh Virtual Reality Industry Newsletter*, Cyber-Wizard Ltd. www.vrefresh.com (25-04-2005)

Waggener, S. (2010) Cloud Computing, in *Educause Quarterly Magazine, Vol 33, No 2, 2010*, Boulder, Col: EDUCAUSE. http://www.educause.edu/EDUCAUSE%2BQuarterly/EDUCAUSEQuarterlyMagazineVolum/CloudComputing/206553 (20-02-2011)

Warburton, N. (Ed.) (1999) *Philosophy: Basic Readings*, London: Routledge.

Ward, J. & Peppard, J. (2002) *Strategic Planning for Information Systems*, Chichester: John Wiley & Sons.

Ware, C. (2004) *Information Visualization: Perception for Design, 2nd Ed.*, San Francisco: Morgan Kaufmann Publishers.

Weber, L. (2011) *Everywhere,* Hoboken, NJ: John Wiley & Sons.

Weber, M. (1947) *The Theory of Social and Economic Organizations*, ed. Parsons, T., trans. Henderson, A.M. & Parsons, T., New York: Free Press.

Wells, H.G. (1898) *War of the Worlds*, UK: William Heinemann.

White, A. & Bessant, J. (2007) Managerial Responses to Cognitive Dissonance: Causes of the Mismanagement of Discontinuous Technological Innovations, in Hashem Sherif, M & Khalil, T. (Eds.) (2007) *Management of Technology: New Directions in Technology Management*, Kidlington Oxon: Elsevior.

White, G. R. (1978) Management Criteria for Effective Innovation, in *Technology Review 80*, Feb. 1978.

Williams, B. & Magee, B. (1999) Descartes, Chapter 27 in Warburton, N. (Ed.) (1999) *Philosophy: Basic Readings*, London: Routledge.

Williams, T. (1998) *Otherworld*, London: Little Brown and Company.

Winner, L. (2004) The Culture of Technology, in Kaplan, D. (Ed.) (2004) *Readings in the Philosophy of Technology,* Maryland: Rowman & LittleField Publishers.

Woolgar, S. (2002) *Virtual Society? Technology, Cyberbole, Reality*, Oxford: Oxford University Press.

Worchel, S., Cooper, J. & Goethals, G. R. (1991) *Understanding Social Psychology,* Pacific Grove: Brooks/Cole Publishing Company.

Wouters, P. Vann, K. Scharnhorst, A. Ratto, M. Hellsten, I. Fry, J. & Beaulieu, A. (2008) Messy Shapes of Knowledge: STS Explores Informatization, New Media and Academic Work, in Hackett, E.J. Amaterdamska, O. Lynch, M. & Wajcman, J. (2008) *The Handbook of Science and Technology Studies 3rd Ed.*, Cambridge, Mass: MIT Press.

Wren, D. A. (1994) *The Evolution of Management Thought, 4th Ed..,* New York: Wiley.

Wyeld, T.G. Kenderdine, S. & Docherty, M. (Eds) (2008) *Virtual Systems and Multimedia*, Berlin: Springer-Verlag.

Yoffie, David (1997) *Competing in the Age of Digital Convergence*, Boston: Harvard Business School Press.

Zegveld, M. A. (2006) Corporate Strategy and Technology, chapter 11 in Verburg, R. M. Ortt, J. R. & Dicke, W. M. (2006) *Managing Technology and Innovation: An Introduction*, Abingdon, Oxon: Routledge.

Internet & World Wide Web Resources

Dates noted represent the last time site was checked.

www.acmc.uq.edu.au/aboutACMC.htm (28-04-2005)
University of Queensland, Advanced Computational Modelling Centre

www.agocg.ac.uk/reports/virtual/vrtech/title.htm (29-08-2000)
Report by Prof R.S. Kalowsky

www.avrrc.lboro.ac.uk/ (21-04-2004)
Virtual Reality Centre, Loughborough University.

www.barco.com (20-11-2007)
Barco Simulation Products, a division of BARCO.

www.bmj.com/cgi/content/full/323/7318/912 (22-01-2007)
British Medical Journal: Clinical Review: Science, Medicine and the Future

www.btinternet.com/~jd.gosling/wotw/radio.htm (19-04-2004)
John Gosling, analysis of H.G. Wells: War of the Worlds.

www.cam.ac.uk, (22-04-2004)
University of Cambridge.

www.coginst.uwf.edu, (05-05-2005)
Institute of Human & Computer Cognition, University of West Florida,

www.colorado.edu/Carillon/volume43/stories/10bechtel.html (30-04-2004)
University of Colorado. Carillon Vol. 43. May 2000.

www.concordia.ca, (05-05-2005)
Concordia University, Montreal

www.crg.computer-science.nottingham.ac.uk/ (21-04-2004)
Computer Science, Nottingham University.

www.csiro.au (28-04-2005)
Commonwealth Scientific and Industrial Research Organisation (CSIRO)

www.cs.rochester.edu/research/brain/vrlab/vrlab.shtml (21-04-2004)
Virtual Reality Laboratory, University of Rochester

www.cs.ucl.ac.uk/ (21-04-2004)
Computer Science, University College London.

www.cs.umd.edu/users/north/infoviz.html, (05-05-2005)
University of Maryland at College Park

www.cvrlab.org (21-04-2004)
Cultural VR Lab at University of California, Los Angeles.

www.cvr.uci.edu (21-04-2004)
Virtual Reality Laboratory, University of California, Irvine

www.difac.net (15-06-2009)
DiFac Consortium, European Commission

www.dsto.defence.gov.au (19-04-2004)

Defence Science & Technology Organisation, Department of Defence (Australia)

www.dsto.defence.gov.au/corporate/publicity/ads/v10n2/page 7.html (18-07-2002)

Defence Science & Technology Organisation, Australian Defence Science Vol 10 No 2

www.dmso.mil/public/ (18-07-2002)

Defense Modeling & Simulation Office, United States Department of Defense.

www.earley.com/consulting-services/digital-asset-management (29-03-2011)

Earley & Associates (2011) Digital Asset management, Stow, MA: Earley & Associates.

www.educause.com (20-02-2011)

Educause Quarterly Magazine, EDUCAUSE, Boulder, Colarado.

www.evl.uic.edu/intro.php3 (21-04-2004)

Electronic Visualisation Laboratory, University of Illinois

www.hitchins.co.uk/SysMods.html (29-05-2003)

Professor Derek K. Hitchins

www.icinema.unsw.edu.au/ic_research.html (22-04-2004)

www.icinema.unsw.edu.au/projects/infra_dome.html (25-10-2007)

www.icinema.unsw.edu.au/projects/prj_convostudio_1.html (25-10-2007)

www.icinema.unsw.edu.au/projects/prj_mining.html (25-10-2007)

iCinema at University of New South Wales.

www.ihmc.us, (05-05-2005)

Institute for Human and Machine Cognition

www.iii.rmit.edu.au (24-04-2004)

RMIT University Interactive Information Institute (I^3)

www.ims.org/sites/default/files/EU%20IMS%20Newsletter%2022.pdf (14-06-2009)

European Intelligent Manufacturing Systems (IMS) Secretariat, European Commission

www.itea.org, (05-05-2005)

International Test and Evaluation Association

www.kcmetro.cc.mo.us/longview/ctac/blooms.htm, (05-05-2005)

Longview Community College.

www.panoramtech.com/products.html (03-01-2008)

Panoram Technologies Inc.

www.purpleinsight.com/home.html, (05-05-2005)

Purple Insight Ltd.

www.qmisolutions.com.au/article.asp?aid=61&sid=0&pfid=5 (21-04-2004)

Queensland Manufacturing Institute

www.salford.ac.uk 30-04-2004)

University of Salford.

www.http://www.samsung.com/au/consumer/pc-peripherals/monitor/lcd-monitor/LS23MURHB/XP/index.idx?pagetype=prd_detail&pid=au_monitortype_keyvisual1_md230x6_20100701 (29-5-2011)

Samsung Electronics

www.sandiegomuseum.org/lautrec/intro.html (30-04-2004)

Sandiego Museum

www.siaa.asn.au (07-01-2004) Simulation Industry Association of Australia

www.siaa.asn.au/simtect/2003/simprog.html (07-01-2004)

Dr Michael Armitage Presentation to SimTecT 2003

www.siac.com/in_the_news/3d_project.html (21-04-2004)

Securities Industry Automation Corporation

www.sgi.com (24-04-2004)

Silicon Graphics: (multiple pages)

www.sgi.com/realitycenter/display_configs.html (24-04-2004)

Silicon Graphics: Reality Center details

www.sgi.com/realitycenter/ (24-04-2004)

Silicon Graphics: Virtual Reality Centre Technical Details

www.sgi.com/industries/manufacturing/aerospace/index.html (12-12-2002)

Silicon Graphics: Aerospace Industry Technologies

www.sgi.com/company_info/investors/annual_report/012/media.html, (05-05-2005)

Silicon Graphics: 2001 Annual Report

www.sgi.com/company_info/newsroom/press_releases/2004/march/statoil.html (30-11-2007)

Silicon Graphics: Statoil Onshore Support Centre

www.sgi.com/pdfs/3404.pdf (22-04-2004)

Silicon Graphics: Creating a New Air Defence System

www.sgi.com/features/2003/apr/onyx350/ (19-04-2004)

Silicon Graphics: Large Data Visualisation for Everyone.

www.sgi.com/services/professional/success/univ_colo.html (21-04-2004)

Silicon Graphics: Facility at University of Colorado.

www.sgi.com/newsroom/press_releases/2002/september/ford.html (20-04-2004)

Silicon Graphics: Ford Selects SGI Reality Center.

www.sgi.com/features/2003/jul/onyx4/ (20-04-2004)

Silicon Graphics: Harnessing the Data Tsunami through the Power of Visualisation.

www.tinmith.net/wearable.htm (28-04-2005)

Wearable Computer Lab, University of South Australia.

www.transparencynow.com/virtual.htm (24-04-2004)

Ken Sanes website.

www.vetl.uh.edu/index.html (21-04-2004)

Visual Computing Laboratory, University of Houston.

www.virart.nottingham.ac.uk/projects/DiFac.htm (22-01-2007)

VIRART, Human Factors Research Group, University of Nottingham.

www.virtalis.com (24-04-2005)

Virtalis Homepage: virtual reality and simulation consultancy.

www.vislab.usyd.edu.au/ (28-04-2005)

University of Sydney, Visualisation and High-Performance Computing Lab.

www.vrac.iastate.edu/ (21-04-2004)

Virtual Reality Applications Center, Iowa State University.

www.vrefresh.com (25-04-2005)

VREfresh virtual reality industry newsletter published by Cyber-Wizard Ltd.

www.vr.iao.fhg.de/index.en.php (25-04-2005)

Fraunhofer Institut fur Arbeitswissenschaft und Organization (IAO)

www.vrlab.buffalo.edu/index.html (21-04-2004)

Virtual Realty Laboratory, University at Buffalo.

www.vrl.umich.edu (21-04-2004)

Virtual Reality Laboratory University of Michigan.

www.vroom.org.au (21-04-2004)

Virtual Reality Room at Museum Victoria.

http://vr.swin.edu.au/index.html (22-04-2004)

Swinburne University, Centre for Astrophysics & Supercomputing.

www.vr.tees.ac.uk (30-04-2004)

VR Laboratory Teeside University.

www.vuzix.com/iwear/products_ip230.html (12-12-2007)

Vuzix Corporation, iwear products.

http://hbswk.hbs.edu/item/5445.html (22-01-2007)

Harvard Business School: Working Knowledge, (on-line journal) Harvard University.

http://hwr.nici.kun.nl/~miami/taxonomy/taxonomy.html, (05-05-2005)

A report of the ESPRIT Project 8579 WP1.

http://members.aol.com/jeff1070/wotw.html (28-01-2007)

Documentary web site addressing: Radio's War of the Worlds, 1938.

http://projects.edtech.sandi.net/staffdev/tpss98/patterns-taxonomy.html, (05-05-2005)

Sandiego City Schools Department of Educational Technology.

http://secondlifegrid.net/slfe/corporations-use-virtual-worlds, (18-02-2009)

Linden Lab Second Life Grid web site.

http://usenet.jyxo.cz/cz.comp.grafika/0210/post-doc-vo-francvzsku.html, (05-05-2005)

Reference site to research at: Institut National Polytechnique de Grenoble.

http://users.ece.gatech.edu:80/~linda/revengr/taxonomy2.html, (05-05-2005)

IEEE Computer Society Technical Council of Software Engineering, Taxonomy Project.

http://wedge.anu.edu.au (19-04-2004)

The WEDGE Virtual Reality Theatre, Australian National University, Canberra.

Background Bibliography

Listing of materials used to inform the research but not directly referenced within the main body of the thesis.

Albright, S.C., Winston, W.L. & Zappe, C. (2004) *Data Analysis for Managers: with Microsoft Excel 2nd Ed*., Belmont, CA: Thomson Learning.

Anders, P. (1999) *Envisioning Cyberspace: Designing 3D Electronic Spaces,* New York: McGraw-Hill.

Bederson, B. & Shneiderman, B. (2003) *The Craft of Information Visualization: Readings and Reflections*, San Francisco, CA: Morgan Kaufmann Publishers.

Bell, D. and Kennedy, B. M. Editors. (2000) *The Cybercultures Reader,* London: .Routledge.

Blanchard, B.S. (2004) *System Engineering Management, 3rd Ed*.., Hoboken, New Jersey: John Wiley & Sons.

Boar, B. (2001) *The Art of Strategic Planning for Information Technology, 2nd Ed..,* New York: John Wiley & Sons.

Boy, G. (1998) *Cognitive Function Analysis*, London: Ablex Publishing Corp.

Brown, S., Lamming, R., Bessant, J. & Jones, P. (2000) *Strategic Operations Management*, Oxford: Butterworth Heinemann.

Burke, R. J. & Cooper, C. L. Edts. (2004) *Leading in Turbulent Times: Managing in the new World of Work*, Oxford: Blackwell Publishing.

Capra, F. (1982) *The Turning Point: Science, Society and the Rising Culture,* London: Flamingo/ HarperCollins.

Cotton, B. & Oliver, R. (1993) *Understanding Hypermedia from Multimedia to Virtual Reality*, Phaidon Press Ltd.

Coyne, R. (1995) *Designing Information Technology in the Postmodern Age: From Method to Metaphor,* Cambridge, Mass: The MIT Press,

Crotty, M. (1998) *The Foundations of Social Research: Meaning and Perspective in the Research Process,* Crows Nest, NSW: Allen & Unwin.

Davison, R. B. (1991) *Multiple Attribute Evaluation: The Development and Application of a General Model*, Graduate School of Management, Macquarie University.

Defence Science and Technology Organisation (2002) Department of Defence (Australia) www.dsto.defence.gov.au (19-4-2004)

Defence Science and Technology Organisation (2002) *Forem Express – R&D in 'Super-smart' Information Management Systems*, Australian Defence Science Vol. 10 Number 2, 2002, Department of Defence (Australia) www.dsto.defence.gov.au/corporate/publicity/ads/v10n2/page7.html (18-07-2002)

Eco, U., Gould, S. J., Carriere, J. C. & Delumeau, J. (1999) *Conversations about the End of Time*, London.: Allen Lane-The Penguin Press,

Eisner, H. (1997) *Essentials of Project and Systems Engineering Management*, New York: John Wiley & Sons.

