The Development of a Best Practice Framework for the Implementation of Advanced Manufacturing Technologies within Low-Technology-Enabled Small & Medium Enterprises

by

Rupert Lorraine BSc (Hons)

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In an increasingly challenging business climate, rapid developments in Advanced Manufacturing Technologies (AMTs) such as 3D Computer Aided Design (3D CAD), Computer Aided Manufacturing (CAM) and Computer Aided Engineering (CAE) create new opportunities for innovative firms to capture market share, and spearhead new directions and trends within their industrial sectors.

This exploratory study examines the challenges faced by Low-Technology-Enabled Small & Medium Enterprises (LTESMEs), identifying the characterisations that contribute to poor innovation performance and explaining how these can become manifested as barriers and constraints to technology uptake. A best practice model is developed to enlighten and guide decision makers in the implementation of AMTs - uncovering the underlying principles of successful technology adoption / exploitation, and effective change management.

Linkages, such as the Knowledge Transfer Partnerships (KTP) scheme, are shown to facilitate LTESME access to technology; transferring the pre-requisite knowledge and expertise whilst mitigating the associated risks. A case study, comprising action research by the author, documents the implementation of a 3D CAD/CAM/CAE system in a traditional SME boatbuilding firm via a three-year KTP project.

Despite their inherent problems, SMEs are found to be ideally positioned to exploit AMTs, provided they select an appropriate linkage - allowing them to match their needs to specific technological capabilities. This investigation illuminates the subject area, providing a framework for further study, whilst contributing to the growth and sustainability of SMEs.

Chapter 1 Introduction

Chapter 2 Research Design

Chapter 3 Literature Review

Chapter 4 Case Study

Chapter 5 Development of the Model

Chapter 6 Discussion & Conclusions

Appendices

References

List of Figures & Tables

List of Figures & Tables (Continued)

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3D CAD	Three-Dimensional Computer Aided Design
AMT	Advanced Manufacturing Technology
BERR	Department for Business, Enterprise & Regulatory Reform
BSI	British Standards Institution
CAE	Computer Aided Engineering
CAM	Computer Aided Manufacture
CBI	Confederation of British Industry
CEG	Cornwall Engineering Group
CNC	Computer Numerically Controlled
COTS	Commercial Off-The-Shelf
CUC	Combined Universities in Cornwall
DTI	Department for Trade & Industry[1]
EC	European Commission
EU	European Union
FE	Further Education
FEA	Finite Element Analysis
GRP	Glass Reinforced Plastic
HEI	Higher Education Institution
HRM	Human Resource Management
HSE	Health & Safety Executive
ICT	Information Communication Technology
IGES	Initial Graphics Exchange Specification
IOD	Institute of Directors
IP	Intellectual Property
KESW	Knowledge Exploitation South West
KTN	Knowledge Transfer Network
KTP	Knowledge Transfer Partnerships

[1] The DTI has now been replaced by the Department for Business, Enterprise and Regulatory Reform (BERR).

LMC	Local Management Committee
LTESMEs	Low-Technology-Enabled Small & Medium Enterprises
MD	Managing Director
NCN	National Composites Network
NDA	National Development Agency
NURBS	Non-Uniform Rational B-Spline
PLM	Product Lifecycle Management
PR	Public Relations
PRO	Public Research Organisation
R&D	Research & Development
RAM	Random Access Memory
RDA	Regional Development Agency
RIO	Department for Research & Innovation
ROI	Return on Investment
RTAC	Regional Technology Advice Centre
RTO	Research and Technology Organisation
SET	Science, Engineering & Technology
SMART	Specific, Measurable, Achievable, Realistic & Time-bound
SMEs	Small & Medium Enterprises
SWMAS	South West Manufacturing Advisory Service
SWOT	Strengths, Weaknesses, Opportunities and Threats
SWRDA	South West Regional Development Agency
TCO	Total Cost of Ownership
TCS	Teaching Company Scheme
TD	Technology Diffusion
TT	Technology Transfer
UCP	Unlocking Cornish Potential
VRML	Virtual Reality Modelling Language

Author's Declaration

At no time during the registration for the degree of Master of Philosophy has the author been registered for any other University award without prior agreement of the Graduate Committee.

The research described in this thesis was carried out part-time, whilst the author was managing a three-year Knowledge Transfer Partnerships (KTP*) project between the University of Plymouth and Kingfisher Boats Ltd. The research was supported by the School of Engineering within the Faculty of Technology.

* KTP is one of the Department for Trade & Industry's (DTI's) key business support products. The scheme aims to strengthen the competitiveness, wealth creation and economic performance of the UK's Small and Medium Enterprises (SMEs) by the enhancement of knowledge and skills and the stimulation of innovation through collaborative projects between business and the knowledge base.

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Chapter 1 Introduction

Chapter Outline

This chapter aims to explain the area of research, outline the framework on which it has been based and introduce some of the main concepts, which are discussed in more detail throughout the later chapters of the thesis.

The objectives of this chapter are to:

1. Introduce Small and Medium Enterprises (SMEs), describing their definition, role and importance.

2. Discuss the contemporary business challenges faced by SMEs and the importance of Innovation and Continuous Improvement in addressing the challenges.

3. Introduce Advanced Manufacturing Technologies (AMTs) and explain their significance for contemporary SMEs.

4. Discuss problems with the dissemination of AMTs into SMEs, and introduce the concept of the 'Low-Technology-Enabled' SME (LTESME).

5. Describe the purpose and focus of this research, including the aims and objectives of the investigation.

1.1 Introduction

According to the European Commission (EC) "the category of micro, small and medium-sized enterprises (SMEs) is made up of enterprises which employ fewer than 250 persons and which have an annual turnover not exceeding €50 million, and/or an annual balance sheet total not exceeding €43 million" [1].

SMEs play a central role in the European economy [1-6]. There are some 23 million SMEs within the enlarged European Union (EU); providing around 75 million jobs and representing 99% of all enterprises [7]. SMEs are considered an essential source of entrepreneurial skills, innovation and employment [1], they are thus crucial for fostering competitiveness in both the European and global economies.

SMEs are extremely diverse, comprising all types of firms and operating across a broad range of industrial sectors. SMEs range from one-person, 'sole-trader' businesses to co-operative enterprises [8]. Some SMEs are highly technology-focussed whilst others are involved in the provision of more traditional goods and services.

According to *Levy & Powell* SMEs are "a volatile, yet vibrant part of the business environment throughout Europe" [9]. However, SMEs share many common industrial challenges and as *Theng & Boon* (and many others) have shown: they tend to have a high mortality rate [10].

It follows therefore that the successful establishment of SMEs and their subsequent evolution and development "has long been a source of interest and concern for researchers, governments and policy makers" [3].

1.2 Contemporary Challenges for SMEs

SME manufacturing firms face a number of common challenges which demand a rapid and strategic[2] response in order to maintain or increase competitive advantage and profitability.

Goodman comments that there are a number of important social, political and economic issues affecting contemporary business [12]. Pressures such as globalisation, increasing competition, demands for increasingly complex and innovative products and processes, a faster response, shorter product lifetimes and continual technological development have made it increasingly difficult for organisations to compete effectively [13-16].

Jones & Jain observe that companies who had previously been able to remain competitive without investing heavily in product and process innovation are now experiencing difficulties in the contemporary marketplace [15].

1.3 Addressing the Challenges

Pressure from government, associated companies and customers has forced SMEs to respond. Approaches such as the implementation of new technologies, improvement programs, process improvements, advanced management practices and the development of external relationships have been adopted and linked to higher performance in SMEs [11, 16-19].

Hayes & Upton and *Kennedy & Hyland* suggest that enhanced operations capabilities can also allow small firms to compete successfully [11, 20]. *Rouach* suggests that SMEs need to "differentiate themselves from the larger enterprises, and become more innovative" in order to gain a competitive advantage [21].

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[2] According to *Davies*, business strategy is a design or plan for achieving a company's policy goals and objectives [11].

Whatever their approach, SMEs face the prospect of managing significant organisational change in their attempts to remain competitive. Whilst some SMEs are able to respond faster to change than their larger counterparts, they also frequently lack the resources and experience necessary to deal with the 'realities' of change.

1.4 Innovation & Continuous Improvement

Contemporary management thinking popularises two (quite different, but not mutually exclusive) main approaches for SMEs - 'radical change' through Innovation (the successful exploitation of new ideas) and 'incremental change' through Kaizen (continuous improvement processes) [15]. In reality, both approaches are essential, but because this research is primarily concerned with the implementation of new and potentially disruptive technology, the focus of this investigation will be innovation (continuous improvement practices usually follow, being applied to iteratively enhance new systems once established).

Barber asserts that innovation is "not just about new technology" [22] - innovative activity can include the development of new business models and practices, the pursuit of new markets and new forms of organisation. He also suggests that innovative practices are self-perpetuating in that new ideas can arise at any stage of the innovation process.

Innovation is considered to underpin the performance of contemporary SMEs. Work by *Porter* linked innovation to competitiveness [23]. *Jones & Jain* observe that the "SMEs ability to innovate has an impact on its ability to survive in the long run" [15]. *Lambert & Barber* hold that "innovation in some form is essential for the growth and future profitability of all types of small firms" [24].

It must be acknowledged that in apparent contradiction to these findings, a number of organisations remain profitable even though they do not attempt to change their working practices over time. However, research by *Lambert & Barber*, *Barber* and *Porter* shows that the overwhelming majority of SMEs are vulnerable to changes in their input and output markets (in economic, social and technological terms) and are therefore unlikely to 'survive and prosper' without adopting innovative approaches over time [8, 16, 22-24].

Lambert & Barber observe that in pursuing technological innovation, small firms rely on a combination of new technology generated / developed in-house and technology acquired from external sources [24]. They also note that the two sources are 'complementary' in that as the creative capacity of small businesses increases, so too does their capacity to seek-out, access, understand and absorb information from external sources.