Ellson, T. (2004) *Culture and Positioning as Determinants of Strategy*, Basingstoke: Palgrave MacMillan.

Fairchild, A. (2004) *Technological Aspects of Virtual Organizations: Enabling the Intelligent Enterprise*, Dordrecht: Kluwer Academic Publishers.

Floyd, S.W., Roos, J., Jacobs, C.D. & Kellermanns, F.W., Eds. (2005) *Innovating Strategy Process*, Malden, MA: Blackwell Publishing.

Fong, M.W.L. (2005) *e-Collaborations and Virtual Organizations*, Hershey, PA: IRM Press.

Geels, F. (2002) *Understanding the Dynamics of Technological Transitions: A Co-evolutionary and Socio-technical Analysis*, Enschede: Twente University Press.

Gibbs, S. J. & Tsichritzis, D. C. (1994) *Multimedia Programming: Objects, Environments and Frameworks*, Addison-Wesley Publishing Company.

Gill, J. & Johnson, P. (2002) *Research Methods for Managers, 3rd Ed..,* London: SAGE Publications.

Glaser, B. Ed., (1995) *Grounded Theory 1984-1994*, Mill Valley, CA: Sociology Press.

Goos, G. Hartmanis, J. & van Leeuwen, J. (1995) *Computer Vision, Virtual Reality and Robotics in Medicine*, First International Conference, CVRMed '95, Heidelberg: Springer-Verlag Berlin.

Green, L. & Guinery, R. (1994) *Framing Technology Society, Choice & Change*, Allen & Unwin Pty Ltd.

Grenier, R. & Metes, G. (1995) *Going Virtual: moving your organization into the 21st century,* Upper Saddle River, NJ: Prentice Hall.

Gump, D. (1993) *Virtual Reality Handbook: Products, Services & Resources*, Pasha Publications Inc.

Hargadon, A. (2003) *How Breakthroughs Happen: The Surprising Truth About How Companies Innovate*, Boston: Harvard Business School Press.

Hayward, P. & Wollen, T. (1993) *Future Visions: New Technologies of the Screen*, British Film Institute.

Heidegger, M. (Translated by Michael Heim) (1984) *The Metaphysical Foundations of Logic*, Bloomington: Indiana University Press.

Hill, C. W. L. (2003) *International Business: Competing in the Global Marketplace, 4th Ed.*, Boston: Irwin McGraw-Hill.

Hodson, R. & Sullivan, T. A. (2002) *The Social Organization of Work, 3rd Ed.*, Belmont, CA: Wadsworth-Thomson Learning.

Hoefling, T. (2001) *Working Virtually: Managing People for Successful Virtual Teams and Organisations*, Sterling Virginia: Stylus Publishing.

Holtzman, S. R. (1994*) Digital Mantras: The Languages of Abstract and Virtual Worlds*, Cambridge, Mass: MIT Press.

Howarth, C., Gillin, M. & Bailey, J. (1995) *Strategic Alliances*, Melbourne: Pitman Publishing.

Huber, J. (2004) *New Technologies and Environmental Innovation*, Northampton, MA:.Edward Elgar Pub. Inc.

Jarvis, P. (1999) *The Practitioner Researcher: Developing Theory from Practice*, San Francisco: Jossey-Bass Inc.

Ketchen, D.J. & Bergh, D.D., Eds. (2005) *Research Methodology in Strategy and Management, Vol. 2*., Oxford: Elsevier.

Lipsey, M. W. & Wilson, D. B. (2001) *Practical Meta-Analysis*, Thousand Oaks, Ca: Sage Publications.

Lopuck, L. (1996) *Designing Multimedia: A Visual Guide to Multimedia and Online Graphic Design*, Peachpit Press.

Luttwak, E. N. (2001*) Strategy: The Logic of War and Peace*, Cambridge, Mass:.The Belknap Press.

Magee, B. (1973) *Popper*, London: Fontana/Collins.

McErlean, J. (2000) *Philosophies of Science: From Foundations to Contemporary Issues*, Belmont, Ca:.Wadsworth/Thomson Learning.

McLaughlin, M. L., Hespanha, J. P. & Sukhatme, G. S. (2002) *Touch in Virtual Environments: Haptics and the Design of Interactive Systems*, Upper Saddle River, NJ: Pentice Hall PTR.

McLay, A. & Davison, R (1995) A Systems Approach to Teaching & Learning Models in Graduate Engineering Education, in *Proceedings of the 7th Annual Convention & Conference: Australian Association for Engineering Education, 1995,* Edited by Aldeen, M. &. Pudlowski, Z. (1995) USICEE, Melbourne: Monash University.

McLay, A. (2002) Applying Visualisation Technologies and Strategies for Effective Knowledge Management and Decision Analysis in Engineering and Technology-based Enterprises, in *Proceedings of 3rd International Conference on Quality and Reliability, 2002*, Edited by Subic, A.J., Tsang, H.C., Tang, C.Y., & Netherwood, G. (2002) Melbourne: RMIT University.

Mintzberg, H. (1989) *Mintzberg on Management: Inside our Strange World of Organizations*, London: Collier Macmillan.

Mintzberg, H. (2003) *The Strategy Process: Concepts, Contexts, Cases 4th Ed.*., Harlow: Pearson Education.

Morecroft, J., Sanchez, R., & Heene, A. Editors (2002) *Systems Perspectives on Resources, Capabilities, and Management Processes*, Oxford: Elsevior Science Ltd.

Mukerji, D. (2000) *Managing Information: New Challenges & Perspectives*, Frenchs Forest, NSW: Pearson Education Australia.

Nonaka, I. & Nishiguchi, T. (Eds) (2001) *Knowledge Emergence: Social, Technical, and Evolutionary Dimensions of Knowledge Creation*, New York: Oxford University Press.

Orvell, M. (1995) *After The Machine: Visual Arts and the Erasing of Cultural Boundaries*, University Press of Mississippi.

Porter, M. E. (2004) *Competitive Advantage: Creating & Sustaining Superior Performance, Free Press Export Ed*., New York: Free Press.

Richards, L. (2005) *Handling Qualitative Data: A Practical Guide*, London: SAGE Publications.

Schiffman, H. R. (2001) *Sensation and Perception: An Integrated Approach*, *5th Ed..,* New York: John Wiley & Sons.

Silicon Graphics Inc, (2002) *Ford Selects SGI Reality Center Technology for Visualisation and Design Optimisation*, Silicon Graphics Inc, www.sgi.com/newsroom/press_releases/2002/september/ford.html (20-04-2004)

Silicon Graphics Inc, (2002) *2001 Annual Report: Visualising Success: Media*, Silicon Graphics Inc, www.sgi.com/company_info/investors/annual_report/012/media.html (19-04-2004)

Silicon Graphics Inc, (2002) *Creating a New Air Defense System for the 21st*, Silicon Graphics Inc, www.sgi.com/pdfs/3404.pdf (22-04-2004)

Silicon Graphics Inc, (2002) *Solutions for the Aerospace industry*, Silicon Graphics Inc, www.sgi.com/industries/manufacturing/aerospace/index.html (19-4-2004)

Silicon Graphics Inc, (2003) *SGI Professional Services Helps Crystallize a Visionary Facility at the University of Colorado*, Silicon Graphics Inc, www.sgi.com/features/2003/jul/onyx4/ (20-04-2004)

Silicon Graphics Inc, (2003) *Harnessing the Data Tsunami through the Power of Visualisation*, Silicon Graphics Inc, www.sgi.com/features/2003/jul/onyx4/ (20-04-2004)

Silicon Graphics Inc, (2004) *SGI Reality Center: Display Configurations*, Silicon Graphics Inc, www.sgi.com/realitycenter/display_configs.html (19-04-2004)

Stanney, K. M., Hale, K. S., Nahmens, I. and Kennedy, R. S., (2003) What to Expect from Immersive Virtual Environment Exposure: Influences of Gender, Body Mass Index, and Past Experience, in *Human Factors, Fall 2003. Vol. 45, Issue 3*, Santa Monica: Human Factors and Ergonomics Society.

Steinmetz, R. & Nahrstedt, K. (1995*) Multimedia: Computing, Communications & Applications,* Prentice Hall PTR.

Stone, A. R. (1995) *The War of Desire and Technology at the Close of the Mechanical Age*, Cambridge, Mass: The MIT Press.

Stuart, R. (1996) *The Design of Virtual Environments*, McGraw-Hill USA.

Sundbo, J., Gallina, A., Serin, G. & Davis, J., Eds. (2006) *Contemporary Management of Innovation: Are We Asking the Right Questions?* Basingstoke, Hamps: Palgrave Macmillan.

Sun Tzu (translated by Samuel B. Griffith) (1971) *The Art of War*, Oxford: Oxford University Press.

Thagard, P. (1988) *Computational Philosophy of Science*, Cambridge, Mass:.MIT Press.

Thilmany, J. (2004) Flowing into the Future, in *Mechanical Engineering Feb 2004, Vol.126, Issue 2*, New York: American Society of Mechanical Engineers.

Tiffin, J. & Terashima, N. Editors (2001) *HyperReality: Paradigm for the Third Millenium*, London: Routledge.

Toffler, A. (1970) *Future Shock*, London: Bodley Head.

Tofts, D., Jonson, A. & Cavallaro, A., Eds. (2002) *Prefiguring Cyberculture: An Intellectual History*, Cambridge, MA:.MIT Press.

Tsoukas, H. & Mylonopoulos, N. Eds., (2004) *Organizations as Knowledge Systems: Knowledge, Learning and Dynamic Capabilities,* Basingstoke, Hamps:.Palgrave Macmillan.

Viner, D. (1991) *Accident Analysis and Risk Control*, VHMS Pty Ltd., Fairfield.

Warwick, K., Gray, J. & Roberts, D. (1993) *Virtual Reality in Engineering*, London: IEE.

Watson, J. & Hill, A. (2000) *Dictionary of Media & Communication Studies, 5th Ed.*., London: Hodder Headline Group.

Williams, T. (2002) *Modeling Complex Projects*, Chichester: John Wiley & Sons.

Zikmund, W. G. (2003) *Business Research Methods, 7th Ed.*., Mason, Ohio: Thomson South-Western.

Glossary of Terms

The following Glossary of Terms addresses many of the key words or terms used throughout this thesis and/or widely used in relation to research into simulation and virtual reality systems and technologies. The definitions used are drawn from:

- Oxford English Dictionary 2nd Ed., Oxford University Press (1989)
- Shorter Oxford English Dictionary 5th Ed., Oxford University Press (2002)
- The World Book Dictionary, Doubleday & Company (1975)
- Websters New World Encyclopaedia, Prentice Hall (1992)
- Websters Third New International Dictionary, Mirriam Webster (1993).

Classification: "The action of classifying or arranging in classes, according to common characteristics or affinities; assignment to the proper class. The result of classifying; a systematic distribution, allocation, or arrangement, in a class or classes; especially of things which form the subject matter of a science or of a methodic inquiry." (Oxford University Press, 1989, Vol. 3, p. 283)

Cognition: "The action or faculty of knowing; knowledge, consciousness; acquaintance with a subject. The action or faculty of knowing taken in its widest sense, including sensation, perception, conception, etc. As distinguished from feeling and volition; also more specifically, the action of cognizing an object in perception proper. A product of such an action; a sensation, perception, notion, or higher intuition." (Oxford University Press, 1989, Vol. 3, p. 445-446)

Context: "A context is the interrelated conditions in which something exists or occurs." (Mirriam-Webster, 1993, p. 492)

Cyber: "Of, relating to, or characteristics of the culture of computers, information technology, the Internet, and virtual reality." (Oxford University Press, 2002, Vol.1, p. 558)

Episteme: "Scientific knowledge, a system of understanding; Foucalt's term for the body of ideas that shape the perception of knowledge at a particular period." (Oxford University Press, 1989, Vol. 5, p. 338)

Epistemology: "The theory or science of the method or grounds of knowledge." (Oxford University Press, 1989, Vol. 5, p. 338)

Deduce: "To derive or draw as a conclusion from something already known or assumed; to derive by a process of reasoning or inference; to infer." (Oxford University Press, 1989, Vol. 4, p. 357)

Deductive: "Of the nature of, or characterised by the use of, deduction; specially in Logic, reasoning from general to particular; opposed to induction… reasoning deductively " (Oxford University Press, 1989, Vol. 4, p. 359)

Deductive system (Logic): "A set of propositions or formulas, in which some are derived from others according to rules of proof, all such possible derivations being held to be included."
(Oxford University Press, 1989, Vol. 4, p. 358)

Illusion: "The action, or an act, of deceiving the bodily eye by false or unreal appearances, or the mental eye by false prospects, statements, etc.; deception, delusion, befooling… Sensuous perception of an external object, involving a false belief or conception: strictly distinguished from *hallucination*, but in general use often made to include it, and hence = the apparent perception of an external object when no such object is present, or of attributes of an object which do not exist… *the argument from illusion* (Philos.): the argument that the objects of sense-experience, usually called ideas, appearances, or sense-data, cannot be objects in a physical world independent of the perceiver, since they vary according to his condition and environment."

(Oxford University Press, 1989, Vol. 7, p. 661)

Immerse: "To plunge or sink into a (particular) state of body or mind; to involve deeply, to steep, absorb, in some action or activity." (Oxford University Press, 1989, Vol. 7, p. 684)

Induce: "To lead to (something) as a conclusion or inference; to lead one to infer, to suggest, imply." (Oxford University Press, 1989, Vol. 7, p. 888)

Inductive: "Of the nature of, based upon, or characterised by the use of induction, or reasoning from particular facts to general principles." (Oxford University Press, 1989, Vol. 7, p. 892)

Interaction: "Reciprocal action; action or influence of persons or things on each other." (Oxford University Press, 1989, Vol. 7, p. 1085)

Interactionism: "The theory that in the causal relations between mind and body the causal influence runs in both directions, in sensation from body to mind and in volition from mind to body." (Oxford University Press, 1989, Vol. 7, p. 1085)

Meta-media: **Meta: "denoting a nature of a higher order" (Oxford University Press, 2002, Vol.1, p. 1756)**

Mind: "The seat of a person's consciousness, thoughts, volitions, and feelings; the system of cognitive and emotional phenomena and powers that constitutes the subjective being of a person; also, the incorporeal subject of the physical faculties, the spiritual part of a human being; the soul as distinguished from the body." (Oxford University Press, 1989, Vol. 9, p. 799)

Mind-Body: "A term used in relation to the question of whether a distinction can be made between mental and physiological events" (Oxford University Press, 1989, Vol. 9, p. 800)

Ontology: "The science or study of being; that department of metaphysics which relates to the being or essence of things, or to being in the abstract." (Oxford University Press, 1989, Vol. 10, p. 824)

Organization: "The action of organizing or putting into systematic form; the arranging and coordinating of parts into a systematic whole... an organized body, system or society." (Oxford University Press, 1989, Vol. 10, p. 923)

Phenomenal: "Of the nature of a phenomenon; consisting of phenomena; cognizable by the senses, or in the way of immediate experience; apparent, sensible, perceptible; of or relating to a phenomenon as it is directly perceived or sensed, especially as compared with its objective reality; also in special collocations, as phenomenal regression, the tendency for a shape, especially as a perspective, to be perceived as nearer to the shape of a related and known object than it actually is." (Oxford University Press, 1989, Vol. 11, p. 672)

(The) phenomenal: "That which is cognizable by the senses." (Oxford University Press, 1989, Vol. 11, p. 672)

Phenomenology: "The science of phenomena as distinct from that of being (ontology)." (Oxford University Press, 1989, Vol. 11, p. 673)

Reality: "The quality of being real or having an actual existence. Real existence; what is real; the aggregate of real things or existences; that which underlies and is the truth of appearances or phenomena." (Oxford University Press, 1989, Vol. 13, p. 276)

Science: "Science is the branch of study that is concerned with observation and classification of facts and especially with the establishment or strictly with the quantifiable formulation of verifiable general laws chiefly by induction and hypotheses." (Miriam-Webster, 1993, p. 2032)

"Science: any systematic field of study or body of knowledge that aims, through experiment, observation, and deduction, to produce reliable explanation of phenomena, with reference to the material and physical world." (Prentice Hall, 1992, p. 992)

Simulation: "The technique of imitating the behaviour of some situation or process (whether economic, military, mechanical, etc.) by means of a suitably analogous situation or apparatus, esp. for the purpose of study or personnel training." (Oxford University Press, 1989, Vol. 15, p. 503)

Sociological: "Concerned or connected with the organization, condition, or study of society." (Oxford University Press, 1989, Vol. 15, p. 916)

Strategic: "Of or pertaining to strategy; useful or important with regard to strategy. Also concerned with or involving careful planning towards an advantage." (Oxford University Press, 2002, Vol.2, p. 3055)

System: "A set or assemblage of things connected, associated, or independent, so as to form a complex unity; a whole composed of parts in orderly arrangement according to some scheme or plan." (Oxford University Press, 1989, Vol. 17, p. 496)

"A set of things or parts forming a whole." (Doubleday & Company Inc., 1975, p. 2112)

"A system is a complex unity formed of many often diverse parts subject to a common plan or serving a common purpose." (Miriam-Webster, 1993, p. 2322)

Taxonomy: "Classification, especially in relation to its general laws or principles; that department of science, or of a particular science or subject, which consists in or relates to classification; especially the systematic classification of living organisms." (Oxford University Press, 1989, Vol. 17, p. 682)

Technological: "Pertaining or relating to technology; using technology; belonging to technical phraseology or methods; resulting from developments in technology." (Oxford University Press, 2002, Vol.2, p. 3198)

Technology: "The branch of knowledge that deals with the mechanical arts or applied sciences; a discourse or treatise on one of these subjects… the terminology of a particular subject; technical nomenclature." (Oxford University Press, 2002, Vol.2, p. 3198)

Technophobe: "A person who fears technology" (Oxford University Press, 1989, Vol. 17, p. 704)

Telematics: "The branch of information technology which deals with the long distance transmission of computerized information." (Oxford University Press, 2002, Vol.2, p. 3202)

Tetrad: "A sum, group, or set of four." (Doubleday & Company, 1975, Vol.2, p.2151)

Tetradic: "Of or having to do with a tetrad." (Doubleday & Company, 1975, Vol.2, p.2151)

Virtual: "(Anything) that is so in essence or effect, although not formally or actually; admitting of being called by the name so far as the effect or result is concerned." (Oxford University Press, 1989, Vol. 19, p. 674)

Virtual Reality: "The generation by computer software of an image or environment that appears to be real to the senses." (Oxford University Press, 2002, Vol.2, p. 3544)

Visual: "Of, pertaining to, or connected with the faculty of sight or the process of vision." (Oxford University Press, 2002, Vol.2, p. 3548)

Visualization: The action or process of visualizing… a mental image formed by visualizing." (Oxford University Press, 2002, Vol.2, p. 3548)

Visualize: "Make visible to the mind or imagination (something abstract or not visible or present to the eye); form a mental vision or image. Make visible to the eye." (Oxford University Press, 2002, Vol.2, p. 3548)

List of Abbreviations

The following listing contains the most common relevant abbreviations to be found in the reviewed literature and as used throughout this document.

2-D	Two Dimensional
3-D	Three Dimensional
CAD	Computer Aided Design
CAVE	Cave Automatic Virtual Environment
GB	Giga Byte (10^9Bytes)
HMD	Head-mounted Display
I^3	(RMIT University) Interactive Information Institute
ICT	Information & Communications Technology
IT	Information Technology
LCD	Liquid Crystal Display
MHz	Mega Hertz (10^6 Hz)
NASA	National Aeronautical & Space Administration
MB	Mega Byte (10^6Bytes)
PC	Personal Computer
QM	Quality Management
RAM	Random Access Memory
RMIT	Royal Melbourne Institute of Technology
SGI	Silicon Graphics Incorporated
SSM	Soft Systems Methodologies
TB	Tera Byte (10^{12}Bytes)
UK	United Kingdom
USA	United States of America
VR	Virtual Reality
WWW	World Wide Web

Appendices

Appendix 1.

Virtual Reality User Survey

The attached Copy of the VR User Survey was distributed to senior staff in a range of organizations, both active users of virtual reality technology and systems and otherwise. Sunsequent analysis of survey returns has been used as the basis for testing the validity of research findings and associated structural content of the proposed taxonomy.

Virtual Reality User Survey

This survey is part of a research program investigating the application of advanced visualisation technology and simulation systems in supporting management decision making processes. Key areas being researched address issues associated with: visualisation; simulation; and synthetic environment building (Virtual Reality).

The research thus addresses how contemporary organisations and enterprises, with their established body of knowledge, theory, practice and history of resolving 'real-world' problems, can make effective use of 'virtual world' technologies and systems.

Please respond to as many questions as possible.

Tick or circle the most appropriate response or responses.

Please feel free to enter any additional observations/responses as appropriate in the open boxed areas.

All research data will be aggregated, ie. no specific reference will be made to individuals or companies.

Principal Researcher: Mr Allan McLay
Senior Lecturer: Engineering Management
School of Aerospace, Mechanical & Manufacturing Engineering
RMIT University

The following four key questions relate to characterisation of your organisation.......

1. **In terms of the 'organisational behaviours' identifiable within your organisation,** please indicate to what extent your organisation's 'behaviour' is characterised by the following:

	Not Relevant 1.	2.	3.	4.	5. Highly Relevant
A product or service orientation					
Defined skills and expertise orientation					
IT related skills and expertise orientation					
Quality management/performance orientation					
Normative/relatively benign approach to suppliers, customers, staff and the market place at large					
Hyper-competitive approach					

Any comments on your responses to the above?

2. **In terms of the knowledge base and level of intellectual capital, skills and expertise in the organisation,** please indicate to what extent your organisation is characterised by the following:

	Not Relevant 1.	2.	3.	4.	5. Highly Relevant
Mature systems thinking approach					
Knowledge management orientation					
Active engagement in strategic planning					
Managing for strategic purpose/objectives					
Active engagement in innovation					
Demonstrated high levels of creativity					
Mission focused					

Any comments on your responses to the above?

3. **In terms of the technological orientation of your organisation**, eg. the scope of its technology base, dependence on technology, extent of internal or external reliance for technological services, please indicate to what extent your organisation is characterised by the following:

	Not Relevant 1.	2.	3.	4.	5. Highly Relevant
Technology ‘user’					
Technology ‘developer’					
Technology ‘push’ environment					
or technology ‘pull’ environment					
Stable technology environment					
or changing technology environment					
Dependent on specific technology					
or capable of using alternative technologies					
IT technology orientation					

Any comments on your responses to the above?

4. **In terms of the Product orientation of your organisation,** eg. the perceptions of product/services of the organisation, low-tech versus high-tech, stable versus changing profile, please indicate to what extent your organisation is characterised by the following:

	Not Relevant 1.	2.	3.	4.	5. Highly Relevant
Supply driven product or service					
or demand driven product or service					
High added-value product or service					
or low added-value product or service					
Niche market segmentation					
or across market sectors					
High competition in the marketplace					
Multiple competitors in the market place					

Any comments on your responses to the above?

The following questions relate to your company's exposure to Virtual Reality technology and systems........

5. Does your organisation <u>currently</u> use <u>Virtual Reality</u> systems? ***YES NO Don't know***

If YES please identify the technology used and briefly outline the area of application and usage.

TECHNOLOGY: VR Cave Reality Centre Head-mounted Display Shutter Glasses Immersive Desk Data-glove Boom Display

I-Wall IMAX Prosthetics Robotics 3D Mouse/Wand Hemisphere Display Other ………………………………………………………………

APPLICATION or USAGE:

6. What Virtual Reality 'attributes' do you think could be most useful to you or your organisation?

Please describe in your own words what you believe such attributes to be and why you think they are of potential value.

7. What demerits do you see in the application/use of Virtual Reality systems?

Please describe in your own words what you believe such demerits might be and why.

8. Do you see value in being able to 'interact' with a VR simulation in <u>'real-time'</u>?

If YES, please describe in your own words what values, why and in what contexts. ***YES NO Don't know***

9. Do you see value in the use of 'immersive' technologies in the use of simulations?

YES	*NO*	*Don't know*

If YES, please explain in your own words 'why' and in what contexts.

10. Do you see value in the use of '3-D' visualisation technologies in the use of VR simulations?

YES	*NO*	*Don't know*

If YES, please explain why and in what contexts.

11. Has your experience/use of Virtual Reality met your expectations?

Please rate your experience/use according to the following classification (circle the appropriate response).

Failed Miserably	*No, did NOT meet expectations*	*UNSURE*	*YES, did meet expectations*	*EXCEEDED expectations*

Please briefly explain any particular reasons for your rating.

12. Which of the following factors do you consider relevant to your use of VR?

Please 'rank' the following 'factors' in terms of relevance to you/your organization and add any additional factors you believe are relevant. (tick the box in the appropriate column using a ranking from 1(not relevant) through 5 (highly relevant))

	Not Relevant 1.	2.	3.	4.	5. Highly Relevant
Interactivity					
Immersion					
Image fidelity					
Image complexity					
Ease of use					
Human-factors (eg. ergonomics)					
Development time (eg. from simulation concept to implementation)					
In-house 'Technology' base required for development and implementation					
Outsourcing of required 'Technology' base					
In-house 'Expertise' base required for development and implementation					
Out-sourcing of required 'Expertise' base					
Other factors:					

13. Have you or your organization used Virtual Reality or related visualization technologies or systems to assist in management level decision making?

If YES please outline briefly which technologies or systems and how used. ***YES*** ***NO*** ***Don't know***

14. Which of the following best describes your current or proposed use of Virtual Reality systems?

(Please tick as many as are relevant to your applications/plans)

To design your own products or services	
To design products or services for other clients	
To test/evaluate your own products or services	
To test/evaluate products or services for other clients	
To investigate system or phenomena behaviours through simulation	
To create/develop entertainment products/services	
To deliver entertainment products/services	
To design/develop automated manufacturing systems	
To manage/operate automated manufacturing systems	
To manage/implement complex data analysis	
To create/develop knowledge management systems	
To manage/implement knowledge management systems	
To market products/services	
Training for your own staff/personnel	
Training for other clients	
Demonstrate/illustrate complex concepts to your own staff/personnel	
Demonstrate/illustrate complex concepts to other clients	
To design/develop robotic control systems	
To manage/operate robotic control systems	
To undertake medical/surgical research	
To manage/implement medical/surgical procedures	
To undertake pharmaceutical research	
To manage/implement pharmaceutical product development	
To undertake architectural design	
CAD/Graphics systems toolset	
To plan/operate construction projects	
Other	

15. Please indicate your Industry Sector:

Education	
Manufacturing / Production	
Government	
Defence / Security / Police	
Commerce	
Medical	
Construction / Architecture	
Information & Communication Technology	
Automotive / Aerospace	
Energy / Oil / Gas / Electricity	
Other: … (Please identify) …	

16. To what extent do the following factors affect your organization and its achieving its objectives?

	Not Relevant 1.	2.	3.	4.	5. Highly Relevant
Staff Related Factors					
Occupational Health & safety					
Work satisfaction					
Meaningful work					
Motivation					
Teamwork orientation					
Imagination & creativity					
Leadership capabilities					
Interpersonal skills					
Communication Skills					
Technology skills & competencies					
Skills Upgrading					
Job Creation					
Job re-design					
Job displacement					
Operational Related Factors					
Productivity					
Process re-engineering					
Risk & feasibility management					
Time-cost profiles					
Information intensity					
Organisational processes formalized					
Security					
Organisational Related Factors					
Organisational complexity					
Formalised Organisational structure					
Change management					
Internal economic environment					
Social organization of work					
Geo-spatial distribution					
Risk taking					
Technological impact					
Socially responsible /ethical behaviours & norms					
Global village concept					
Changes in the nature of work					
Spread of technology in the workplace					

Industry sector ethnographics					
Sectoral transformation					
Globalisation					
Technological Related Factors					
Structural requirements					
Support requirements					
Resource requirements					
Functional requirements					
Upgradability					
Longevity					
Cost-performance					
Advanced computing					
Human-machine interface systems					
Telecommunications					
Transparent systems integration					
Display systems					
Product Related Factors					
Customer expectations					
Compliance with customer requirements					
Product differentiation					
Virtual Reality/Simulation Related Factors					
Position tracking					
Acoustic fidelity					
3D surround sound					
Auditory acuity					
Haptic stimulation					
Haptic fidelity					
Illusion					
Visual acuity					
Movement					
Latency					
Virtuality as social phenomenon					
Mediated environments					
Proprioception					
Dynamic environments					
Engagement					
Presence					
Tele-presence					
Tele-robotics					

Spaciality					
Virtual workspace					
Realism					
Repeatability					

Any comments on your responses to the above?

17. Any other comments you feel may be of assistance?

Thank you for taking the time to assist with this research. It is much appreciated.

If you are interested in being contacted about further involvement in the research program, or following up its results, please provide contact details below or email your contact details to: allan.mclay@rmit.edu.au

Name: ……………………………………………………………………………………..

Position: ……………………………………………………………………………………..

Company: …………………………………………………………………………………….

Phone: …………………………………………………………………………………….

Email: …………………………………………………………………………………….

Postal Address:……………………………………………………………………………………..

…………………………………………………………………………………….

…………………………………………………………………………………….

Appendix 2.

Mapping & Evaluation of Virtual Reality User Surveys

Details the data transformation processes used to map the VR User surveys to an Excel spreadsheet based analysis instrument.

The analysis instrument is based on the use of tabulated scored entries summed across the rows and divided by the number of entries to obtain a mediated score. Scores are further mapped across Domains and Paradigm columns and summed. As such it is an adaptation of the survey analysis work of educational psychologist Klas Mallendar (1993).