1.5 Advanced Manufacturing Technologies

In order to address the challenges posed by the contemporary business climate, SMEs are becoming increasingly concerned with the potential benefits offered by a range of both emerging and established technologies. Technology has been shown to strengthen the individual performance, national development and international competitiveness of small firms [4, 25].

Technology can be broadly defined as the method or technique for converting inputs to outputs in accomplishing a specific task [26]. AMT is the collective term used to describe the application of new technologies, particularly those which are computer-based, in manufacturing processes. The term encompasses technologies such as Computer Aided Design (CAD), Computer Aided Manufacturing (CAM), Computer Aided Engineering (CAE), Computer Numerically Controlled Cutting (CNC), Robotics and Automation, and can also apply to Manufacturing Resource Planning (MRP) systems [14, 27-29].

AMT systems usually consist of two separate elements: hardware and software. Hardware typically refers to physical products, components or other tangible elements, whilst software refers to knowledge (both codified and tacit), skills, routines, techniques or procedures [22, 25]. To a great extent, the way in which these two facets are combined (and the appropriateness of this combination) determines success in any given application of AMT.

SME access to AMTs has improved considerably in the last twenty years, mainly due to the falling cost of hardware coupled with increased processing power, the emergence of affordable 'Windows-based' software, improved means of communication (particularly e-mail) and access to information via the internet. Despite this *Lambert & Barber* show that a significant proportion of industrial output (amongst SMEs) comes from firms with 'moderate or low levels of technological sophistication' [24].

This research will focus on the implementation of design-oriented AMTs, specifically: 3D CAD (which is principally concerned with the enhancement of design capabilities) and the associated / integrated technologies of CAM and CAE (both of which are concerned with the automation of specific functions of the product cycle, and making them more efficient [14]). The integration of CAD systems with manufacturing activities has been shown to provide industry with large economic and commercial benefits [30]. These technologies are discussed in more detail throughout subsequent sections of the report.

It should be noted that in the context of this research investigation, the 'implementation' of AMT refers collectively to the following activities: specification, identification, selection, acquisition, implementation and embedding.

1.6 The Significance of AMTs for SMEs

The benefits of adopting AMTs are extremely diverse and far-reaching. For example, *Jones & Jain* observe that AMT can allow SMEs to compete more effectively with larger or more successful organisations via the eradication of certain advantages such as in-house sales and marketing capabilities, more efficient manufacturing capabilities etc. [15].

Effectively implemented AMT produces technically superior products whilst reducing design and production lead-times [13]. *Meredith* showed that SMEs can use AMT to improve competitiveness through faster innovation and production, increased flexibility and reduced costs [27]. *Jones & Jain* also observed productivity and efficiency improvements, reduced waste, long-run cost savings and enhanced performance [15].

Rouach found that new technology can help SMEs overcome diseconomies of scale (allowing them to compete with larger organisations) as well as improving the flow of information between organisations (enhancing their collective ability to adapt) [21]. *Jayaraman & Agrawal* also observe that AMT can strengthen both the national development and international competitiveness of firms [25].

The development of AMT has also led to the integration of product development (design) and manufacturing engineering (production) functions, which has had a considerable impact on manufacturing management in general [31, 32].

1.7 SME Barriers & Constraints

SMEs tend to display distinctly different characteristics to their larger counterparts in terms of structure, culture, behaviour, focus and strategy: *Kennedy & Hyland* observed a 'considerable body of literature' reporting on the differences between large organisations and SMEs [11]. *Estrin et al.* describe these differences as 'limitations' which can manifest themselves as constraints or barriers to technology uptake [33].

Lybaert suggests that the majority of limitations can be attributed to the size of the SME, arguing that larger firms are 'less constrained' due to their considerable internal resources, particularly with regard to finance, management and their knowledge base [2]. The EC observes that "undertaking the research and development needed to put innovative ideas into practice is often much harder for SMEs than for large firms" [8]. *Rouach* suggests that this is due to their relative lack of in-house skills, expertise and technological development [21]. Large organisations are also at a significant financial advantage over most SMEs, with better access to human capital resources [21, 34-36].

However, *Windrum & Berranger* dismiss the notion that organisational performance can be simplistically linked to firm size in order to explain differences in competitive or innovation performance, or rates of technological adoption [36]. Other, potentially more relevant factors must be considered, including sector-specific issues, access to resources, market conditions, market position and technology-specific issues [23, 35, 36].

Koc & Bosdag comment on SME issues, risks and barriers to adopting AMT - identifying five major categories: lack of information, lack of expertise, perception that advanced technologies are not affordable, pressure to be productive and lack of fit [37].

Jones & Jain suggest that SMEs have reduced access to technological information, and may lack the financial and personnel support needed for technological research and development. They also suggest that SMEs have less ability to absorb the costs and risks associated with new technology [15].

Rouach asserts that "SMEs usually cannot catch up with the latest technology, obtain appropriate and correct information, nor fully utilise the information they have" [21]. *Jones & Jain* found that the 'active monitoring' of technological development was an essential factor in SME survival [15], but one that is often neglected.

Corso et al. identify four primary limitations for technology uptake in SMEs - availability of human and financial resources, inability to rely on external sources of expertise, a lack of strategic planning for the application of technologies (in other words, a primary focus on short-term solutions) and the 'cultural lag' experienced due to high internal resistance [19].

1.8 The Dissemination of AMTs into SMEs

There are a number of organisational, structural, management and strategic implications for SMEs engaged in the implementation of AMT. As *Chorafas* observes, "implementing CAD/CAM is an activity vastly greater and more complex than purchasing equipment or software... the key problem is the change that must take place within the organisation" [32].

Research indicates that success or failure is related to a number of factors, most notably the level and quality of planning activities employed in the early stages of implementation i.e. the way in which organisational change is handled rather than the technological change itself [31].

Jonsson suggests that organisations should consider the need for a supporting infrastructure in order to fully exploit the potential of AMTs [28]. *Castrillon & Cantorna* found that "shortcomings registered in (AMT) are frequently the result of insufficient attention to company organisation, infrastructure and maintenance" [38].

In response to the difficulties faced by SMEs attempting to interface directly with AMTs, a number of 'linkage mechanisms' have emerged. These linkages are rapidly becoming essential pathways for the dissemination of technological knowledge, and hence new technologies, into industry. *Brychan* comments on the importance of "fostering technological knowledge and establishing network links from external sources such as universities and research providers for the dissemination of know-how into SMEs" [39].

Fundamentally, both the new technologies and the linkage mechanism must be appropriate to each other, and the needs of the business. *Pursell* defines 'appropriate technologies' as those which are "inexpensive, easily maintained, suitable for small-scale application, compatible with ones need for creativity, and relatively easy to learn to use" [40]. *Rouach* expands on this concept, commenting that appropriate technologies match the wants and needs of an organisation in terms of levels of knowledge, commitments and financial constraints [21]. The definition of 'appropriate linkage mechanisms' is less straightforward, but includes those which are inexpensive, efficient, mutually beneficial, low-risk and sympathetic to the constraints of the SME.

There are two key processes involved in the dissemination of new technologies into industry - Technology Transfer (TT) (active / planned dissemination) and Technology Diffusion (TD) (passive / natural dissemination) [21, 39]. In reality both processes are inextricably linked, and usually always occur together. In order to support the development of a best practice framework this investigation will focus on dissemination via TT.

TT is regarded as an important route to increased competitiveness within manufacturing firms of all sizes. *Brychan* observes that this is particularly true for SMEs, who have the advantages of flexibility, dynamism and responsiveness [39]. However, as *Rouach* points out, "benefits will be achieved only if the companies select the right technology and the right strategy, and understand the process of (TT)" [21].

Lambert & Barber assert that the processes of innovation and TT are also inextricably linked [24]. *Rouach* suggests that SMEs should "integrate technology transfer into their overall strategy" [21] and closely monitor new technological developments - drawing on a number of sources including government agencies, consultants, suppliers, competitors and customers. *Barber* also proposes a number of sources for new technology / knowledge including in-house Research and Development (R&D) (either collaborative or bought in), universities and other Higher Education Institutions (HEIs), Public Research Organisations (PROs), customers, suppliers, competitors, reverse-engineering, systems integration and 'learning by doing' [22].

Jones & Jain observe that TT can allow companies to "benefit from research and development conducted by external organisations or subsidiaries, while avoiding exposure to the costs and risks associated with in-house development" [15]. However, they also observe that SMEs find TT difficult due to their lack of established contact networks, on-going relationships with large research organisations and available personnel dedicated to the task of scanning for technological developments and potential technology partners.

It is therefore essential that organisations strategically plan the introduction of new policy, technology or processes, in order to ensure the benefits are delivered, and a Return On Investment (ROI) is achieved [11], whilst minimising the associated 'risk of adoption' [21].

Research by *Kennedy & Hyland* showed that SME change efforts (via linkage pathways) do not always provide the desired results [11]. Organisations cannot rely on simply lifting an approach out of context, and instead must develop their own company-specific systems.

It is also crucial that any solutions considered must have the potential to become permanent, and that SMEs avoid the 'tendency to focus on short-term solutions' identified by *Corso et al.* [19].

1.9 Purpose & Focus of the Research

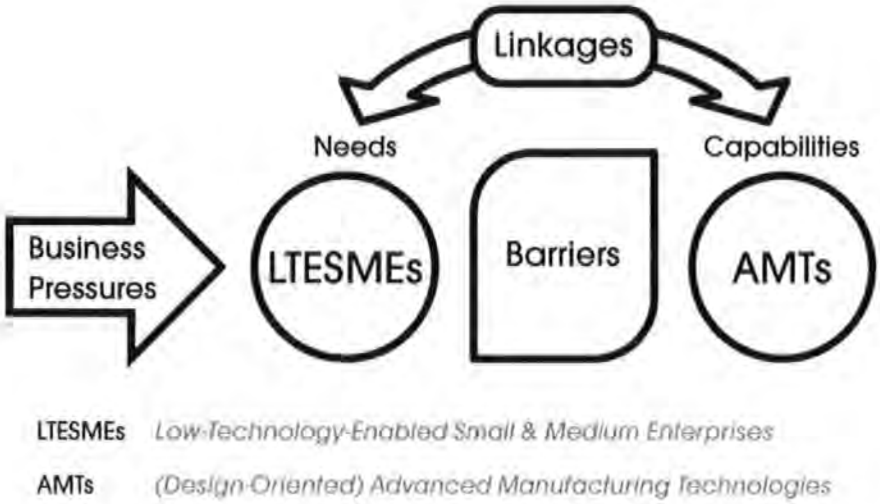

Figure 1. The Research Context

Figure 1 illustrates the conceptual framework around which the research will be based.

Research has shown that the contemporary business pressures facing LTESMEs force them towards the adoption of AMTs in order to enhance or maintain their competitive advantage. However, a number of barriers appear to preclude their direct access to these technologies. Linkage mechanisms (such as TT) have emerged to bridge the gap between individual business needs and specific technological capabilities, providing LTESMEs with the requisite knowledge to overcome their barriers whilst offering guidance in all aspects of the implementation of new technology.

However, there is a substantial lack of research in this area which addresses the specific needs of the LTESME. This investigation aims to make some progress towards redressing the balance by illuminating the overall subject area and providing LTESME managers with clear and practical implementation guidance.

It is hoped that this investigation (and further research in this area) will help to enhance the competitiveness of LTESMEs through more effective technology uptake; hence supporting their continued growth and development.

1.9.1 Research Aim

The aim of this research is to examine the features of contemporary AMTs, LTESMEs and the various linkage mechanisms available to them in order to develop to a more realistic and accurate understanding of the key factors. The research will also contribute to the development of a best practice framework (in the form of a model and associated guidance) for the implementation of AMTs within LTESMEs.

1.9.2 Research Objectives

The objectives of this investigation are to:

1. Characterise LTESMEs in terms of technology, structure, management, behaviour, infrastructure and processes, culture, strategy and access to financial resources. And examine how these features can manifest themselves as barriers or constraints to the uptake of AMT.

2. Examine the features, characteristics, capabilities, benefits and associated challenges of contemporary design-oriented AMTs, and the various ways in which these can be leveraged by SMEs to gain competitive advantage.

3. Identify the primary knowledge sources and various types of linkages available to assist in the dissemination of AMT into LTESMEs.

4. Discuss change management concepts, and issues within LTESMEs.

5. Case study the implementation of AMT within one SME manufacturing firm via a formal linkage with an HEI.

6. Develop a model and associated guidance to assist LTESME managers in the implementation of AMT.

Chapter 2 Research Design

Chapter Outline

This chapter aims to introduce some of the basic principles and concepts of contemporary academic research and describe the way in which this particular investigation has been designed and carried out.

The objectives of this chapter are to:

1. Introduce some basic principles and fundamental components of academic research including: the nature of learning, investigative approaches to research, research outcomes and research validity. Their influences on the selection of an appropriate research methodology for this investigation will also be examined.

2. Define and discuss the research design / methodology used for this investigation, including specific techniques and approaches, sources and nature of the data.

3. Comment on the validity and limitations of the proposed design / methodology.

2.1 Introduction

The word 'research' originates from the French *recherche* - 'the act of searching closely'. Contemporary academic researchers seek to answer important philosophical and scientific questions based on a critical analysis of the various sources of information available to them, which is presented in the form of a 'thesis' (from the Greek *thesis* - 'a proposition').

Research investigations benefit from the application of a detailed plan and formal structure, commonly referred to as the 'research design'. The first step in developing a design for this study is to define, in the broadest possible terms, the central 'research question' that the investigation will attempt to answer. For this investigation the initial research question is:

"What factors affect the implementation of AMTs within LTESMEs?"

However, as *Creswell* observes, this question is likely to evolve and change throughout the investigation, and new questions will emerge [41]. To address this he encourages the identification of a 'framework' for the researcher to work flexibly within, which addresses the knowledge claims[3], strategies of enquiry, and methods of data collection and analysis.

A number of factors influence the formation of *Creswell's* framework including: the circumstances in which the investigation is undertaken, the limitations of the investigation (or the way in which data is collected), aspects of the phenomenon itself as well as the availability and relevance of information [41]. It will be essential to address each of these issues in order to develop the framework for this investigation.

In addition, it will be beneficial to explore in greater detail some key research concepts - including the nature of learning, research outcomes and validity (see Appendix 1) and investigative approaches to research - in order to develop the overall research design.

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[3] *Creswell* explains that, in a scientific context, 'knowledge claims' are the views held by the researcher. Knowledge claims may be based on information from two main sources - primary (the author's own novel understanding and judgement) and secondary (knowledge proposed by others) [41].

2.2 Investigative Approaches to Research

Creswell describes the use of a 'theoretical lens or perspective' to guide research investigations, and identifies three distinct approaches: quantitative, qualitative and mixed methods[4] [41].

Quantitative research, according to *Golafshani* and *Hoepfl*, involves the use of experimental methods and quantitative results to test hypothetical generalisations [46, 48]. *Bogdan & Biklen* explain that the emphasis is on 'facts and causes of behaviour' [49] or in other words 'cause and effect'. Quantitative studies therefore rely heavily on objectivity and impartiality.

In contrast, the qualitative approach, according to *Creswell*, is 'fundamentally interpretive' and useful for those seeking 'broad panoramic views' of their topic, rather than 'micro-analyses' [41]. Qualitative studies tend to be highly subjective, allowing the researcher to take into account their particular insights in order to draw conclusions. *Meredith et al.* observe that whilst objectivity is valuable for prediction, the goal of research is understanding, and so subjectivity also has its place [42].

The qualitative approach is particularly appropriate for this investigation, and will therefore be examined in greater detail throughout the following sub-section.

2.2.1 Qualitative Research

Creswell observes that qualitative research is 'exploratory' and useful when the researcher does not know the important variables to examine, the concept is 'immature' due to a lack of relevant research or when existing research is thought to be inaccurate, inappropriate, incorrect or biased [41]. He also notes that qualitative research takes place 'in the natural setting' and uses multiple methods, which are both 'interactive' and 'humanistic'.

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[4] A mixed methods approach, as the name suggests, uses a combination of quantitative and qualitative methods.

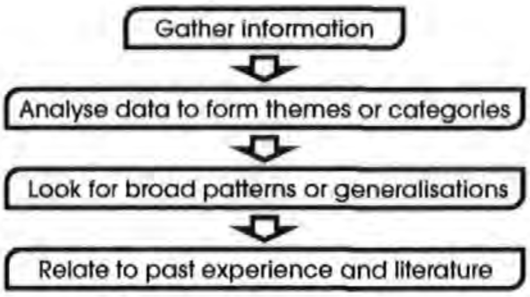

Figure 2. The Inductive Logic of Qualitative Research [41]

Figure 2, which is adapted from *Creswell*, shows the 'inductive logic' of the qualitative approach. He observes that the end-point of qualitative investigations tends to vary, and in some cases may be limited to a 'broad explanation' of the subject [41].

Creswell also observes that "the strategies of inquiry chosen in a qualitative project will have a dramatic influence on the procedures" [41]. He views the qualitative approach as 'emergent' rather than 'tightly prefigured' allowing room for the researcher "to be innovative and to work more within researcher-designed frameworks".

2.3 Methodology for this Investigation

The aim of this investigation is to answer the question - "what factors affect the implementation of AMTs within LTESMEs?" - in order to illuminate the subject area for subsequent research, whilst contributing to the development of a best practice framework which is intended to enlighten and guide LTESME decision makers / operational managers involved in the implementation process.

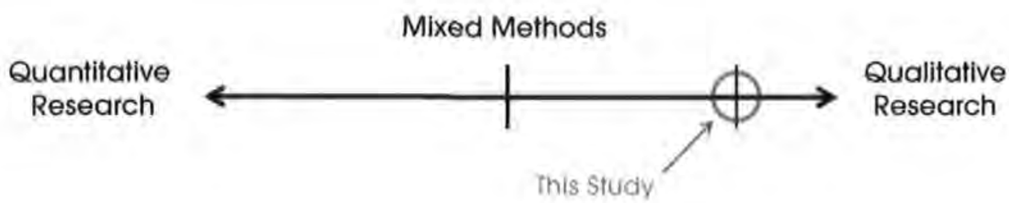

Figure 3. Approach for this Investigation

Figure 3 indicates the position of the study on the spectrum between purely quantitative, and purely qualitative research. As the subject of this investigation is relatively immature (based on the apparent lack of relevant, targeted research) and very situational, involving people and processes, a primarily 'interpretive', qualitatively-biased approach is required[5].

2.3.1 Contribution to the Research Cycle

As has been proposed in Appendix 1, research can be viewed as a cyclic process which iteratively moves towards a more detailed explanation of a phenomenon. *Meredith et al.* comment on the importance of "employing a plurality of research methods" within the cycle, and describe the simultaneous use of multiple methods as 'triangulation' - which can lead to increased robustness and confidence in the results [42]. The appropriateness of a particular combination of research methods is determined by relevance to the problem under investigation, and the circumstances under which the research is undertaken.

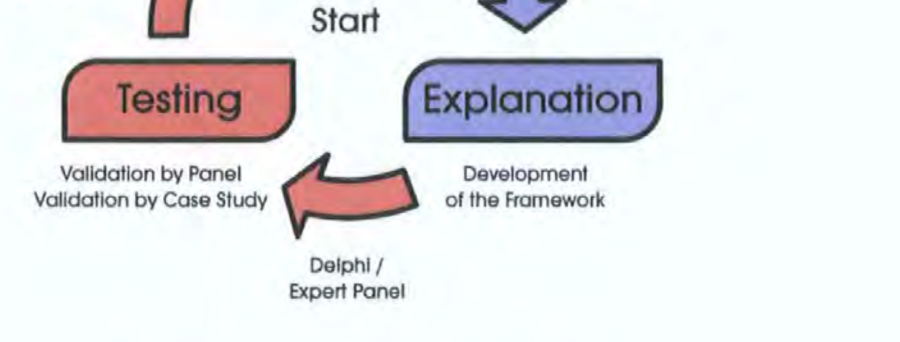

Figure 4. Proposed Research Cycle [42, 43]

[5] *Meredith et al.* comment that the implementation of new technologies "is an area that lends itself particularly well to the use of the interpretive paradigm" [42].