Appendix 2.1

Survey Questions to Systems Element Mapping

Survey Question	Elements →	Survey Question	Elements →	Survey Question	Elements →
12.6	Ergonomics	16.20	Organisational processes formalised	16.52	Acoustic fidelity
16.1	OH&S	1.2, SUM Q2, 12.10	Core Competencies	16.56	Haptic fidelity
14.16, 14.17	Cognition aspects	12.7	Lead-times to market	16.45	Tele-communications
13	Decision making skills	16.19	Information Intensity	16.48	Customer expectations
16.9	Communication skills	4.3, -4.4	Added value	16.49	Compliance with customer requirements & needs
2.5	Innovation culture	16.24	Change management	16.50	Product differentiation
SUM Q1	Organisational Culture	2.2, 14.11, 14.12	Knowledge management	16.58	Visual acuity
16.4	Motivation	2..3, 2.4, 2.7	Strategic Positioning	16.54	Auditory acuity
16.7	Leadership capabilities	12.8, -12.9, -12.11	Availability	16.2	Work satisfaction
16.8	Interpersonal skills	16.36	Structural requirements	16.3	Meaningful work
16.5	Teamwork orientation	16.37	Support requirements	16.10	Technology skills and competencies
2.5	Strategic attitude	16.38	Resource requirements	16.6	Imagination & creativity
2.1	Systems thinking	16.36	Globalisation	16.26	Social organization of work
SUM Q2	Intellectual capital	16.25	Internal economic environment	16.11	Skills upgrading
16.18	Time-cost profiles	4.7, 4.8	External economic environment	16.27	Geo-spatial distribution
16.15	Productivity	16.21	Security	16.14	Job displacement
14.10	Data-integrity	16.39	Functional requirements	16.12	Job creation
13, 5, 14.5	Simulation skills	16.40	Upgradability	16.13	Job redesign
2.1	Defined Operational systems	16.41	Longevity	16.28	Risk taking
2.3	Planning & control	16.42	Cost-performance	16.29	Technological impact
16.16	Process re-engineering	16.43	Advanced computing	16.61	Virtuality as Social phenomenon
1.4	Performance management	12.5	Ease-of-use	16.34	Industry sector ethnographics
1.4	Quality management	16.44	Human interface systems	16.35	Sectoral transformation
SUM Q2	Corporate memory	16.51	Position tracking	16.32	Changes in the nature & organization of work
16.17	Risk & Feasibility management	16.71	Realism	16.33	Spread of technology in the workplace

Survey Question	Elements	Survey Question	Elements	Survey Question	Elements
16.22	Organisational complexity	16.47	Display systems	16.57	Illusion
16.23	Formailsed Organisational structure	12.3	Image fidelity	10, 13	3D-stereoscopic vision
16.30	Socially responsible/Ethical behaviours & norms	16.62	Mediated environments	13, 14.25	Visualization & graphics
12.4	Visual stimulation	16.9	Information rich environments	16.53	3D-surround sound
16.55	Haptic stimulation	16.60	Latency	16.72	Repeatability
16.63	Proprioception	2.7, 2.3, 4.6, 2.4, 4.7, 4.8	Increasing global competition		
16.64	Dynamics	16.31	Global village concept		
9	Immersion	3.9, 12.8	IT Orientation		
16.65	Engagement	SUM Q3, 12.8	Reliance on Technology		
8, 12.1	Interactivity	3.1, 3.4, 12.8, 12.10	Technology User		
16.66	Presence	3.2, 3.3, 4.1, 14.1, 14.3, 14.6, 14.8, 14.13, 14.18, 14.19, 14.23, 14.24	Technology/ Product developer		
16.67	Tele-presence	3.6, 3.8, -3.7, -3.5,	Dynamic Technology environment		
16.68	Tele-robotics	5, 11	Active VR user		
16.59	Movement	14.7, 14.4, 14.9, 14.10, 14.12, 14.13, 14.17, 14.15, 14.26	Service provider		
16.27	Geo-spatial factors	14.20, 14.22, 14.21, 14.23	Research orientation		
16.46	Transparent systems integration	16.70	Virtual work-space		
16.69	Spaciality	1.6, -1.5	Competitiveness		

Appendix 2.2

Stage 1. Analysis Instrument for VR-Users

STAGE 1. ANALYSIS INSTRUMENT: VR USERS

	ORGANISATIONS																							SEMSS
Elements	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**	**L**	**M**	**N**	**O**	**P**	**Q**	**R**	**S**	**T**	**U**	**V**	**W**	
Ergonomics	-1	2	0	0	0	0	1	1	0	0														0.3
OH&S	0	0	0	0	0	0	0	0	0	0														0
Cognition aspects	0	1	0	1	0.5	0.5	0.5	1	1	1														0.65
Decision making skills	-1	1	0	-1	0	-1	1	1	-1	-1														-0.2
Communication skills	2	2	0	1	0	2	2	1	1	1														1.2
Innovation culture	0	2	2	2	2	1	2	1	2	1														1.5
Organisational Culture	1	1	0.3	1.3	1	0.8	1.3	1.5	1	1.5														1.0833
Motivation	1	0	0	1	0	2	1	0	1	1														0.7
Leadership capabilities	0	2	0	1	0	1	2	1	0	0														0.7
Interpersonal skills	2	2	0	1	0	2	2	1	1	1														1.2
Teamwork orientation	0	2	0	-1	0	1	2	1	0	0														0.5
Strategic attitude	0	2	2	2	2	1	2	1	2	1														1.5
Systems thinking	0	-2	0	2	1	1	2	1	2	1														0.8
Intellectual capital	0.6	-1	0.6	1.7	1.6	1.3	1.9	1.3	1.7	0.9														1.0857
Time-cost profiles	1	2	0	1	0	2	1	1	2	2														1.2
Productivity	1	2	0	1	0	2	2	1	0	0														0.9
Data-integrity	0	1	0	0	1	1	1	0	1	1														0.6
Simulation skills	0	1.3	0.7	0.7	1	0.3	1.3	0.7	0.3	0.3														0.6667
Defined Operational systems	0	-2	0	2	1	1	2	1	2	1														0.8
Planning & control	1	-2	0	1	1	2	2	2	2	1														1
Process re-engineering	0	2	0	0	0	0	1	1	1	1														0.6
Performance management	1	0	-1	2	0	1	1	1	1	1														0.7

	ORGANISATIONS																							SEMSS
Elements	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**	**L**	**M**	**N**	**O**	**P**	**Q**	**R**	**S**	**T**	**U**	**V**	**W**	
Quality management	1	0	-1	2	0	1	1	1	1	1														0.7
Corporate memory	0.7	-1	0.7	2	1.8	1.5	2.2	1.5	2	1														1.2667
Risk & Feasibility management	0	-1	0	0	0	1	2	1	2	2														0.7
Organisational complexity	0	0	0	-1	0	-1	2	1	2	2														0.5
Formalised Organisational structure	0	0	0	-1	0	-1	2	2	2	2														0.6
Organisational processes formalised	-1	1	0	-1	0	0	2	0	1	1														0.3
Core Competencies	2.4	1.6	1.3	3.3	3.2	3.1	3.4	3.2	3.4	2.6														2.7667
Lead-times to market	1	2	-1	1	2	1	1	0	0	2														0.9
Information Intensity	1	0	0	0	0	0	2	1	2	2														0.8
Added value	-1	-2	-2	-1	-1	-2	-1	-1	-1	-1														-1.05
Change management	-1	2	0	-1	0	2	1	1	1	1														0.6
Knowledge management	0	0	-0	1	0.7	0.3	1	0.3	1	0.7														0.4667
Strategic Positioning	1.3	-1	0.7	1.3	1.3	1.3	1.7	2	1.7	0.7														1.0667
Availability	-0	-1	-0	0	-1	-1	-0.7	1	0.3	-1														-0.3
Structural requirements	-1	2	0	0	0	1	1	1	0	0														0.4
Support requirements	-1	2	0	1	0	1	2	1	1	1														0.8
Resource requirements	0	2	0	1	0	1	2	1	1	1														0.9
Globalisation	-1	2	0	0	0	1	1	1	0	0														0.4
Internal economic environment	-1	0	0	-1	0	0	1	1	0	0														0
External economic environment	-1	0	-1	-1	0	0.5	-0.5	0.5	1	1														0.05
Security	0	0	0	-1	0	-1	2	1	2	2														0.5

Appendix 2.

	ORGANISATIONS																							SEMSS
Elements	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**	**L**	**M**	**N**	**O**	**P**	**Q**	**R**	**S**	**T**	**U**	**V**	**W**	
Functional requirements	-1	2	0	1	0	1	1	1	1	1														0.7
Upgradability	-1	2	0	1	0	1	2	1	2	2														1
Longevity	1	2	0	1	0	0	2	1	2	2														1.1
Cost-performance	1	0	0	1	0	2	1	1	2	2														1
Technological Complexity	0	2	0.5	0.4	1.5	0.5	1.4	0.8	0.8	0.6														0.8375
Advanced computing	-2	2	0	2	0	0	2	0	2	2														0.8
Ease-of-use	-1	2	0	0	0	0	1	1	0	0														0.3
Human interface systems	-2	2	0	1	0	2	1	1	2	2														0.9
Position tracking	0	2	0	-1	0	-1	2	1	0	0														0.3
Display systems	-2	1	0	1	0	1	2	2	2	2														0.9
Image fidelity	0	2	2	0	2	1	2	1	1	-1														1
Acoustic fidelity	0	2	0	-1	0	0	2	-1	0	0														0.2
Haptic fidelity	0	1	0	-2	0	-1	2	0	0	0														0
Tele-communications	2	2	0	1	0	1	2	0	2	2														1.2
Customer expectations	2	2	0	1	0	2	2	2	2	2														1.5
Compliance with customer requirements & needs	2	2	0	2	0	2	1	2	2	2														1.5
Product differentiation	1	2	0	1	0	2	2	1	2	2														1.3
Visual acuity	0	2	0	-1	0	1	2	1	0	0														0.5
Auditory acuity	0	2	0	-1	0	0	2	-1	0	0														0.2
Work satisfaction	0	2	0	1	0	2	2	-1	1	1														0.8
Meaningful work	1	0	0	1	0	2	1	0	1	1														0.7
Technology skills and competencies	0	1	0	2	0	1	2	0	1	1														0.8
Imagination & creativity	0	2	0	1	0	1	2	1	0	0														0.7

	ORGANISATIONS																						SEMSS
Elements	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**	**L**	**M**	**N**	**O**	**P**	**Q**	**R**	**S**	**T**	**U**	**V**	**W**	
Social organization of work	-1	1	0	0	0	0	2	2	0	0														0.4
Skills upgrading	1	0	0	-1	0	-2	2	-1	0	0														-0.1
Geo-spatial distribution	-1	1	0	0	0	1	1	1	-1	-1														0.1
Job displacement	1	2	0	1	0	2	2	1	0	0														0.9
Job creation	0	0	0	-1	0	-2	1	1	0	0														-0.1
Job redesign	1	0	0	-1	0	-2	1	1	-1	-1														-0.2
Risk taking	1	1	0	1	0	2	2	2	2	2														1.3
Technological impact	-1	0	0	0	0	1	1	1	1	1														0.4
Virtuality as Social phenomenon	0	1	0	-1	0	0	1	-1	0	0														0
Industry sector ethnographics	-1	0	0	-1	0	-1	1	1	0	0														-0.1
Sectoral transformation	1	0	0	0	0	-1	1	2	2	2														0.7
Changes in the nature & organization of work	-1	2	0	0	0	2	2	1	1	1														0.8
Spread of technology in the workplace	-1	0	0	0	0	-1	1	1	1	1														0.2
Increasing global competition	0.5	-0	0	0.7	0.7	0.3	1	1.3	1.5	1														0.66667
Global village concept	2	-2	0	0	0	0	1	2	1	1														0.5
Socially responsible/Ethical behaviours & norms	-1	0	0	0	0	1	1	1	1	1														0.4
Visual stimulation	0	2	0	0	2	0	2	2	1	1														1
Haptic stimulation	0	1	0	-2	0	-1	2	0	0	0														0
Proprioception	0	0	0	0	0	0	2	0	0	0														0.2
Dynamics	0	0	0	0	0	0	2	0	0	0														0.2
Immersion	2	2	2	1	2	1	2	1	-1	-1														1.1

	ORGANISATIONS																							SEMSS
Elements	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**	**L**	**M**	**N**	**O**	**P**	**Q**	**R**	**S**	**T**	**U**	**V**	**W**	
Engagement	0	1	0	0	0	2	2	1	0	0														0.6
Interactivity	1	2	0.5	0.5	1.5	0	2	0.5	-1	-1														0.7
Presence	0	2	0	0	0	2	1	0	0	0														0.5
Tele-presence	0	2	0	0	0	1	2	0	0	0														0.5
Tele-robotics	0	2	0	-1	0	2	1	0	0	0														0.4
Movement	0	2	0	-1	0	1	2	1	0	0														0.5
Geo-spatial factors	-1	1	0	0	0	0	2	2	0	0														0.4
Transparent systems integration	2	2	0	1	0	1	2	0	2	2														1.2
Spaciality	0	0	0	-2	0	-2	2	0	0	0														-0.2
Illusion	0	1	0	-2	0	-1	2	0	0	0														0
3D-stereoscopic vision	0	1.5	1	0	1	0	1	1	0	0														0.55
visualisation	-1	1	0	-1	0	-1	0.5	1	-1	0														0.05
3D-surround sound	0	2	0	-1	0	0	2	-1	0	0														0.2
Repeatability	0	2	0	0	0	1	2	2	0	0														0.7
Realism	0	2	0	0	0	1	2	2	0	0														0.7
Virtual work-space	0	2	0	-1	0	-1	2	2	0	0														0.4
Mediated environments	0	1	0	-1	0	0	1	-1	0	0														0
Information rich environments	2	2	0	1	0	2	2	1	1	1														1.2
Latency	0	0	0	-1	0	2	2	1	0	0														0.4
Competition	-1	0	-1	-1	-1	-1	-0.5	0.5	1	0.5														-0.25
IT Orientation	0.5	2	-1	0.5	2	0	1.5	0.5	1	2														0.95
Dynamic Technology Orientation	0	0.5	0	-0	0.3	0	-0.3	0.3	0.8	0.5														0.175
Technology User	0	2	0.3	1	1.5	1	1.5	0.5	1	1														0.975

	ORGANISATIONS																							SEMSS
Elements	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**	**L**	**M**	**N**	**O**	**P**	**Q**	**R**	**S**	**T**	**U**	**V**	**W**	
Technology/Product Developer	-0	0.9	0.2	0.4	-0.1	0.2	0.7	0.1	0.5	0.5														0.325
Service Provider	0	1	0.1	0.4	0.4	0.3	0.4	0.3	0.4	0.6														0.41111
Research Orientation	0	1	0	0	0.5	0	0	0	0	0														0.15
Reliance on Technology	-1	2.3	0.6	1.3	1.3	0.3	1.7	0.3	2	1.1														1.01429
ISMSS	14	116	8.7	29	35	65	168	90	88	77														
OSEMS																								69.0069