Figure 4 (adapted from *Hobbs*) shows the proposed research methodology for this investigation superimposed on *Meredith et al.'s* research cycle. Although the proposed methodology fulfils their requirement for triangulation / plurality (the use of multiple methodologies) the investigation will not cover a complete revolution of the cycle.

The descriptive phase will concentrate on identifying key characteristics and contributing factors within the phenomenon. For example, the various organisational barriers and constraints to technology uptake present within LTESMEs, as well as the range of available linkage mechanisms. The explanatory phase will be based on analysing the knowledge gained in the description, leading to the development of the best practice model.

The testing phase (undertaken as part of a separate future study) will be used to validate the findings of both the descriptive and explanatory stages. This could be achieved using a variety of techniques including a Delphi / expert panel (comprised of industrialists / technology managers with relevant experience) to review the findings of the investigation and assess the extent to which the members agree or disagree with the proposed framework. Retrospective testing of the model against the case study (which is partly covered by this investigation) could also be legitimately used to demonstrate 'internal validity'.

The main components of the proposed research cycle will be examined in greater detail throughout the following sub-sections.

2.3.2 Literature Review

A broad, thorough and critical review of the current literature relating to LTESMEs, AMTs, linkages and change management will be undertaken in order to highlight the significant factors, and assess the extent to which this subject has already been addressed by the research community. *Creswell* observes that (in qualitative research) the literature 'helps to substantiate the research problem' without constraining the views of the researcher [41].

2.3.3 Case Study

Case studies are used to investigate a specific phenomenon through an in-depth, limited scope study [42]. They allow real operational experiences to be compared and contrasted with existing theory, and for new theories to be generated directly from the data. Case studies tend to produce highly qualitative data.

The breadth of case study investigations can vary dramatically. For this investigation the case study is restricted to a single site, documenting the implementation of a 3D CAD system within Kingfisher Boats Ltd. over a three-year period.

The aim of the case study will be to accurately record the implementation, including the results and lessons learned, and to assess the extent to which the findings of the literature review hold true. This will be a 'longitudinal case study' (involving repeated observations over an extended period) allowing for the study of processes and developments in real-time.

2.3.3.1 Ethnographic, Holistic & Reductionist Aspects

Case studies are an example of ethnographic research methods, which are commonly used in human social research. Ethnography is the study of people or processes in their natural context, and is based on the assertion that a phenomenon cannot be understood purely by observing its component parts[6].

This view is echoed in the related concept of 'scientific holism' - the idea that the properties of a given system cannot be determined or explained by its component parts alone, and that the system as a whole must be examined in order to determine how the parts behave.

In contrast, the 'reductionist view' insists that any complex system can be explained by reduction to its fundamental parts. Despite their apparent contradiction, the views are

[6] Affirming *Aristotle's* rhetorical notion that "the whole is more than the sum of its parts" [44].

complementary - using a combination of approaches will result in a better account of a given system. Hence the combination of literature review (reductionism) and case study (holism) will help to provide robustness in the results of this investigation.

2.3.4 Action Research

Action research describes the direct involvement of the researcher with the phenomenon under observation. For industrial studies this usually involves the comparison of research theory with the activities occurring within a firm. It is possible for the researcher to consciously and/or unconsciously influence the situation whilst collecting data and observing the various dependant variables.

Meredith et al. cite several advantages of action research, including the immediacy of the results and their relevance to the organisation/s involved in the study [42]. *Creswell* also comments that there may be "a strong personal stimulus for (the researcher) to pursue topics that are of personal interest" [41].

2.3.4.1 The Author's Position within the Action Research

This research investigation was undertaken part-time whilst the author was managing a three-year TT project between the University of Plymouth and Kingfisher Boats Ltd. to implement a new 3D CAD system and exploit CAE / CAM outputs.

Throughout this period the author was exposed to prolonged contact with staff at every level throughout Kingfisher Boats Ltd. and the University of Plymouth, as well as individuals from competitors, suppliers, collaborating organisations, other HEIs and advisory groups such as the DTI South West Manufacturing Advisory Service (SWMAS).

This has provided the author with a unique opportunity to influence, as well as observe, the issues surrounding the implementation of AMT within a small firm - whilst building rapport and credibility with those involved. The experience has significantly enhanced the author's understanding of the issues facing LTESMEs as well as building empathy for the 'small businesses perspective' of the issues examined by the investigation.

2.3.5 Personal Experience & Introspective Reflection

Introspective reflection requires the researcher to reflect on their own experience in order to describe, explore, formulate concepts about or evaluate some situation of interest. In this approach the researcher is analysing his / her own impressions, rather than someone else's.

Despite its effectiveness, it can be difficult to control the bias of the researcher (i.e. personal opinions and judgements). For this reason, introspective reflection is often poorly regarded by the wider research community. However, when properly used, *Meredith* observes that the technique can be "highly productive, especially when used in conjunction with action research or some other real-world involvement by the researcher" [45].

Creswell observes that in qualitative studies, the researcher systematically reflects on their position within the enquiry and how it is likely to shape the research. He comments that the qualitative researcher uses complex reasoning which is multi-faceted, iterative and simultaneous, acknowledging the influence of the researcher's own personal training and experiences, which he refers to as 'naturalistic generalisations' [41].

2.3.6 Analysis

Meredith et al. explain that the purpose of analysis is to evaluate factors, make comparisons, note apparent contradictions, observe similarities, make inference and generally gain insight into problems [42]. In this investigation, analysis of the case study should reveal the significance, or lack thereof, of factors identified within the descriptive stages.

Meredith et al. also stress that analysis is always from a particular perspective, over a given period of time. As has already been observed: technological developments tend to occur rapidly, and the validity or relevance of research can diminish as new challenges and solutions emerge [42].

2.3.7 Development of the Framework

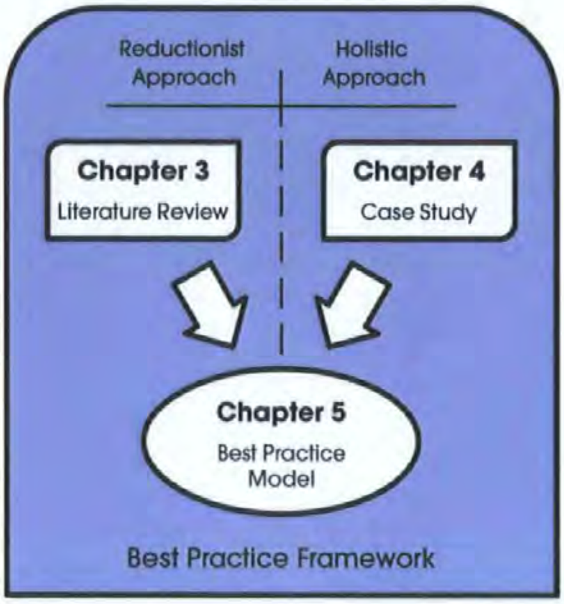

Figure 5. Development of the Framework

Figure 5 shows how the best practice framework will be developed. The insights provided by the literature review will be combined with the knowledge acquired during the case study in order to develop a best practice model for the implementation of AMTs within LTESMEs.

The development of the model will be an interpretive process, heavily influenced by the author's own views and opinions. As a result, the validity of the model is likely to be highly questionable without further testing. Collectively, the various components of the investigation highlighted in figure 5 will provide a balanced conceptual framework around which new studies / future investigations can be designed.

2.4 Limitations & Validity of the Investigation

It is crucial to acknowledge the extent to which this investigation is likely to yield valid results. As a result of the breadth of scope of this study, and the complexity of the phenomenon under investigation, it is unlikely that every aspect will be examined and validated to the fullest possible extent.

One of the major strengths of this investigation is that it is partly based on information obtained 'first-hand' whilst the author was engaged with the process of TT into an LTESME - as stated by *Meredith et al.* "clearly the most valid information is that obtained by direct involvement with the phenomenon" [42].

However, whilst this approach is likely to allow unusual aspects of the phenomenon to be observed, there are limitations: *Creswell* notes that the involvement of the author with the phenomenon under investigation raises a number of strategic, ethical and personal issues which should be acknowledged [41]. For example, the researcher may be seen as 'intrusive' and there may be compromises in their ability to disclose confidential information. Furthermore, the objectivity of the author is likely to be questionable, and the results may be subject to biases in the form of personal interpretation and/or opinion.

Both action research and case studies are highlighted by *Meredith et al.* as 'natural research methods' [42]. It is therefore anticipated that, whilst the data collected is likely to be highly 'internally valid' (as it is based on direct involvement with an implementation of AMT) and current (as it has been undertaken in real-time, and to-date), the results are likely to be highly variable and less easily transferred to other contexts (external validity).

2.5 Summary

This research will be a primarily qualitative investigation intended to contribute to the description and explanation phases of *Meredith et al.'s* research cycle [42]. Testing of the findings will form part of a future study.

The research will seek to identify the factors affecting the implementation of AMTs within LTESMEs, leading to the development of a best practice model to enlighten and guide decision makers / operational managers.

Referring back to the requirements of *Creswell's* framework for research [41](section 2.1), the 'primary knowledge claims' for this investigation will derive from the author's first-hand experience of the implementation of an AMT system within an LTESME throughout the case study. The 'secondary knowledge claims' will derive from a critical analysis of the literature. In addition to the literature review, the 'strategies of enquiry' will encompass a case study and action research by the author.

The 'methods of data collection and analysis' will include direct observation throughout the case study and action research, and introspective reflection by the author. The development of a best practice model from the findings of the previous stages will attempt to interpret the results.