Appendix 2.3

Systems Elements to Domains Mapping: Stage 2. Analysis Instrument for VR-Users

Systems Elements to Domains Mapping: Stage 2. Analysis Instrument for VR-Users

SEMSS		Organisational Domain			Technological Domain			Sociological Domain			Phenomenal Domain		
	Elements	**Human Factors**	**Operational Factors**	**Strategic Factors**	**Base Tech. Factors**	**Enabling Tech. Factors**	**Product Specific Factors**	**The Individual Factors**	**Group Factors**	**Broader Societal Factors**	**Sensory Factors**	**Engagement Factors**	**Virtuality Factors**
0.3	Ergonomics	0.3					0.3	0.3			0.3	0.3	
0	OH&S	0	0					0	0		0	0	
0.65	Cognition aspects	0.65						0.65					0.65
-0.2	Decision making skills	-0.2	-0.2	-0.2				-0.2					
1.2	Communication skills	1.2	1.2	1.2				1.2	1.2			1.2	
1.5	Innovation culture	1.5		1.5				1.5	1.5				
1.0833	Organisational Culture	1.083	1.08333	1.0833				1.08333	1.083				
0.7	Motivation	0.7						0.7					
0.7	Leadership capabilities	0.7	0.7	0.7				0.7					
1.2	Interpersonal skills	1.2						1.2	1.2				
0.5	Teamwork orientation	0.5	0.5					0.5	0.5				
1.5	Strategic attitude	1.5		1.5				1.5	1.5				
0.8	Systems thinking	0.8	0.8	0.8									
1.0857	Intellectual capital	1.086		1.0857				1.08571	1.086				
1.2	Time-cost profiles		1.2				1.2						
0.9	Productivity		0.9										
0.6	Data-integrity		0.6										

SEMSS		Organisational Domain			Technological Domain			Sociological Domain			Phenomenal Domain		
	Elements	**Human Factors**	**Operational Factors**	**Strategic Factors**	**Base Tech. Factors**	**Enabling Tech. Factors**	**Product Specific Factors**	**The Individual Factors**	**Group Factors**	**Broader Societal Factors**	**Sensory Factors**	**Engagement Factors**	**Virtuality Factors**
0.6667	Simulation skills		0.66667			0.6667		0.66667					
0.8	Defined Operational systems		0.8						0.8				
1	Planning & control		1						1				
0.6	Process re-engineering		0.6						0.6				
0.7	Performance management		0.7						0.7				
0.7	Quality management		0.7				0.7			0.7			
1.2667	Corporate memory		1.26667	1.2667									
0.7	Risk & Feasibility management		0.7	0.7			0.7			0.7			
0.5	Organisational complexity		0.5						0.5				
0.6	Formalised Organisational structure		0.6						0.6				
0.3	Organisational processes formalised		0.3						0.3				
2.7667	Core Competencies		2.76667	2.7667				2.76667	2.767				
0.9	Lead-times to market			0.9			0.9						
0.8	Information Intensity			0.8								0.8	0.8

SEMSS		Organisational Domain			Technological Domain			Sociological Domain			Phenomenal Domain		
	Elements	**Human Factors**	**Operational Factors**	**Strategic Factors**	**Base Tech. Factors**	**Enabling Tech. Factors**	**Product Specific Factors**	**The Individual Factors**	**Group Factors**	**Broader Societal Factors**	**Sensory Factors**	**Engagement Factors**	**Virtuality Factors**
-1.05	Added value			-1.05							-1.05	-1.05	
0.6	Change management		0.6	0.6			0.6		0.6				
0.4667	Knowledge management		0.46667	0.4667					0.467				
1.0667	Strategic Positioning			1.0667		1.0667			1.067				
-0.3	Availability				-0.3	-0.3	-0.3				-0.3	-0.3	-0.3
0.4	Structural requirements		0.4		0.4	0.4							
0.8	Support requirements		0.8		0.8	0.8							
0.9	Resource requirements		0.9		0.9	0.9							
0.4	Globalisation			0.4			0.4			0.4			
0	Internal economic environment		0										
0.05	External economic environment			0.05						0.05			
0.5	Security		0.5	0.5	0.5	0.5							
0.7	Functional requirements		0.7		0.7	0.7	0.7				0.7	0.7	0.7
1	Upgradability		1		1	1	1						
1.1	Longevity		1.1		1.1	1.1	1.1						
1	Cost-performance		1		1	1	1						
0.8375	Technological Complexity		0.8375		0.838	0.8375	0.8375						

SEMSS		Organisational Domain			Technological Domain			Sociological Domain			Phenomenal Domain		
	Elements	**Human Factors**	**Operational Factors**	**Strategic Factors**	**Base Tech. Factors**	**Enabling Tech. Factors**	**Product Specific Factors**	**The Individual Factors**	**Group Factors**	**Broader Societal Factors**	**Sensory Factors**	**Engagement Factors**	**Virtuality Factors**
0.8	Advanced computing				0.8								
0.3	Ease-of-use	0.3	0.3			0.3	0.3	0.3				0.3	
0.9	Human interface systems	0.9				0.9		0.9			0.9	0.9	
0.3	Position tracking	0.3				0.3		0.3				0.3	
0.9	Display systems	0.9				0.9		0.9			0.9		0.9
1	Image fidelity	1				1		1			1		1
0.2	Acoustic fidelity	0.2				0.2		0.2			0.2		
0	Haptic fidelity	0				0		0			0	0	
1.2	Tele-communications		1.2			1.2		1.2	1.2	1.2			
1.5	Customer expectations			1.5			1.5			1.5			
1.5	Compliance with customer requirements & needs		1.5				1.5			1.5			
1.3	Product differentiation			1.3			1.3						
0.5	Visual acuity							0.5			0.5		
0.2	Auditory acuity							0.2			0.2		

SEMSS | Organisational Domain | Technological Domain | Sociological Domain | Phenomenal Domain

	Elements	Human Factors	Operational Factors	Strategic Factors	Base Tech. Factors	Enabling Tech. Factors	Product Specific Factors	The Individual Factors	Group Factors	Broader Societal Factors	Sensory Factors	Engagement Factors	Virtuality Factors
0.8	Work satisfaction		0.8					0.8	0.8				
0.7	Meaningful work		0.7					0.7	0.7				
0.8	Technology skills and competencies	0.8	0.8	0.8		0.8		0.8	0.8				
0.7	Imagination & creativity	0.7		0.7			0.7	0.7	0.7				0.7
0.4	Social organization of work		0.4						0.4				
-0.1	Skills upgrading		-0.1			-0.1		-0.1	-0.1				
0.1	Geo-spatial distribution		0.1						0.1				
0.9	Job displacement		0.9					0.9	0.9				
-0.1	Job creation		-0.1					-0.1	-0.1				
-0.2	Job redesign		-0.2					-0.2	-0.2				
1.3	Risk taking		1.3	1.3				1.3	1.3				
0.4	Technological impact		0.4	0.4		0.4				0.4			
0	Virtuality as Social phenomenon								0	0			0
-0.1	Industry sector ethnographics			-0.1			-0.1			-0.1			
0.7	Sectoral transformation			0.7	0.7				0.7	0.7			
SEMSS		**Organisational Domain**			**Technological Domain**			**Sociological Domain**			**Phenomenal Domain**		

	Elements	Human Factors	Operational Factors	Strategic Factors	Base Tech. Factors	Enabling Tech. Factors	Product Specific Factors	The Individual Factors	Group Factors	Broader Societal Factors	Sensory Factors	Engagement Factors	Virtuality Factors
0.8	Changes in the nature & organization of work		0.8	0.8				0.8	0.8	0.8			
0.2	Spread of technology in the workplace		0.2	0.2		0.2		0.2	0.2	0.2			
0.6667	Increasing global competition			0.6667			0.6667			0.6667			
0.5	Global village concept			0.5						0.5			
0.4	Socially responsible/Ethical behaviours & norms	0.4	0.4	0.4				0.4	0.4	0.4			0.4
1	Visual stimulation	1						1			1		
0	Haptic stimulation	0						0			0		
0.2	Proprioception	0.2						0.2			0.2		
0.2	Dynamics							0.2	0.2		0.2		0.2
1.1	Immersion	1.1						1.1			1.1	1.1	1.1
0.6	Engagement	0.6				0.6		0.6				0.6	
0.7	Interactivity	0.7				0.7		0.7			0.7	0.7	
0.5	Presence	0.5						0.5			0.5	0.5	0.5
0.5	Tele-presence	0.5					0.5	0.5	0.5		0.5	0.5	0.5
0.4	Tele-robotics					0.4	0.4		0.4			0.4	
0.5	Movement	0.5					0.5	0.5				0.5	

SEMSS		Organisational Domain			Technological Domain			Sociological Domain			Phenomenal Domain		
	Elements	**Human Factors**	**Operational Factors**	**Strategic Factors**	**Base Tech. Factors**	**Enabling Tech. Factors**	**Product Specific Factors**	**The Individual Factors**	**Group Factors**	**Broader Societal Factors**	**Sensory Factors**	**Engagement Factors**	**Virtuality Factors**
0.4	Geo-spatial factors						0.4		0.4	0.4		0.4	0.4
1.2	Transparent systems integration					1.2	1.2					1.2	
-0.2	Spaciality						-0.2	-0.2	-0.2				-0.2
0	Illusion	0					0	0			0		0
0.55	3D-stereoscopic vision	0.55				0.55	0.55	0.55			0.55	0.55	0.55
0.05	Visualisation & graphics	0.05				0.05	0.05	0.05	0.05		0.05		0.05
0.2	3D-surround sound	0.2				0.2	0.2	0.2			0.2	0.2	0.2
0.7	Repeatability		0.7				0.7						0.7
0.7	Realism	0.7					0.7	0.7			0.7		0.7
0.4	Virtual work-space		0.4				0.4	0.4	0.4				0.4
0	Mediated environments		0				0	0			0	0	0
1.2	Information rich environments		1.2				1.2	1.2	1.2			1.2	1.2
0.4	Latency	0.4					0.4	0.4				0.4	0.4
-0.25	Competition			-0.25				-0.25	-0.25				
0.95	IT Orientation		0.95	0.95	0.95								
0.175	Dynamic Technology Orientation		0.175										

SEMSS		Organisational Domain			Technological Domain			Sociological Domain			Phenomenal Domain		
	Elements	**Human Factors**	**Operational Factors**	**Strategic Factors**	**Base Tech. Factors**	**Enabling Tech. Factors**	**Product Specific Factors**	**The Individual Factors**	**Group Factors**	**Broader Societal Factors**	**Sensory Factors**	**Engagement Factors**	**Virtuality Factors**
0.975	Technology User		0.975			0.975	0.975						
0.325	Technology/ Product Developer			0.325			0.325						
0.4111	Service Provider			0.4111						0.4111			
0.15	Research Orientation			0.15			0.15						
1.0143	Reliance on Technology			1.0143		1.0143							
	DFLS	23.52	39.4875	27.903	9.388	20.46	23.454	33.7024	28.77	10.428	9.05	11.4	11.55
	FDS		90.9093			53.302			72.9			32	

Appendix 2.4

Evaluation of Virtual Reality User Survey: Stage 2. Domains to Paradigm Mapping

Domain to Paradigm Mapping

	Paradigms			
System Elements	**Behaviour Paradigm 1.**	**Cognitive Paradigm 2**	**Technological Paradigm 3.**	**Product Characterisation Paradigm 4.**
Ergonomics	Org + Tech	Soc	Tech	Phen
OH&S	Org + Soc			Phen
Cognition aspects		ALL		
Decision making skills	Org	Soc		
Communication skills	Org	Org + Soc		Phen
Innovation culture	Org	Org +Soc	Org + Soc	
Organisational Culture	Org	Org + Soc		
Motivation	Org	Org + Soc		
Leadership capabilities	Org	Org + Soc		
Interpersonal skills	Org	Org + Soc		
Teamwork orientation	Org	Org + Soc		
Strategic attitude	Org	Org + Soc		
Systems thinking	Org	Org		
Intellectual capital	Org + Soc	Org		
Time-cost profiles	Org		Tech	
Productivity	Org		Org	
Data-integrity	Org		Org	
Simulation skills	Org + Tech	Org + Tech + Soc	Org + Tech	
Defined Operational systems	Org			
Planning & control	Org			
Process re-engineering	Org	Org		
Performance management	Org		Org	

	Paradigms			
Elements	**Paradigm 1**	**Paradigm 2**	**Paradigm 3**	**Paradigm 4**
Quality management	Org		Org + Tech	Org + Tech + Soc
Corporate memory		Org		
Risk & Feasibility management	Org	Soc		Tech
Organisational complexity	Org + Soc	Org		
Formalised Organisational structure	Org + Soc	Org		
Organisational processes formalised	Org + Soc	Org		
Core Competencies	Org	Org + Soc	Org	
Lead-times to market	Org + Tech			Org + Tech
Information Intensity	Org	Org + Phen		Phen
Added value	Org			Phen
Change management	Org	Org + Soc		Tech
Knowledge management	Org	Org + Soc		
Strategic Positioning	Org + Soc	Org	Org + Tech	Org + Tech
Availability	Tech		Tech + Phen	Tech + Phen
Structural requirements	Org + Tech		Org + Tech	
Support requirements	Org + Tech		Org + Tech	
Resource requirements	Org + Tech		Org + Tech	
Globalisation	Org + Soc	Org + Soc		Tech
Internal economic environment	Org			
External economic environment	Org + Soc			
Security	Org + Tech		Org + Tech	

	Paradigms			
Elements	Paradigm 1	Paradigm 2	Paradigm 3	Paradigm 4
Functional requirements		Org + Tech + Phen		Org + Tech + Phen
Upgradability	Org		Org + Tech	Org + Tech
Longevity	Org		Org + Tech	Org + tech
Cost-performance	Org		Org + Tech	Org + tech
Technological Complexity			Tech	Org + Tech
Advanced computing			Tech	
Ease-of-use	Org + Phen		Org + Tech	Org + Tech + Phen
Human interface systems	ALL	Phen	Tech	ALL
Position tracking	Org + Phen		Tech	ALL
Display systems	Org + Phen		Tech	ALL
Image fidelity	Org + Phen		Tech	ALL
Acoustic fidelity	Org + Soc + Phen		Tech	ALL
Haptic fidelity			Tech	Tech
Tele-communications	Org + Soc		Org + Tech + Soc	Org + Soc
Customer expectations		Tech		Org + Tech + Soc
Compliance with customer requirements & needs	Org + Tech			Org + Tech + Soc
Product differentiation				Org + Tech
Visual acuity		Soc + Phen		Soc + Phen
Auditory acuity		Soc + Phen		Soc + Phen
Work satisfaction		Org + Soc		
Meaningful work		Org + Soc		
Technology skills and competencies	Org + Tech + Soc	Org + Soc	Org + Tech	
Imagination & creativity	Org + Soc	Org + Soc		Tech