The validity of the investigation will be primarily attributed to the author's position within the study. Although this should yield highly 'internally valid' observations, the associated bias must be acknowledged. Furthermore, as the testing phase will not be carried out, the external validity of the results might be questioned.

It is also likely that the investigation will highlight areas for further exploratory research, or more detailed study, which will be proposed in chapter 6.

Chapter 3 Literature Review

Chapter Outline

This chapter aims to examine the literature relating to LTESMEs and AMTs. The various sources of technological knowledge and expertise will be reviewed alongside the linkages that can facilitate LTESME access to new technologies. A broad review of the principles of change management will also be presented.

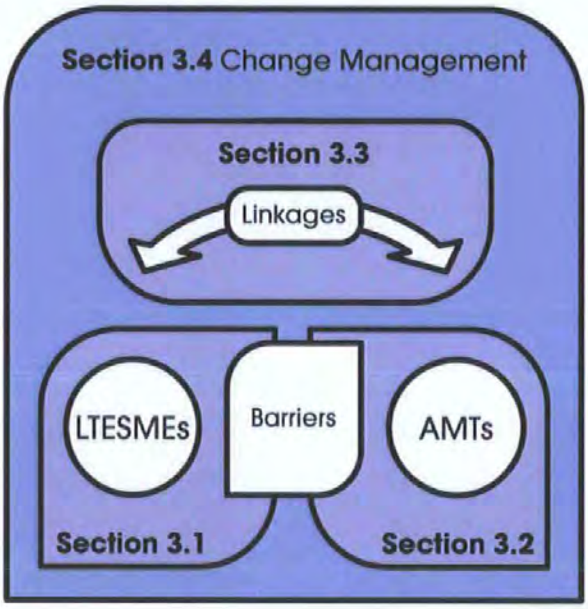

Figure 6. Structure of the Literature Review

Figure 6 outlines the structure of the literature review, and shows the order in which each element of the research context will be examined throughout the subsequent sections.

Presenting the literature review in this compartmentalised manner aims to enhance clarity and understanding. It is acknowledged that as a result, some 'overlaps' or complex inter-relationships present between the main elements may be outside the scope of the study.

The main findings of the literature review will be summarised in section 3.5.

Section 3.1

Low-Technology-Enabled SMEs (LTESMEs)

3.1.1 Introduction

Windrum & Berranger suggest that the SME definition[7] is "problematic since it places under one roof companies that differ enormously in nearly all conceivable dimensions, not only in terms of numbers of employee and turnover but also in their business activities (manufacturing and services), degree of international exposure, customer bases, sector characteristics and technological sophistication" [36].

The current SME definition covers an extremely large and diverse range of organisations, operating across a vast range of industrial sectors, it cannot be used to differentiate between the varying technological levels of firms, nor does it take into account other significant factors such as ownership or the 'character' of organisations, cultural aspects, management styles or entrepreneurial tendencies. Therefore, for the purposes of this research, a new definition was required, to group SMEs in relation to their potential to successfully implement AMTs.

The LTESME definition attempts to group SMEs that display a combination of organisational, behavioural, financial and cultural characteristics which have resulted in: relatively low levels of technology uptake, a lack of technology-specific knowledge and expertise, and inappropriate selection and application of new technologies.

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[7] "Enterprises which employ fewer than 250 persons and which have an annual turnover not exceeding €50 million, and/or an annual balance sheet total not exceeding €43 million" [1].

3.1.2 Characterisation of LTESMEs

Figure 7. LTESME Characteristics

This section aims to identify the main characteristics of LTESMEs that have been shown to inhibit their ability to successfully adopt and exploit new technology. Figure 7 highlights the main areas which were identified within the literature and that will be examined throughout the following sub-sections.

1. Lack of Technology

Both *Thong & Yap* and *Estrin et al.* found that a high proportion of manufacturing SMEs lack 'required technologies' such as CAD/CAM/CAE, high-speed communication networks, and enhanced process management and control tools [33, 46]. *Enzenhofer & Chroust* suggest that SMEs initially struggle to identify appropriate systems due to their unstructured procedures for analysing business needs, and subsequently fail to fully understand the operational aspects once they have been implemented [47].

In a study examining small business needs, *Scientia* reported that pressure to adopt technology usually comes from the outside [48] which is consistent with later findings concerning the traits of typical SME owner-managers. The introduction of new technology implies that a host of related activities such as training will also be required, and this can act to further dissuade SME managers from pursuing technological change.

Resistance may not always come from within the organisation. For example, customers may also resist change efforts for a variety of reasons (particularly if they may have to 'share' some of the cost of the implementation). Concerns may also exist over the longevity of technologies or their service providers - this is particularly common in the software market, where technologies are superseded relatively quickly. Other research has shown that a 'fear of the unknown' is a significant contributing factor towards low technology uptake in small businesses [4, 49-51].

Furthermore, advances in technology tend to occur rapidly, whilst the rate of 'acceptance' of new technology within SMEs is relatively low. Many SMEs tend to be comfortable with their existing technologies (so-called 'legacy systems') and will continue to work with them for as long as possible in order to avoid the risks of implementing new technologies - particularly the risk associated with 'transition' from old to new systems.

Jones-Evans comments on the disadvantages experienced by SMEs which are related to a lack of technology, showing that these could lead to problems both in their ability to source technology appropriate to their needs as well as their capability to absorb it into their organisation, and diffuse it into their industrial sector [52].

A lack of technology amongst small firms can also lead to a 'technology gap' between organisations, precluding their involvement on certain projects. For example, a supplier providing manually operated sheet metal cutting services who moves to CNC technology may no longer be able to work with customers who do not have CAD capability.

2. Structure, Management & Behavioural Issues

Small Business	Medium Business	Large Business
Owner-managed with few layers of management	Owners plus professionals in key leadership roles	Professional management
Micro-management of employees	Empowerment of employees	Freedom to act within corporate guidelines
Informal processes	Formal processes	Formal structures and processes
Short-term planning horizon	Longer-term planning horizon	Short-term results / long-term planning horizon
Low external input	External input from professionals	Governance structure separate from management
Equity held by founder / family	Wider equity base	Diversified equity base
Small customer base	Diversified customer base	Diversified markets with diversified customers
Limited personnel development opportunities	Culture enables employee / management development	Multiple career development paths
Low borrowing requirement - government support possible	Borrowing needed long-term / funding available shorter term	Wide pool of funding sources

Table 1. Size-Related Organisational Characteristics [53]

Table 1 illustrates some of the main differences between firms of different sizes. SMEs tend to have small management teams, loosely defined organisational structures and a lack of dedicated departments for areas such as IT. There is an emphasis on day-to-day operations and immediate concerns. LTESMEs owner-managers tend to have little time for formal planning and 'strategy' [9, 33, 54, 55], nor do they appreciate the need for rigorous management information [48].

Despite being extremely familiar with their products, market and customers, SME managers may suffer from a lack experience and knowledge in other business areas [56]. As *Thong & Yap* observe, SME managers "may not understand the relationship among business and operational processes, the software technologies that can streamline those processes or the ability of those technologies to serve as a strategic asset" [46].

Hence the SME manager is likely to be absorbed with the day-to-day running of the business and less engaged in any potential application of technology, or the decision-making process required to implement it [33, 46]. *Enzenhofer & Chroust* found that this can lead to excessive time needed to make IT decisions [47]. The management style within the LTESME therefore tends to be one which either actively or passively hinders the process of innovation with regard to technology uptake.

2.1 The Owner-Managed SME

To a great extent, the behavioral characteristics of SMEs stem from the fact that many small businesses are owner-managed. The owner-manager is a considerable force within the small firm; *Lefebvre et al.* found that the personal characteristics of SME CEO's (in terms of personality and decision making styles) were positively correlated with innovativeness [57].

However, owner-managers may also display reluctance, or even a resistance, to implementing change or taking in external help [2]. *Smallbone* suggests a number of reasons for this behaviour, including: doubts over 'value for money', scepticism about generalist advice (particularly where the advice is offered by those lacking detailed sector-specific knowledge), and a preference for 'autonomy' in the running of the business which could be threatened by a reliance on external advice [58].

When technology uptake does occur, the emphasis is usually on cost-saving, efficiency and effectiveness, rather than investment [48]. Owner-managers need to be convinced to introduce technology [56]. *Krumwiede & Sheu* found that a lack of upper management support posed a significant problem in introducing statistical process control in small businesses [59], other studies encountered similar problems in the adoption of total quality management [60] and Just-In-Time (JIT) manufacturing [61, 62].

In contrast, a study by *Haksever* found that the implementation of TQM in small firms was made easier by the informal style of management within SMEs and the leadership qualities of owner-managers [56] - so the influence of the organisational structure and management style is not always negative. Despite the risk of poor performance in terms of actively 'seeking-out' or embracing technology, once a decision is taken SMEs managers can often bring about change more quickly than is generally possible in larger organisations.

Haksever also suggests that small businesses tend to have fewer layers of bureaucracy, are less geographically dispersed, have shorter communication lines, and are less bound by tradition than their larger counterparts [56]. *Estrin et al.* observe that SME owner-managers are "under tremendous pressure to be productive" [33] leading them to respond rapidly to change, with an emphasis on activities / purchases directly affecting profitability.

2.2 SME Flexibility

Organisational flexibility relates to the extent to which organisations are able to respond to their external environment [63]. Flexibility is an essential factor for successful innovation within firms of all sizes. SMEs tend to display more flexibility than their larger counterparts, and several areas of research support this view. *Levy & Powell*, amongst others, hold that flexibility is one of the 'defining characteristics' of SMEs [5, 9, 55, 64].

Manoochehri suggests that SME flexibility can be largely attributed to their low 'labour specialisation', small production volumes and a tendency for participatory decision making [62]. *Levy & Powell* also cite several reasons for greater flexibility amongst SMEs, including: the considerable knowledge of SME owner-managers, relatively flat management structures, an absence of bureaucracy, as well as a tendency for SME production runs to be small (leading to greater flexibility in terms of responding to changes in demand) [9].

Technology and information systems clearly influence organisational flexibility; however, several studies have shown that the other factors (including people, organisational structure and management style) potentially have a greater impact [5, 9, 36, 55, 65]. *Levy & Powell* also comment on research undertaken by *Carrie et al.* which suggests that organisational flexibility can be largely attributed to people, rather than processes and systems [66].

3. Organisational Infrastructure & Process Issues

SMEs generally exhibit informal rules and infrastructures. *Thong & Yap* comment on the tendency for small businesses to rely on so-called 'tribal knowledge' i.e. a combination of knowledge, experience and expertise that is transmitted between employees via informal pathways [46]. They also found a lack of documented procedures and effective communication channels within SMEs.

Evans showed that rapid organisational response to changes in both the environment and technology requires flexibility both in strategic processes and in organisational infrastructures [67]. SMEs, with their relatively informal structures, therefore display a good propensity to be flexible in response to new technology or working practices.

4. Cultural Issues

Organisational culture is a significant, but hard to define force within organisations of all sizes. Cultures are usually described in relation to 'patterns of behaviour' within organisations, as well as the mechanisms (either formal or informal) that can influence behaviour and perception.

In simple terms culture can be thought of as 'the sum of the shared values and beliefs of members of an organisation' or the accepted views and working practices which are naturally transferred to new employees either formally or informally.

Perhaps due to the prevalence of the owner-managed SME, their organisational cultures tend to be distinctly 'centralist' [2]. In other words, there is a strong controlling interest from the Managing Director (MD) in most areas of the business. As with any organisation, the potential for a healthy, collaborative and positive culture exists within SMEs. However, in some cases the lack of formal management training, strategy or vision can result in problems or even a 'broken' culture, further compounding the challenges faced by the small business.

Lybaert found that the individual traits of the owner-manager and the way in which they run the business have a knock-on effect on management behaviour and attitudes to risk [2]. The culture of the SME is therefore likely to be strongly influenced by the approach of the owner-manager or the collective senior management.

5. Strategic Issues

SMEs commonly lack the qualified management teams and knowledge of contemporary management practices found within larger organisations. As a result, SME managers may lack sufficient understanding of the concept of business strategy, or awareness of the potential for a competitive advantage to be realised through the integration of technology and strategy.

Parsons observes a 'lack of attention' given both to understanding the influence of technology on competitiveness, and the support that technology can offer the business strategy [68]. *Hagmann & McCahon* found that this is especially true of SMEs that display a lack of strategic planning and investment [54].

6. Lack of Financial Resources

A lack of financial resources is perhaps the most common characterisation attributed to the small business. In a study of 311 SMEs, *Lybaert* found that 75% of the firms that had identified a need to raise levels of technology (and technological competence) experienced barriers, and that 59% of these firms identified finance as a key factor [2]. Furthermore, in the majority of cases the challenges resulted from raising finance internally (45%) rather than externally (14%). The extent to which financial constraints were present was shown to vary across different industrial sectors. Engineering, for example, tended to be more technically specialised and capital intensive than other sectors.

Lybaert also cites the 'considerable attention' given by the government, the Confederation of British Industry (CBI) and the Bank of England to addressing the financial difficulties faced by SMEs. Interestingly, he found that a lack of financial resources within SMEs is not always related to their difficulty in obtaining external finance, rather that many SMEs simply do not actively seek it [2]. The reasoning behind such behavior is difficult to ascertain, but it may be related to unrealistic perceptions over their eligibility for financial assistance, or the fact that they wish to minimise their exposure to debt.

The effects of financial constraints have been shown to exert immense pressure on organisations; forcing managers to focus on short-term opportunities, rather than long-term strategy [19]. *Thong & Yap* suggest that the same pressures force SME management decisions relating to technology uptake to be cost-led rather than capability-led [46].

Jones & Jain found that limited financial resources could preclude the acquisition of information [15]. A lack of financial resources therefore limits the small businesses ability to support (and benefit from) innovative activity. Financial constraints also preclude the hiring of experienced or qualified individuals capable of driving AMT implementations [2].

3.1.3 LTESME Barriers & Constraints

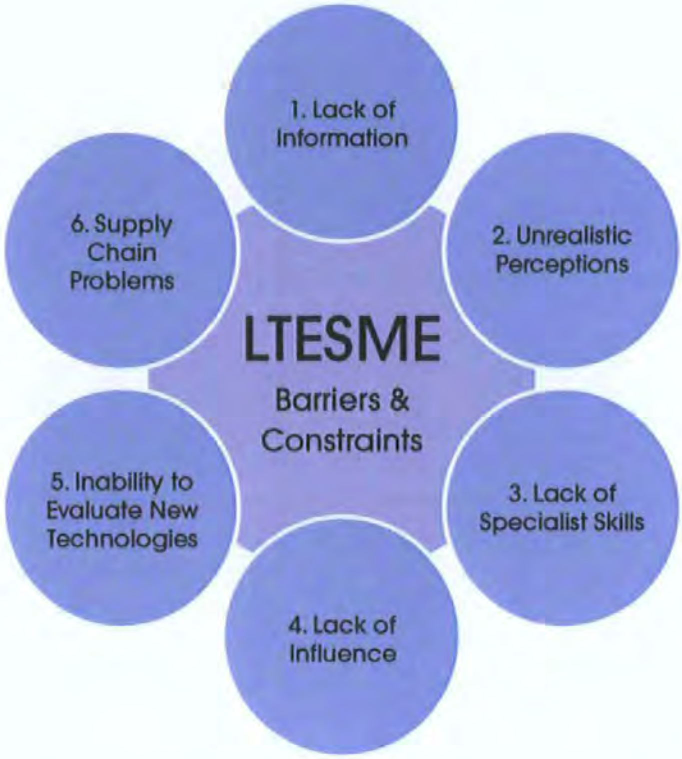

Figure 8. LTESME Barriers & Constraints

This section aims to identify the main barriers and constraints that have been shown to inhibit the LTESME's ability to successfully adopt and exploit new technologies. Figure 8 highlights the main areas which were identified within the literature and will be examined throughout the following sub-sections.

Lybaert observes that "the distinctiveness of SMEs affects their support needs and how much support is delivered if it is to be effective" [2]. Identifying and understanding the main LTESME constraints is therefore essential for the development of the best practice framework. Research in this area consistently highlights a number of inter-related, and in some cases inter-dependant, characteristics which have been shown to influence the uptake of technology (and its subsequent exploitation).

Jones & Jain identified "four primary obstacles or 'challenge areas' faced by SMEs with regard to new technology development and acquisition" including: learning about new technologies, evaluating new technologies, successful technology adoption, and learning about and utilising technology development options [15]. *Martin* supports these observations, proposing that SMEs generally lack the technological knowledge and expertise necessary to scope, acquire, implement and exploit new technologies [69].

1. Lack of Information

In this context, a 'lack of information' broadly encompasses: unawareness of the range of available technologies, their capabilities, benefits and ROI as well as a lack of knowledge about technology selection, adoption and implementation, organisational development and strategic planning [33, 46].

Obtaining accurate information is crucial for success in the adoption of new technologies. *Levy & Powell* propose that innovation itself is driven by information, particularly about the external environment [9]. Despite the widespread availability of external information relevant to many different areas of the business, the main positive relationships of advice and performance in SMEs are dominated by private sector sources such as lawyers, suppliers, customers and business friends / relatives.

Jones & Jain observe that "information about new technologies is widely available and relatively easy to obtain" [15], mainly due to significant developments in communications technology and the widespread availability of information via the internet. They outline a number of sources including: networking, outside consultants, chambers of commerce, customers (primarily for product development purposes), government organisations, technical / industrial publications, the internet, research institutions, existing employees, competitors and suppliers.

Despite this, SMEs tend to display a relative lack of information which is often directly linked to their limited human resources. People within the company provide the link with the 'outside world' and therefore influence an organisation's ability to respond to the external threats and opportunities it faces [30]. Larger organisations tend to have dedicated staff and/or departments to undertake the Research and Development (R&D) role[8] [15] - SMEs often lack this resource.

Managers within LTESMEs may also find it difficult to search for, access and relate to academic research material due to poor links with the knowledge base, the use of complex scientific language and a general lack of 'targeted' or industry-specific research. There may also be problems with the perceived separation of academic and business interests.

SMEs may also lack information as a result of the low value placed on networking, discussion and other non-value adding activities. *Jones & Jain* identify networking as an "important source of information for product and process innovations" [15]. Obtaining external advice in fields such as business strategy and staff recruitment is associated with positive firm performance [3].

Rouach asserts that "due to financial constraints, lack of capabilities and limited human resources to closely monitor technology development, SMEs usually cannot catch up with the latest technology, obtain appropriate and correct information, nor fully utilise the information they have" [21]. *Lybaert* observes that the "limited internal knowledge-base and scanning ability of smaller firms is a key rationale for the publicly subsidised provision of technology support by intermediary organisations in terms of information, advice and consultancy" [2].

[8] R&D activities typically include scanning for new knowledge, technology, materials, applications and processes. The development aspect in this context might include the re-evaluation of existing internal processes or the refinement of new technologies before they are implemented within the production cycle [2, 72, 73].

2. Unrealistic Perceptions

Perhaps as a result of the relative lack of awareness of technology and the presence of 'specialist knowledge' within small organisations, a common phenomenon occurs where management have a range of misconceptions about the capability of a technology, its cost, and the issues surrounding its implementation.

A focus group conducted by *Estrin et al.* found that SME managers viewed technology as an expense rather than a strategic investment [33]. Their research also showed that managers sometimes view technology adoption as a 'never-ending process' and one which could lead to costs 'spiralling out of control'. The common theme in their research was that many managers felt they could not afford 'advanced technologies' irrespective of whether or not their assertions were valid.