	Paradigms			
Elements	**Paradigm 1**	**Paradigm 2**	**Paradigm 3**	**Paradigm 4**
Social organisation of work	Org + Soc	Soc		
Skills upgrading	Org + Soc	Org + Soc	Tech	
Geo-spatial distribution	Org + Soc			
Job displacement	Org + Soc			
Job creation	Org + Soc			
Job redesign	Org + Soc			
Risk taking	Org + Soc	Org + Soc		
Technological impact	Org		Org + Tech + Soc	Tech
Virtuality as Social phenomenon	Org + Phen	Org + Phen		Tech + Soc + Phen
Industry sector ethnographics	Org + Soc			
Sectoral transformation	Org + Soc	Org + Soc	Tech	
Changes in the nature & organization of work	Org + Soc	Org + Soc		
Spread of technology in the workplace	Org + Soc	Org + Soc	Org + Tech + Soc	
Increasing global competition	Org + Tech + Soc			
Global village concept	Org + Soc	Org + Soc		
Socially responsible/Ethical behaviours & norms	Org + Soc	Org + Soc		
Visual stimulation	Phen	Org + Soc	Phen	Org + Soc + Phen
Haptic stimulation	Phen	Org + Soc	Phen	Org + Soc + Phen
Proprioception	Phen	Org + Soc	Phen	Org + Soc + Phen
Dynamics	Soc		Phen	Phen

	Paradigms			
Elements	**Paradigm 1**	**Paradigm 2**	**Paradigm 3**	**Paradigm 4**
Immersion	Org	Org	Soc + Phen	Soc + Phen
Engagement	Org + Tech	Soc + Phen	Tech	Soc + Phen
Interactivity	Org + Tech	Soc + Phen	Tech	Soc + Phen
Presence	Org	Org + Soc + Phen		Soc + Phen
Tele-presence	Org	ALL	Tech	Tech + Soc + Phen
Tele-robotics	Soc		Tech + Phen	Tech + Phen
Movement	Org	Tech + Soc + Phen	Tech + Soc + Phen	Tech + Soc + Phen
Geo-spatial factors		Soc + Phen		Tech + Soc + Phen
Transparent systems integration			Tech + Phen	Thech + Phen
Spaciality			Tech + Soc + Phen	Tech + Soc + Phen
Illusion		Org + Phen	Tech + Soc + Phen	Tech + Phen
3D-stereoscopic vision		Org + Soc	Tech + Phen	Tech + Phen
Visualisation & graphics	Org	Org	Tech + Soc + Phen	Tech + Soc + Phen
3D-surround sound		Org	Tech + Soc + Phen	Tech + Soc + Phen
Repeatability	Org		Tech + Phen	Tech + Phen
Realism		Org	Tech + Soc + Phen	Tech + Soc + Phen
Virtual work-space	Org	Tech + Soc + Phen	Tech + Soc + Phen	Tech + Soc + Phen
Mediated environments	Org + Soc	Tech + Phen		Tech + Phen
Information rich environments	Org + Soc	ALL		ALL
Latency		ALL	Tech + Phen	ALL
Competition	Org + Soc			
IT Orientation	Org	Org	Tech	Tech

	Paradigms			
Elements	**Paradigm 1**	**Paradigm 2**	**Paradigm 3**	**Paradigm 4**
Dynamic Technology Orientation	Org	Org	Org	Org
Technology User	Org + Tech		Org + Tech	
Technology/ Product Developer	Org		Org	Org
Service Provider	Org + Soc			
Research Orientation	Org	Org	Org + Tech	Org + Tech
Reliance on Technology	Org		Org + Tech	

Appendix 2.5

Stage 3. Domains to Paradigm Mapping: Analysis Instrument for VR-Users and Final VR-Index Scores

Paradigm Scores: VR-Users

	Paradigms				INDEX
Elements	**Behaviour. Paradigm 1.**	**Cognitive Paradigm 2**	**Technological Paradigm 3**	**Product Charact. Paradigm 4**	
Ergonomics	0.6	0.3	0.3	0.6	
OH&S	0			0	
Cognition aspects		1.95			
Decision making skills	-0.6	-0.2			
Communication skills	3.6	6		1.2	
Innovation culture	3	6	6		
Organisational Culture	3.25	5.41667			
Motivation	0.7	1.4			
Leadership capabilities	2.1	2.8			
Interpersonal skills	1.2	3.6			
Teamwork orientation	1	2			
Strategic attitude	3	6			
Systems thinking	2.4	2.4			
Intellectual capital	2.171429	2.17143			
Time-cost profiles	1.2		1.2		
Productivity	0.9		0.9		
Data-integrity	0.6		0.6		
Simulation skills	1.333333	2	1.33333		
Defined Operational systems	0.8				
Planning & control	1				
Process re-engineering	0.6	0.6			
Performance management	0.7		0.7		

	Paradigms				INDEX
Elements	Paradigm 1	Paradigm 2	Paradigm 3	Paradigm 4	
Quality management	0.7		1.4	2.1	
Corporate memory		2.53333			
Risk & Feasibility management	1.4	0.7		0.7	
Organisational complexity	1	0.5			
Formalised Organisational structure	1.2	0.6			
Organisational processes formalised	0.6	0.3			
Core Competencies	5.533333	11.0667	5.53333		
Lead-times to market	1.8			1.8	
Information Intensity	0.8	2.4		1.6	
Added value	-1.05			-2.1	
Change management	1.2	1.8		0.6	
Knowledge management	0.933333	1.4			
Strategic Positioning	2.133333	1.06667	2.13333	2.13333	
Availability	0.166667		-1.8	-1.8	
Structural requirements	1.2		1.2		
Support requirements	2.4		2.4		
Resource requirements	2.7		2.7		
Globalisation	0.8	0.8		0.4	
Internal economic environment	0.4				
External economic environment	0.1				
Security	2		2		

	Paradigms				INDEX
Elements	**Paradigm 1**	**Paradigm 2**	**Paradigm 3**	**Paradigm 4**	
Functional requirements		4.9		4.9	
Upgradability	1		4	4	
Longevity	1.1		4.4	4.4	
Cost-performance	1		4	4	
Technological Complexity			2.5125	3.35	
Advanced computing			0.8		
Ease-of-use	0.9		1.2	1.5	
Human interface systems	4.5	1.8	0.9	4.5	
Position tracking	0.6		0.3	1.2	
Display systems	2.7		0.9	4.5	
Image fidelity	3		1	5	
Acoustic fidelity	0.6		0.2	0.8	
Haptic fidelity			0	0	
Tele-communications	4.8		6	4.8	
Customer expectations		1.5		4.5	
Compliance with customer requirements & needs	3			4.5	
Product differentiation				2.6	
Visual acuity		1		1	
Auditory acuity		0.4		0.4	
Work satisfaction		2.4			
Meaningful work		2.1			
Technology skills and competencies	4.8	4	3.2		
Imagination & creativity	2.8	2.8		0.7	

	Paradigms				INDEX
Elements	Paradigm 1	Paradigm 2	Paradigm 3	Paradigm 4	
Social organization of work	0.8	0.4			
Skills upgrading	-0.3	-0.3	-0.1		
Geo-spatial distribution	0.2				
Job displacement	2.7				
Job creation	-0.3				
Job redesign	-0.6				
Risk taking	5.2	5.2			
Technological impact	0.8		1.6	0.4	
Virtuality as Social phenomenon	0	0		0	
Industry sector ethnographics	-0.2				
Sectoral transformation	2.1	2.1	0.7		
Changes in the nature & organization of work	4	4			
Spread of technology in the workplace	1	1	1.2		
Increasing global competition	2				
Global village concept	1	1			
Socially responsible/Ethical behaviours & norms	2.4	2.4			
Visual stimulation	1	2	1	3	
Haptic stimulation	0	0	0	0	
Proprioception	0.2	0.4	0.2	0.6	
Dynamics	0.4		0.4	0.4	
Immersion	1.1	1.1	4.4	4.4	

	Paradigms				INDEX
Elements	**Paradigm 1**	**Paradigm 2**	**Paradigm 3**	**Paradigm 4**	
Engagement	1.2	1.2	0.6	1.2	
Interactivity	1.4	2.1	0.7	2.1	
Presence	0.5	2.5		2	
Tele-presence	0.5	3	0.5	3	
Tele-robotics	0.4		1.2	1.2	
Movement	0.5	1.5	1.5	1.5	
Geo-spatial factors		1.6		1.6	
Transparent systems integration			3.6	3.6	
Spaciality			-0.8	-0.8	
Illusion		0	0	0	
3D-stereoscopic vision		1.1	2.75	2.75	
Visualisation & graphics	0.05	0.05	0.3	0.3	
3D-surround sound		0.2	1.2	1.2	
Repeatability	0.7		1.4	1.4	
Realism		0.7	2.8	2.8	
Virtual work-space	0.4	1.6	1.6	1.6	
Mediated environments	0	0.8		0	
Information rich environments	3.6	2.4		7.2	
Latency		4	1.2	2	
Competition	-0.75				
IT Orientation	1.9	1.9	0.95	0.95	
Dynamic Technology Orientation	0.175	0.175	0.175	0.175	
Technology User	2.925		2.925		

	Paradigms				INDEX
Elements	**Paradigm 1**	**Paradigm 2**	**Paradigm 3**	**Paradigm 4**	
Technology/ Product Developer	0.325		0.325	0.325	
Service Provider	0.822222				
Research Orientation	0.15	0.15	0.3	0.3	
Reliance on Technology	1.014286		2.02857		
Final Paradigm Scores	125.6829	130.78	90.6661	109.083	
VR-INDEX					705.3

Appendix 3.

Statistical Measures for all Systems Elements

Provides a tabulated listing and charts derived from the scores entered into the analysis instrument for VR Survey responses.

Statistics: VR Users System Elements Q1-16

Elements	Mean	Median	Min.	Max.	Range	Sample Var.	Sample Stand. Dev.
Ergonomics	0.3	0	-1	2	3	0.677	0.823
OH&S	0	0	0	0	0	0	0
Cognition aspects	0.65	0.75	0	1	1	0.169	0.411
Decision making skills	-0.2	-0.5	-1	1	2	0.844	0.918
Communication skills	1.2	1	0	2	2	0.622	0.788
Innovation culture	1.5	2	0	2	2	0.5	0.707
Organisational Culture	1.083	1	0.333	1.5	1.166	0.125	0.353
Motivation	0.7	1	0	2	2	0.455	0.674
Leadership capabilities	0.7	0.5	0	2	2	0.677	0.823
Interpersonal skills	1.2	1	0	2	2	0.622	0.788
Teamwork orientation	0.5	0	-1	2	3	0.944	0.971
Strategic attitude	1.5	2	0	2	2	0.5	0.707
Systems thinking	0.8	1	-2	2	4	1.511	1.229
Intellectual capital	1.085	1.285	-0.571	1.857	2.428	0.558	0.747
Time-cost profiles	1.2	1	0	2	2	0.622	0.788
Productivity	0.9	1	0	2	2	0.766	0.875
Data-integrity	0.6	1	0	1	1	0.266	0.516
Simulation skills	0.666	0.666	0	1.333	1.333	0.197	0.444
Defined Operational systems	0.8	1	-2	2	4	1.511	1.229
Planning & control	1	1	-2	2	4	1.555	1.247
Process re-engineering	0.6	0.5	0	2	2	0.488	0.699
Performance management	0.7	1	-1	2	3	0.677	0.823

Statistics: Prospective Users Elements Q1-16

Elements	Mean	Median	Min.	Max.	Range	Sample Var.	Sample Stand. Dev.
Ergonomics	0.428	0.5	-2	2	4	1.494	1.222
OH&S	0	0	0	0	0	0	0
Cognition aspects	0.464	0.25	0	1	1	0.248	0.498
Decision making skills	-0.857	-1	-1	0	1	0.131	0.363
Communication skills	1.142	2	-1	2	3	1.208	1.099
Innovation culture	0.571	1	-1	2	3	1.494	1.222
Organisational Culture	0.464	0.333	-0.166	1.333	1.5	0.171	0.414
Motivation	0.785	1	-1	2	3	0.796	0.892
Leadership capabilities	0.857	1	-1	2	3	1.054	1.027
Interpersonal skills	0.928	1	-1	2	3	1.302	1.141
Teamwork orientation	0.142	0	-1	2	3	0.439	0.662
Strategic attitude	0.571	1	-1	2	3	1.494	1.222
Systems thinking	0.285	1	-2	2	4	1.450	1.204
Intellectual capital	0.602	0.785	-1	1.857	2.857	0.641	0.800
Time-cost profiles	0.428	1	-2	2	4	1.648	1.283
Productivity	1	1	-2	2	4	1.384	1.176
Data-integrity	0.142	0	0	1	1	0.131	0.363
Simulation skills	-0.476	-0.5	-0.666	0	0.666	0.046	0.215
Defined Operational systems	0.285	1	-2	2	4	1.450	1.204
Planning & control	0.857	1	-1	2	3	0.747	0.864
Process re-engineering	0.071	0	-2	1	3	0.532	0.730
Performance management	0.714	0.5	-1	2	3	0.989	0.994

Statistics: NON VR Users Elements Q1-16

Elements	Mean	Median	Min.	Max.	Range	Sample Var.	Sample Stand. Dev.
Ergonomics	0	0	-2	2	4	1.6	1.264
OH&S	0	0	0	0	0	0	0
Cognition aspects	0.166	0	0	1	1	0.166	0.408
Decision making skills	-1	-1	-1	-1	0	0	0
Communication skills	0	0.5	-2	2	4	2.8	1.673
Innovation culture	-0.5	-0.5	-2	1	3	1.1	1.048
Organisational Culture	0.111	-0.083	-0.5	1.333	1.833	0.407	0.638
Motivation	0.166	0	-1	1	2	0.566	0.752
Leadership capabilities	-0.333	0	-2	2	4	2.266	1.505
Interpersonal skills	-0.166	0	-2	2	4	2.566	1.602
Teamwork orientation	0.166	0	0	1	1	0.166	0.408
Strategic attitude	-0.5	-0.5	-2	1	3	1.1	1.048
Systems thinking	-0.666	0	-2	0	2	1.066	1.032
Intellectual capital	-0.333	-0.357	-1.428	0.428	1.857	0.446	0.668
Time-cost profiles	1	1	0	2	2	1.2	1.095
Productivity	1.333	1.5	0	2	2	0.666	0.816
Data-integrity	0.166	0	0	1	1	0.166	0.408
Simulation skills	-0.666	-0.666	-0.666	-0.666	0	1.776E-16	1.3328E-08
Defined Operational systems	-0.666	0	-2	0	2	1.066	1.032
Planning & control	-0.333	-0.5	-2	2	4	1.866	1.366
Process re-engineering	-0.666	-0.5	-2	1	3	1.466	1.211
Performance management	0.5	0.5	-1	2	3	1.1	1.048

Statistics: VR Users System Elements Q1-16

Elements	Mean	Median	Min.	Max.	Range	Sample Var.	Sample Stand. Dev.
Quality management	0.7	1	-1	2	3	0.677	0.823
Corporate memory	1.266	1.5	-0.666	2.166	2.833	0.760	0.872
Risk & Feasibility management	0.7	0.5	-1	2	3	1.122	1.059
Organisational complexity	0.5	0	-1	2	3	1.388	1.178
Formalised Organisational structure	0.6	0	-1	2	3	1.6	1.264
Organisational processes formalised	0.3	0	-1	2	3	0.9	0.948
Core Competencies	2.766	3.166	1.333	3.444	2.111	0.604	0.777
Lead-times to market	0.9	1	-1	2	3	0.988	0.994
Information Intensity	0.8	0.5	0	2	2	0.844	0.918
Added value	-1.05	-1	-2	-0.5	1.5	0.247	0.497
Change management	0.6	1	-1	2	3	1.155	1.074
Knowledge management	0.466	0.5	-0.333	1	1.333	0.227	0.476
Strategic Positioning	1.066	1.333	-1.333	2	3.333	0.883	0.940
Availability	-0.3	-0.5	-1	1	2	0.356	0.597
Structural requirements	0.4	0	-1	2	3	0.711	0.843
Support requirements	0.8	1	-1	2	3	0.844	0.918
Resource requirements	0.9	1	0	2	2	0.544	0.737
Globalisation	0.4	0	-1	2	3	0.711	0.843
Internal economic environment	0	0	-1	1	2	0.444	0.666
External economic environment	0.05	0	-1	1	2	0.469	0.685
Security	0.5	0	-1	2	3	1.388	1.178