Of all barriers to technology uptake, this is perhaps one of the most crucial. Addressing 'unrealistic perceptions' can often mean challenging deeply held views and beliefs about what a technology is capable of and how it can be implemented; the potential for a negative response is therefore very high. Effective change management (covered in section 3.4) is essential in addressing people's perceptions.

3. Lack of Specialist Skills

Thong & Yap observed that SMEs typically employ 'generalist' employees rather than those with specialist skills [46]. In the same way that SME owner-managers tend to take on a number of different roles within their businesses, their employees are also expected to undertake a diverse range of tasks.

There is a strong tendency for 'generalist' workers to lack the time, skills, experience or resources necessary to drive technology uptake [46]. *Robert et al.* observe that whilst SME managers typically possess high levels of understanding of their businesses and operational processes, they often lack employees with sufficient experience and skill to adopt (software-based) technologies [70].

Walker et al. describe a lack of skills as a 'significant barrier', but suggest that this is easily addressed by a structured program of training [4]. However, SMEs have also been shown to display a reluctance to engage with external sources of assistance, and this can result in a self-perpetuating skills gap. *Smallbone* suggests that SMEs display a preference for informal rather than formal channels of support, and argues that this may be due to a lack of management training or formal qualifications amongst those running the business [58].

In 1988, *Medland & Mullineux* observed a shortage in 'generic design skills and knowledge' within manufacturing firms, commenting that "qualified staff are difficult to find" [71]. However, increasing standards of Higher Education coupled with improved access to CAD both within HEIs and organisations has made it easier for companies to gain access to qualified individuals and AMT knowledge.

SMEs may find it difficult to attract specialist employees for a number of other reasons including: the increased employment costs, the unattractiveness of highly constrained SMEs to specialists (due to their numerous problems), the lack of infrastructure necessary to reap the full benefits of technology.

4. Lack of Influence

Lybaert suggests that SMEs have less ability than their larger counterparts to 'shape and influence their external environment' [2]. He infers that as a result of this, the smaller firm is "typically faced with a more uncertain external environment than a larger firm" and therefore committing to significant change or new technology can be difficult.

5. Inability to Evaluate New Technologies

Jones & Jain suggest that "SMEs should seek to minimise the risk of adoption by first conducting an in-depth strategic analysis of any new technology under consideration" [15] - in other words evaluate the long-term implications of adopting new technologies to balance the risk against the potential rewards. Whilst acknowledging that evaluation programmes should be tailored to suit both the specific technologies and businesses involved, they suggest the following issues for a typical evaluation programme to consider:

1. The degree to which the technology will increase the SME's capability to accomplish its strategic objectives.

2. The degree to which the technology will enable the SME to meet or exceed the expectations of its primary clients and customers.

3. The availability of sufficient internal and/or external resources (i.e. financial and/or human resources) both to acquire and implement the new technology.

4. The degree to which the organisational culture will support the technology adoption and contribute to its success.

5. The availability of either in-house or external expertise needed to integrate the new technology with the existing technology.

6. The SME's level of control over the use of, and profits generated by technology.

7. The degree to which the SME is culpable for liability issues surrounding the application of the new technology. [15]

However, due to a number of the aforementioned challenges, LTESMEs are frequently unable to evaluate new technologies either in full or in part.

6. Supply Chain Problems

SME supply chains tend to be more 'personalised' - firms display close relationships with suppliers, which are based on factors other than cost alone. *Estrin et al.* comment on the emergence of a 'supply-chain paradigm' affecting SMEs [33], providing the following example to illustrate their point:

"..."to participate in a supply chain, (large) defence manufacturers are calling on SMEs to collaborate in developing products, managing and providing just-in-time inventory, and producing near perfect quality" *Boden* [72]. These activities, in turn, require computer-based design, engineering, and manufacturing systems, high-speed communication networks, and enhanced process management and control. Large defence manufacturers and leading SMEs already have these capabilities; however, many SMEs still do not." [33]

Stamm & Golhar note that SMEs 'may lack bargaining power' with suppliers and customers as a direct result of their limited size [73]. However, in some industries - marine design and construction, for example - SMEs may play a pivotal role in supporting other organisations within their supply chain. This has significant implications for the introduction of new (and potentially disruptive) technologies that threaten to alter, and even destabilise, relationships within the supply chain.

Problems emerge where the implementation of new technology radically alters working relationships with existing suppliers. Compatibility issues may also arise where organisations select systems with poor interoperability or conversely where suppliers are using outdated systems. There is therefore pressure both up and down the supply chain.

Section 3.2

Advanced Manufacturing Technologies (AMTs)

3.2.1 Introduction

The application of new technologies in manufacturing is becoming an increasingly important source of competitive advantage. Investing in AMT can enable organisations to enhance productivity and efficiency, increase product and process quality levels, reduce the propensity for mistakes and enhance both internal and external communication [9, 15].

Such benefits are of great appeal to organisations of all sizes, irrespective of the products and systems they develop [32]. However, as section 3.1 has shown, LTESMEs are severely limited in their ability to successfully exploit new technologies due to a number of inherent barriers and constraints. A significant factor is their relative lack of information concerning the features and capabilities of AMTs. This can lead to misunderstanding, the inappropriate selection and application of new technologies, and a failure to realise the expected benefits.

This section aims to explore the key features, capabilities, associated challenges and benefits of design-oriented AMTs (3D CAD/CAM/CAE) identified within the literature, in order to aid understanding of these technologies, and hence contribute to the development of a best practice framework for the implementation of AMTs within LTESMEs.

3.2.2 Computer Aided Design

Groover & Zimmers define CAD as "the technology concerned with the use of computer systems to assist in the creation, modification, analysis and optimisation of a design" [74]. CAD systems consist of hardware and software; hardware describes the computer (commonly referred to as the 'workstation') and associated peripheral equipment, and any computer program that embodies computer graphics and an application facilitating engineering functions in the design process is classified as CAD software [14].

In the manufacturing environment CAD is now an almost essential tool; improvements in accessibility to the technology, and growth in its popularity throughout recent years has transformed the way in which organisations think about design, manufacture and communication.

3D CAD is now more accessible than ever before and has become an increasingly popular technology, implemented across many different sectors. *Gott* comments that the major advantages of 3D technology are generally understood throughout industry, although they are often not fully appreciated until seen in commercial practice [75].

CAD systems have been shown to deliver a range of generally positive, but occasionally negative impacts on SME manufacturers. Success or failure with CAD is related to a number of factors, most notably the level and quality of planning activities employed in the early stages of CAD implementation.

In order to plan effectively, organisations must examine and evaluate a broad range of information sources. However, as has already been shown, LTESMEs may find it difficult to engage with academic communities and other sources of high quality information and tend to rely on less reliable sources such as software vendors and non-specialist advisors.

Medland & Mullineux observe that many of the traditional justifications for the adoption or procurement of CAD systems are based upon the concept of increased drawing and design productivity, and for many years this 'vastly over-simplified view' of its effect has been exploited by both software vendors and managers / design departments alike [71]. In reality the potential benefits available through CAD adoption, whilst they are often far-reaching and extremely diverse, are always unique to the organisations involved [76].

Effectively implemented design-oriented AMT facilitates the rapid design and production of technically superior products [13]. The main benefits of AMT are realised by increasing the productivity of people, machinery and internal processes; improving the speed and consistency of both internal and external information flows, and improving an organisations ability to analyse and evaluate designs before committing to production [13].

Begg notes that CAD systems remove drudgery and frustration, and improve product quality by allowing the designer time to be more precise and thorough [77]. Furthermore, the computer's ability to act as a communications link facilitates the efficient design of complex systems by teams, rather than individual designers.

AMT systems therefore offer the potential both to shorten time to market and produce higher quality goods at lower costs [13] - increasing the responsiveness and competitiveness of the CAD-enabled SME and ultimately its profitability [28].

However, since its conception, and throughout its evolutionary development, there have been numerous misjudgements and misconceptions about what CAD is capable of achieving and how it should be practically applied in the commercial environment.

For example, implementing CAD has traditionally been considered to bring increased productivity using less human resources. However, as *Begg* observes "this is definitely not the case" [77]. Such benefits are not an implicit feature of CAD systems - to achieve them organisations must appreciate the true capabilities of the technology and develop an effective implementation strategy that supports their delivery.

For further information on the associated features and capabilities of contemporary 3D CAD systems see Appendix 2. For a brief outline of their history see Appendix 3.

3.2.3 Computer Aided Manufacture & Computer Aided Engineering

CAM, according to *Medland*, is a technology which "embraces all ways in which computers can contribute to manufacturing processes" [30]. The integration of CAD systems with manufacturing activities provides industry with large economic and commercial benefits [30]. CAE, according to *Lee*, is "a technology concerned with the use of computer systems to analyse CAD geometry, allowing the designer to stimulate and study how a product will behave so that the design can be refined and optimised" [14].

The benefits of CAM / CAE include: improved product and organisational quality levels, improved process and product safety, reduction in engineering time and fewer design iterations, improved product functionality (and usability), reduction in number (or elimination) of prototypes, reduced process and product cost [78].

3.2.4 AMT within the Literature

Contemporary CAD is a relatively mature technology; a great deal of academic material exists on the subject, although the major focus appears to have been the development of the CAD systems themselves (i.e. their underlying code-driven structure and the mathematical basis of their respective geometry descriptions) rather than the associated implementation issues, which are the primary focus of this research investigation.

It is important to acknowledge that some of the sources used in this investigation are far from contemporary e.g. *Begg* (1984), *Groover & Zimmers* (1984), and *Chorafas* (1987).

Despite their age, these sources are important because they capture the views and opinions of the early adopters of CAD technology, at a time when many of the contemporary systems were still in their infancy and many businesses were implementing CAD for the first time.

As the popularity of CAD has developed, non-CAD users such as LTESMEs have become the minority. This has contributed to the inaccessibility of contemporary AMT research for LTESMEs - much of the more recent material assumes a pre-requisite level of knowledge and understanding which is not present within the organisations. Hence the 'knowledge gap' for LTESMEs continues to widen as both technology development and research progresses.