Statistics: Prospective Users Elements Q1-16

Elements	Mean	Median	Min.	Max.	Range	Sample Var.	Sample Stand. Dev.
Quality management	0.714	0.5	-1	2	3	0.989	0.994
Corporate memory	0.702	0.916	-1.166	2.166	3.333	0.872	0.934
Risk & Feasibility management	0.785	1	-1	2	3	0.796	0.892
Organisational complexity	0.285	0	-1	2	3	0.681	0.825
Formalised Organisational structure	0.357	0	-1	2	3	1.016	1.008
Organisational processes formalised	0.142	0	-1	2	3	1.054	1.027
Core Competencies	2	2.611	-0.444	3.222	3.666	1.354	1.163
Lead-times to market	0.214	0	-2	2	4	1.873	1.368
Information Intensity	0.642	0.5	-2	2	4	1.324	1.150
Added value	-1.035	-1	-2	0	2	0.440	0.664
Change management	0.214	0	-1	2	3	0.796	0.892
Knowledge management	0.428	0.333	-0.333	1.333	1.666	0.280	0.529
Strategic Positioning	0.857	1	-1	2	3	0.678	0.823
Availability	0.0238	0	-0.666	1	1.666	0.213	0.461
Structural requirements	0.428	0	-2	2	4	1.032	1.016
Support requirements	0.642	1	-2	2	4	0.862	0.928
Resource requirements	0.857	1	0	2	2	0.285	0.534
Globalisation	0.428	0	-2	2	4	1.032	1.016
Internal economic environment	-0.071	0	-1	1	2	0.532	0.730
External economic environment	0.071	0.25	-1	1	2	0.571	0.755
Security	0.285	0	-1	2	3	0.681	0.825

Statistics: NON VR Users Elements Q1-16

Elements	Mean	Median	Min.	Max.	Range	Sample Var.	Sample Stand. Dev.
Quality management	0.5	0.5	-1	2	3	1.1	1.048
Corporate memory	-0.388	-0.416	-1.666	0.5	2.166	0.607	0.779
Risk & Feasibility management	-0.166	0	-2	2	4	2.566	1.602
Organisational complexity	-0.5	-0.5	-2	2	4	2.3	1.516
Formalised Organisational structure	0.333	0.5	-1	1	2	0.666	0.816
Organisational processes formalised	0.333	0.5	-1	2	3	1.466	1.211
Core Competencies	0.592	0.555	-0.444	2.333	2.777	1.030	1.015
Lead-times to market	-0.5	0	-2	0	2	0.7	0.836
Information Intensity	-0.166	0	-2	1	3	0.966	0.983
Added value	-1	-1.5	-2	0.5	2.5	1	1
Change management	-0.833	-1.5	-2	1	3	2.166	1.471
Knowledge management	-0.055	0	-0.333	0.333	0.666	0.062	0.250
Strategic Positioning	-0.055	-0.166	-0.666	1	1.666	0.507	0.712
Availability	-0.055	0	-0.666	0.666	1.333	0.196	0.443
Structural requirements	-0.5	0	-2	1	3	1.5	1.224
Support requirements	-0.5	-0.5	-2	1	3	1.9	1.378
Resource requirements	-0.166	0.5	-2	1	3	2.166	1.471
Globalisation	-0.5	0	-2	1	3	1.5	1.224
Internal economic environment	-1.333	-1.5	-2	0	2	0.666	0.816
External economic environment	0.25	0.5	-1	1	2	0.475	0.689
Security	-0.5	-0.5	-2	2	4	2.3	1.516

Statistics: VR Users System Elements Q1-16

Elements	Mean	Median	Min.	Max.	Range	Sample Var.	Sample Stand. Dev.
Functional requirements	0.7	1	-1	2	3	0.677	0.823
Upgradability	1	1	-1	2	3	1.111	1.054
Longevity	1.1	1	0	2	2	0.766	0.875
Cost-performance	1	1	0	2	2	0.666	0.816
Technological Complexity	0.837	0.687	0	2	2	0.364	0.603
Advanced computing	0.8	1	-2	2	4	1.955	1.398
Ease-of-use	0.3	0	-1	2	3	0.677	0.823
Human interface systems	0.9	1	-2	2	4	1.655	1.286
Position tracking	0.3	0	-1	2	3	1.122	1.059
Display systems	0.9	1	-2	2	4	1.655	1.286
Image fidelity	1	1	-1	2	3	1.111	1.054
Acoustic fidelity	0.2	0	-1	2	3	1.066	1.032
Haptic fidelity	0	0	-2	2	4	1.111	1.054
Tele-communications	1.2	1.5	0	2	2	0.844	0.918
Customer expectations	1.5	2	0	2	2	0.722	0.849
Compliance with customer requirements	1.5	2	0	2	2	0.722	0.849
Product differentiation	1.3	1.5	0	2	2	0.677	0.823
Visual acuity	0.5	0	-1	2	3	0.944	0.971
Auditory acuity	0.2	0	-1	2	3	1.066	1.032
Work satisfaction	0.8	1	-1	2	3	1.066	1.032
Meaningful work	0.7	1	0	2	2	0.455	0.674
Technology skills and competencies	0.8	1	0	2	2	0.622	0.788
Imagination & creativity	0.7	0.5	0	2	2	0.677	0.823

Statistics: Prospective Users Elements Q1-16

Elements	Mean	Median	Min.	Max.	Range	Sample Var.	Sample Stand. Dev.
Functional requirements	0.5	1	-2	2	4	1.038	1.019
Upgradability	0.357	1	-2	2	4	1.170	1.081
Longevity	0.571	1	-2	2	4	0.879	0.937
Cost-performance	0.857	1	-2	2	4	1.054	1.027
Technological Complexity	0.169	0.25	-0.75	1.25	2	0.287	0.536
Advanced computing	0	0	-2	2	4	1.538	1.240
Ease-of-use	0.428	0.5	-2	2	4	1.494	1.222
Human interface systems	-0.071	0	-2	2	4	1.763	1.328
Position tracking	-0.071	0	-2	2	4	0.686	0.828
Display systems	0.214	0.5	-2	2	4	1.719	1.311
Image fidelity	0.214	0	-2	2	4	1.873	1.368
Acoustic fidelity	-0.142	0	-2	2	4	0.901	0.949
Haptic fidelity	-0.142	0	-1	0	1	0.131	0.363
Tele-communications	0.571	0.5	-1	2	3	1.032	1.016
Customer expectations	1	1	0	2	2	0.769	0.877
Compliance with customer requirements	1	1	0	2	2	0.769	0.877
Product differentiation	0.357	0	-2	2	4	1.939	1.392
Visual acuity	0.142	0	-1	2	3	0.439	0.662
Auditory acuity	0.071	0	-1	2	3	0.379	0.615
Work satisfaction	0.857	1	-1	2	3	0.747	0.864
Meaningful work	0.785	1	-1	2	3	0.796	0.892
Technology skills and competencies	0.5	0	0	2	2	0.423	0.650
Imagination & creativity	0.8571429	1	-1	2	3	1.054	1.027

Statistics: NON VR Users Elements Q1-16

Elements	Mean	Median	Min.	Max.	Range	Sample Var.	Sample Stand. Dev.
Functional requirements	-0.5	-0.5	-2	1	3	1.9	1.378
Upgradability	-0.833	-1	-2	1	3	1.766	1.329
Longevity	-1	-1.5	-2	1	3	1.6	1.264
Cost-performance	0.833	0.5	0	2	2	0.966	0.983
Technological Complexity	-0.208	-0.125	-0.625	0	0.625	0.047	0.218
Advanced computing	-1	-1.5	-2	1	3	1.6	1.264
Ease-of-use	0	0	-2	2	4	1.6	1.264
Human interface systems	-0.833	-1	-2	1	3	1.766	1.329
Position tracking	0.166	0	0	1	1	0.166	0.408
Display systems	-0.833	-1	-2	1	3	1.766	1.329
Image fidelity	0	0	-1	1	2	0.4	0.632
Acoustic fidelity	-0.166	0	-1	0	1	0.166	0.408
Haptic fidelity	0	0	0	0	0	0	0
Tele-communications	-0.333	0	-2	1	3	1.866	1.366
Customer expectations	0.166	1	-2	2	4	2.966	1.722
Compliance with customer requirements	0.5	1	-2	2	4	2.7	1.643
Product differentiation	0	0	-2	2	4	2	1.414
Visual acuity	0.166	0	0	1	1	0.166	0.408
Auditory acuity	0	0	-1	1	2	0.4	0.632
Work satisfaction	-0.166	0	-1	0	1	0.166	0.408
Meaningful work	0.166	0	-1	1	2	0.566	0.752
Technology skills and competencies	-0.333	0	-2	0	2	0.666	0.816
Imagination & creativity	-0.333	0	-2	2	4	2.2666667	1.505545305

Statistics: VR Users System Elements Q1-16

Elements	Mean	Median	Min.	Max.	Range	Sample Var.	Sample Stand. Dev.
Social organisation of work	0.4	0	-1	2	3	0.933	0.966
Skills upgrading	-0.1	0	-2	2	4	1.211	1.100
Geo-spatial distribution	0.1	0	-1	1	2	0.766	0.875
Job displacement	0.9	1	0	2	2	0.766	0.875
Job creation	-0.1	0	-2	1	3	0.766	0.875
Job redesign	-0.2	0	-2	1	3	1.066	1.032
Risk taking	1.3	1.5	0	2	2	0.677	0.823
Technological impact	0.4	0.5	-1	1	2	0.488	0.699
Virtuality as Social phenomenon	0	0	-1	1	2	0.444	0.666
Industry sector ethnographics	-0.1	0	-1	1	2	0.544	0.737
Sectoral transformation	0.7	0.5	-1	2	3	1.122	1.059
Changes in the nature & organization of work	0.8	1	-1	2	3	1.066	1.032
Spread of technology in the workplace	0.2	0	-1	1	2	0.622	0.788
Increasing global competition	0.666	0.666	-0.333	1.5	1.833	0.327	0.571
Global village concept	0.5	0.5	-2	2	4	1.388	1.178
Socially responsible/Ethical behaviours & norms	0.4	0.5	-1	1	2	0.488	0.699
Visual stimulation	1	1	0	2	2	0.888	0.942
Haptic stimulation	0	0	-2	2	4	1.111	1.054
Proprioception	0.2	0	0	2	2	0.4	0.632
Dynamics	0.2	0	0	2	2	0.4	0.632
Immersion	1.1	1.5	-1	2	3	1.433	1.197

Statistics: Prospective Users Elements Q1-16

Elements	Mean	Median	Min.	Max.	Range	Sample Var.	Sample Stand. Dev.
Social organisation of work	0.142	0	-2	2	4	1.362	1.167
Skills upgrading	-0.714	-0.5	-2	1	3	1.296	1.138
Geo-spatial distribution	-0.142	0	-2	2	4	1.362	1.167
Job displacement	1	1	-2	2	4	1.384	1.176
Job creation	-0.785	-1	-2	1	3	0.950	0.974
Job redesign	-0.642	-0.5	-2	1	3	1.478	1.215
Risk taking	0.071	0	-1	2	3	0.532	0.730
Technological impact	0.357	0	-1	2	3	0.862	0.928
Virtuality as Social phenomenon	0.071	0	0	1	1	0.071	0.267
Industry sector ethnographics	-0.714	-0.5	-2	0	2	0.681	0.825
Sectoral transformation	-0.071	0	-2	1	3	0.994	0.997
Changes in the nature & organization of work	0	0	-2	2	4	1.230	1.109
Spread of technology in the workplace	-0.714	-1	-2	2	4	1.604	1.266
Increasing global competition	0.357	0.5	-1.166	1.5	2.666	0.465	0.682
Global village concept	-0.357	-0.5	-2	2	4	1.631	1.277
Socially responsible/Ethical behaviours & norms	0.357	0	-1	2	3	0.862	0.928
Visual stimulation	0.071	0	-2	2	4	1.456	1.206
Haptic stimulation	-0.071	0	-1	0	1	0.071	0.267
Proprioception	0.071	0	0	1	1	0.071	0.267
Dynamics	0.071	0	0	1	1	0.071	0.267
Immersion	-0.285	0	-1	0	1	0.219	0.468

Statistics: NON VR Users Elements Q1-16

Elements	Mean	Median	Min.	Max.	Range	Sample Var.	Sample Stand. Dev.
Social organisation of work	-1	-1	-2	0	2	0.8	0.894
Skills upgrading	-0.833	-1.5	-2	2	4	2.566	1.602
Geo-spatial distribution	-0.666	-1	-2	2	4	2.266	1.505
Job displacement	1.333	1.5	0	2	2	0.666	0.816
Job creation	-1.333	-1.5	-2	0	2	0.666	0.816
Job redesign	-1.166	-1.5	-2	0	2	0.966	0.983
Risk taking	-1.166	-1.5	-2	0	2	0.966	0.983
Technological impact	-0.833	-1.5	-2	2	4	2.566	1.602
Virtuality as Social phenomenon	0.166	0	0	1	1	0.166	0.408
Industry sector ethnographics	-1.333	-1.5	-2	0	2	0.666	0.816
Sectoral transformation	-0.333	-0.5	-2	2	4	2.666	1.632
Changes in the nature & organization of work	-1.333	-1.5	-2	0	2	0.666	0.816
Spread of technology in the workplace	-1.166	-1.5	-2	0	2	0.966	0.983
Increasing global competition	-0.166	-0.166	-0.333	0	0.333	0.033	0.182
Global village concept	-0.833	-1.5	-2	2	4	2.566	1.602
Socially responsible/Ethical behaviours & norms	-0.833	-1.5	-2	2	4	2.566	1.602
Visual stimulation	0	0	-1	1	2	0.4	0.632
Haptic stimulation	0	0	0	0	0	0	0
Proprioception	0	0	0	0	0	0	0
Dynamics	0	0	0	0	0	0	0
Immersion	-0.5	-0.5	-1	0	1	0.3	0.547

Statistics: VR Users System Elements Q1-16

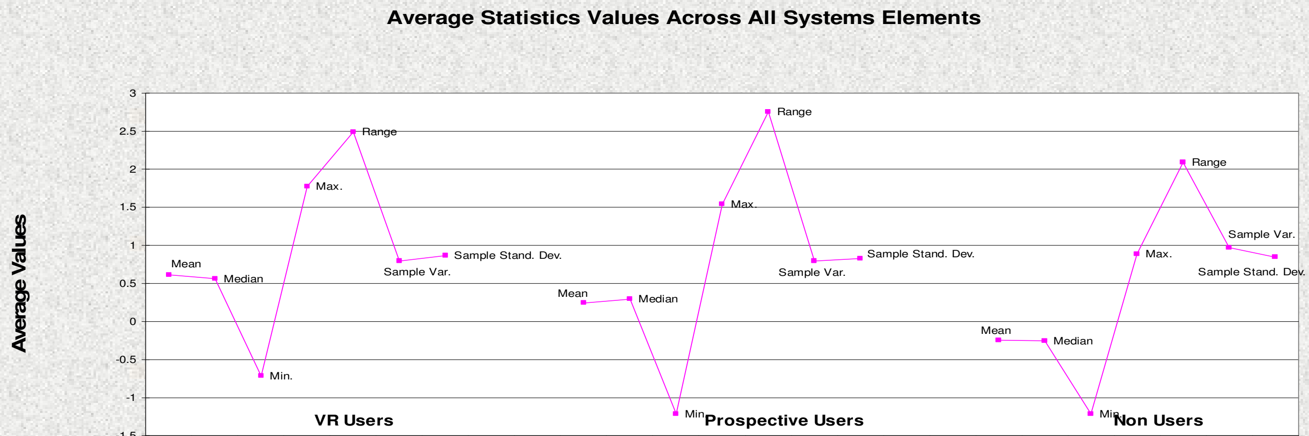
Elements	Mean	Median	Min.	Max.	Range	Sample Var.	Sample Stand. Dev.
Engagement	0.6	0	0	2	2	0.711	0.843
Interactivity	0.7	0.5	-0.5	2	2.5	0.844	0.918
Presence	0.5	0	0	2	2	0.722	0.849
Tele-presence	0.5	0	0	2	2	0.722	0.849
Tele-robotics	0.4	0	-1	2	3	0.933	0.966
Movement	0.5	0	-1	2	3	0.944	0.971
Geo-spatial factors	0.4	0	-1	2	3	0.933	0.966
Transparent systems integration	1.2	1.5	0	2	2	0.844	0.918
Spaciality	-0.2	0	-2	2	4	1.288	1.135
Illusion	0	0	-2	2	4	1.111	1.054
3D-stereoscopic vision	0.55	0.5	0	1.5	1.5	0.358	0.598
Visualisation & graphics	0.05	0	-0.5	1	1.5	0.358	0.598
3D-surround sound	0.2	0	-1	2	3	1.066	1.032
Repeatability	0.7	0	0	2	2	0.9	0.948
Realism	0.7	0	0	2	2	0.9	0.948
Virtual work-space	0.4	0	-1	2	3	1.377	1.173
Mediated environments	0	0	-1	1	2	0.444	0.666
Information rich environments	1.2	1	0	2	2	0.622	0.788
Latency	0.4	0	-1	2	3	0.933	0.966
Competition	-0.25	-0.5	-1	1	2	0.513	0.716
IT Orientation	0.95	0.75	-0.5	2	2.5	0.802	0.895
Dynamic Technology Orientation	0.175	0.125	-0.25	0.75	1	0.111	0.334
Technology User	0.975	1	0	2	2	0.367	0.606
Averages for all Systems Elements:	**0.610**	**0.563**	**-0.712**	**1.777**	**2.489**	**0.796**	**0.863**

Statistics: Prospective Users Elements Q1-16

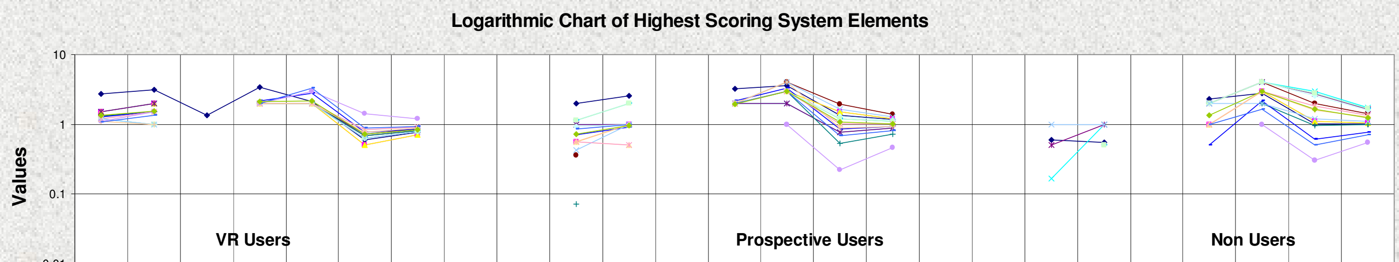
Elements	Mean	Median	Min.	Max.	Range	Sample Var.	Sample Stand. Dev.
Engagement	0	0	-1	1	2	0.153	0.392
Interactivity	0.214	0.5	-1.5	1	2.5	0.565	0.752
Presence	-0.072	0	-1	1	2	0.225	0.474
Tele-presence	-0.142	0	-1	0	1	0.131	0.363
Tele-robotics	-0.071	0	-1	0	1	0.071	0.267
Movement	0.142	0	-1	2	3	0.439	0.662
Geo-spatial factors	0.142	0	-2	2	4	1.362	1.167
Transparent systems integration	0.571	0.5	-1	2	3	1.032	1.016
Spaciality	0	0	-1	1	2	0.153	0.392
Illusion	-0.142	0	-1	0	1	0.131	0.363
3D-stereoscopic vision	-0.214	0	-1	0.5	1.5	0.219	0.468
Visualisation & graphics	-0.357	-0.5	-0.5	0	0.5	0.054	0.234
3D-surround sound	-0.142	0	-2	2	4	0.901	0.949
Repeatability	0.142	0	0	1	1	0.131	0.363
Realism	0.142	0	0	1	1	0.131	0.363
Virtual work-space	0	0	-1	1	2	0.153	0.392
Mediated environments	0.071	0	0	1	1	0.071	0.267
Information rich environments	1.142	2	-1	2	3	1.208	1.099
Latency	-0.071	0	-1	0	1	0.071	0.267
Competition	-0.142	0	-1.5	1.5	3	0.708	0.841
IT Orientation	0.178	0.5	-1.5	2	3.5	1.215	1.102
Dynamic Technology Orientation	-0.035	-0.25	-1.25	1.5	2.75	0.585	0.764
Technology User	0.464	0.5	-0.75	2	2.75	0.585	0.764
Averages for all Systems Elements:	**0.248**	**0.295**	**-1.212**	**1.537**	**2.750**	**0.800**	**0.830**

Statistics: NON VR Users Elements Q1-16

Elements	Mean	Median	Min.	Max.	Range	Sample Var.	Sample Stand. Dev.
Engagement	0.166	0	0	1	1	0.166	0.408
Interactivity	0.083	0	-0.5	0.5	1	0.141	0.376
Presence	0.166	0	0	1	1	0.166	0.408
Tele-presence	0.166	0	0	1	1	0.166	0.408
Tele-robotics	-0.333	0	-2	0	2	0.666	0.816
Movement	0.166	0	0	1	1	0.166	0.408
Geo-spatial factors	-1	-1	-2	0	2	0.8	0.894
Transparent systems integration	-0.333	0	-2	1	3	1.866	1.366
Spaciality	-0.333	0	-2	0	2	0.666	0.816
Illusion	0	0	0	0	0	0	0
3D-stereoscopic vision	-0.583	-0.5	-1	0	1	0.141	0.376
Visualisation & graphics	-0.416	-0.5	-0.5	0	0.5	0.041	0.204
3D-surround sound	-0.166	0	-1	0	1	0.166	0.408
Repeatability	0	0	0	0	0	0	0
Realism	0	0	0	0	0	0	0
Virtual work-space	0	0	0	0	0	0	0
Mediated environments	0.166	0	0	1	1	0.166	0.408
Information rich environments	0	0.5	-2	2	4	2.8	1.673
Latency	0.166	0	0	1	1	0.166	0.408
Competition	0	0	-0.5	0.5	1	0.2	0.447
IT Orientation	-0.75	-1	-1.5	0	1.5	0.375	0.612
Dynamic Technology Orientation	-0.041	0	-0.25	0.25	0.5	0.035	0.188
Technology User	-0.208	-0.25	-0.75	0.5	1.25	0.210	0.458
Averages for all Systems Elements:	**-0.246**	**-0.251**	**-1.212**	**0.883**	**2.095**	**0.970**	**0.845**



	VR Users: Mean	Median	Min.	Max.	Range	Sample Var.	Sample Stand. Dev.	Prospective Users: Mean	Median	Min.	Max.	Range	Sample Var.	Sample Stand. Dev.	Non Users: Mean	Median	Min.	Max.	Range	Sample Var.	Sample Stand. Dev.
Averages of all Systems Elements:	0.61006	0.56301	-0.712	1.77774	2.48975	0.79671	0.8636	0.24825	0.29527	-1.2124	1.53784	2.75022	0.80089	0.83001	-0.246	-0.2516	-1.2121	0.88344	2.09554	0.97024	0.8458



VR Users

	Mean	Median	Min.	Max.	Range	Sample Var.	Sample Stand. Dev.
Core Competencies	2.76667	3.16667	1.33333	3.44444	2.11111	0.6048	0.77769
Innovation culture	1.5	2	0	2	2	0.5	0.70711
Strategic attitude	1.5	2	0	2	2	0.5	0.70711
Customer expectations	1.5	2	0	2	2	0.72222	0.84984
Compliance with customer requirements	1.5	2	0	2	2	0.72222	0.84984
Product differentiation	1.3	1.5	0	2	2	0.67778	0.82327
Risk taking	1.3	1.5	0	2	2	0.67778	0.82327
Corporate memory	1.26667	1.5	-0.66667	2.16667	2.83333	0.76049	0.87206
Information rich environments	1.2	1	0	2	2	0.62222	0.78881

Prospective Users

	Mean	Median	Min.	Max.	Range	Sample Var.	Sample Stand. Dev.
Core Competencies	2	2.61111	-0.44444	3.22222	3.66667	1.35423	1.16371
Innovation culture	0.57143	1	-1	2	3	1.49451	1.2225
Strategic attitude	0.57143	1	-1	2	3	1.49451	1.2225
Customer expectations	1	1	0	2	2	0.76923	0.87706
Compliance with customer requirements	1	1	0	2	2	0.76923	0.87706
Product differentiation	0.35714	0	-2	2	4	1.93956	1.39268
Risk taking	0.07143	0	-1	2	3	0.53297	0.73005
Corporate memory	0.70238	0.91667	-1.16667	2.16667	3.33333	0.87256	0.93411
Information rich environments	1.14286	2	-1	2	3	1.20879	1.09945

Non Users

	Mean	Median	Min.	Max.	Range	Sample Var.	Sample Stand. Dev.
Core Competencies	0.59259	0.55556	-0.44444	2.33333	2.77778	1.03045	1.01511
Innovation culture	-0.5	-0.5	-2	1	3	1.1	1.04881
Strategic attitude	-0.5	-0.5	-2	1	3	1.1	1.04881
Customer expectations	0.16667	1	-2	2	4	2.96667	1.7224
Compliance with customer requirements	0.5	1	-2	2	4	2.7	1.64317
Product differentiation	0	0	-2	2	4	2	1.41421
Risk taking	-1.16667	-1.5	-2	0	2	0.96667	0.98319
Corporate memory	-0.38889	-0.41667	-1.66667	0.5	2.16667	0.60741	0.77936
Information rich environments	0	0.5	-2	2	4	2.8	1.67332

Note that negative or zero values do not compute correctly for logarithmic charts thus only positive values are charted.
VR Users demonstrate strong positive clustering whilst Prospective and Non Users are increasingly dispersed and include more negative values.

Appendix 4.

Summary of VR Technology and Systems

Provides a tabulated listing of VR technology and associated systems, display methods, number of users and exemplar areas of application.

Summary of VR Technology and Systems

Technology	Related Systems	Display Method	Number of Users	Exemplar Applications
Virtual Reality Centre	High performance computer systems often associated with super-computer installations. High-performance multi-projector imaging systems, 3D capable. High performance communications network access and associated technical interfaces. Dedicated physical building resources. Dedicated high-level expertise support personnel.	Imaging projected on floor-to-ceiling wrap-around curved screens. Semi-immersive capable. See exemplar VRC environments illustrated and discussed in Chapter 2. Section 2.3.1 Pages 23-25, 37.	Medium sized groups up to 20-30.	Semi-immersive visualization of real-time or time-displaced events. Visualization of architectural design and development proposals. Full-scale imaging of products and related systems, for example: automotive and aerospace vehicles and related products. Visualization of simulated production systems. Visualization of large complex data sets such as in oil and gas exploration. Visualization of simulated transport logistics and supply-chain systems. Interactive exploration of virtual worlds
CAVE Environments	High performance computer systems. High-performance multi-projector imaging with associated User human-interface systems, 3D capable. Dedicated physical building resources. Access to high-level expertise support personnel	Imaging projected on walls, floor, ceiling of contained environment. Immersive capable. See exemplar CAVE environments illustrated and discussed in Chapter 2. Section 2.3.1 Pages 21-22	Small groups 2-4.	Immersive visualization of complex design problems with real-time interaction with software simulation systems and data sets, for example: automotive and aerospace vehicles and related products. Interactive exploration of virtual worlds
Hemisphere & Globe systems	High performance PC to high performance computer systems. 3D capable projection systems with optical imaging control. User human-interface and control systems. Large systems requiring dedicated physical building resources.	Semi-immersive capable. Projected imaging in various sizes and display methods, from small single-user 2m part-hemisphere, to large scale 12m full hemisphere vertical or overhead screens. See exemplar hemisphere environments illustrated and discussed in Chapter 2. Section 2.3.1 Pages 21-22	Individual to medium groups 10-15.	Semi-immersive visualization of real-time or time-displaced events. Visualization of software simulation systems and data sets with real-time User interaction. Typically used in semi-immersive training environments. Interactive exploration of virtual worlds
Medium to large scale flat-screen systems	High performance computer systems. High-performance multi-projector imaging, 3D capable. Large systems requiring dedicated physical building resources. Access to high-level expertise support personnel	Semi-immersive capable. Projected imaging in various sizes and display methods, from small single-user 'design-desk' systems, to large scale IMAX public theatres. See exemplar flat-screen systems in Chapter 2, Section 2.3.1 page 28, 38-41.	Individual to 200+	From small-scale individual design environments, visualization and exploration of data sets, to large-scale semi-immersive visualization of real-time or time-displaced events. Interactive exploration of virtual worlds
Small-scale flat-screen systems	High performance PC. 3D capable desktop systems with user human-interface and control systems.	From PC driven desktop display screens to head-mounted display units and light-weight video eye-wear viewers. See exemplar small-scale flat screen systems in Chapter 2, Section 2.3.1, pages 29-31.	Individual to small groups 2-3	From small-scale individual work-station design environments requiring visualization and exploration of data sets, to semi-immersive visualization of real-time or time-displaced events. Interactive exploration of virtual worlds
Very-small flat-screen systems (Tablets)	High performance Tablet computers with WiFi network access	Touch sensitive interface high resolution Tablet screen	Networked individuals	Interactive exploration of virtual worlds. Visualization and exploration of data sets.