In addition, the literature review found a distinct lack of information for guiding the implementation of CAD within specific industrial contexts or sectors. Although this could be explained by the enormous scope of the various industrial settings in which CAD could be, or has been implemented or considered, it seems reasonable to assume that there will be numerous similarities between the implementation approaches of all kinds of small businesses - and that their experiences should be well documented by now.

3.2.5 Benefits of 3D CAD Systems

In order for LTESMEs to be able to select from the range of CAD software available for a given application, they must inevitably review the benefits and challenges associated with CAD systems, and identify those which are of greatest relevance.

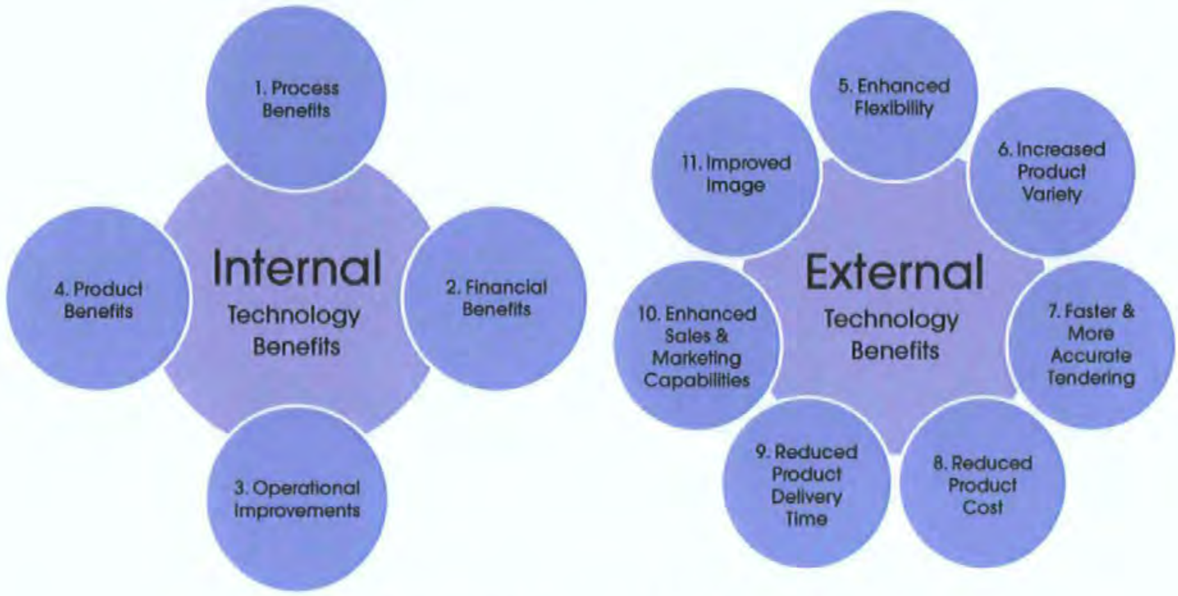

Figure 9. Internal & External Benefits of AMTs

Figure 9 highlights the main internal and external benefits of AMT identified within the literature, which will be reviewed throughout the following sub-sections. For clarity, the benefits have been compartmentalised into those which are of internal benefit (e.g. increased process efficiency) and those which are of external benefit (e.g. improved corporate image). However, it is acknowledged that in reality almost every benefit has both an internal and external influence.

3.2.5.1 Quantifying 3D CAD Benefits

There are conflicting points of view regarding how the benefits of 3D CAD can be quantified. The problem is extremely subjective: CAD provides a functional toolkit that can be applied in a number of ways to any given design situation.

Medland & Mullineux found that major improvements in efficiency and therefore overall development cycle time could be achieved in a number of different ways, depending upon the type of industry and the constraints imposed upon the design and manufacturing processes [71]. In order to begin to estimate (and quantify) where and how benefits and savings may arise it is therefore necessary to examine the entire product cycle and identify the areas in which CAD capability, and possibly automation processes, can be applied.

1. Process Benefits

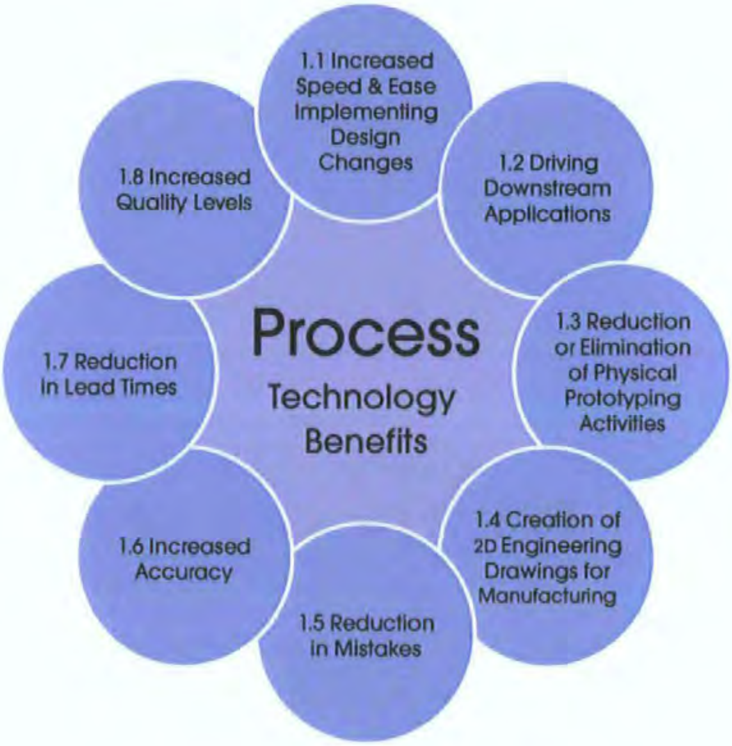

Figure 10. Process Benefits of AMTs

CAD systems offer significant benefits in terms of supporting and enhancing organisational processes, not only within the design function, but also downstream in the manufacturing function as well as other areas such as sales, marketing and communications. Figure 10 highlights the main benefits identified within the literature which will be discussed throughout the following sub-sections.

1.1 Increased Speed & Ease Implementing Design Changes

One of the most fundamental benefits of using 3D CAD systems is the rate at which changes can be made to a design. Some estimates within the literature hold that skilled operators can realise drawing productivity increases of the order of 8:1 in comparison with manual methods [79].

1.2 Driving Downstream Applications

CAD systems output digitally-encoded data which can be used by a number of 'downstream' applications. For example, CAD geometry can be imported to performance prediction software, or used to drive Numerically Controlled (NC) machines. This can lead to significant increases in product quality and process efficiency. CAD can also provide data which can be used within graphic design applications to assist in the generation of illustrations for product manuals, assembly instructions and marketing literature. Traditionally, these processes have involved the time consuming re-creation of data [76].

1.3 Reduction or Elimination of Physical Prototyping Activities

Building physical prototypes can be one of the most expensive and time-consuming aspects of producing a new product, 3D CAD systems provide a 'virtual prototype' which reduces or eliminates the need for a physical prototype [75, 76]. This is potentially a significant benefit for manufacturing LTESMEs who tend to focus on the development of products 'on the shop floor' using expensive and time consuming full-scale physical prototyping.

1.4 Creation of 2D Engineering Drawings for Manufacturing

To varying extents, most modern 3D CAD systems support the creation of 2D drawings directly from 3D CAD data - resulting in drawings which are 100% accurate to the modelled geometry. Most manufacturing operations still rely on 2D drawings as their fundamental guide to building a component or assembly [76]. They are also essential for hard-copy documentation and archiving of design data.

1.5 Reduction in Mistakes

CAD systems provide a significantly enhanced product definition, which can be communicated with greater accuracy and efficiency than is possible using traditional methods such as hand drafting. This can lead to increased understanding throughout every stage of the production cycle - thereby reducing the propensity for mistakes.

1.6 Increased Accuracy

The strong emphasis placed by CAD software vendors on productivity benefits has tended to obscure one of the fundamental benefits of using the technology: principally that CAD systems work to a far higher tolerance than is possible with manual techniques (e.g. a paper drawing). Whilst these have provided an effective means of generating and communicating designs for many years, the accuracy of the representation can be severely limited by the quality and thickness of the pencil lines [80] and the propensity for human error.

Gott asserts that increasing accuracy throughout the product cycle ultimately leads to the 'virtual elimination' of design related tooling and manufacturing errors, reporting reductions in engineering change orders of between 50-90% [75].

Jones observes that data within the CAD-enabled design process "represents the real world far better than the scaled drawing on paper attempted to, and in fact better than the manufacturing process will eventually achieve" [80]. As a result of this manufacturing tolerances are effectively reduced - potentially leading to higher product quality and consistency.

1.7 Reduction in Lead Times

CAD allows for lead times to be reduced across many different business functions / activities including design, production, marketing and communications. Dramatic improvements are commonly found within the design processes of LTESMEs implementing 3D CAD systems for the first time.

Whilst the speed of the cognitive, 'creative' processes undertaken by a designer is unlikely to be affected by the use of CAD, improved access to data reduces design process lead times in terms of information retrieval, verification and design optimisation through the investigation of alternative solutions. *Gott* claims that product development time can be reduced by up to a factor of five, and that a 'doubling of design productivity' can be achieved [75].

Medland & Mullineux observe that complex products (such as boats or aircraft) are expensive both to produce and maintain, so the product cycle must be carefully managed to deliver products 'at the time that the customer requires them' [71]. Items manufactured too early or too late could incur expensive costs for both parties[9]. The advantage of a CAD/CAM system is that the design phase can begin much later than would otherwise be necessary [71], thereby reducing the design lead time and allowing for a faster response and reduced operational costs due to a reduction in the amount of design work required for each product [32, 77, 80, 82].

1.8 Increased Quality Levels

Willows observes that the ability of 3D CAD systems to model products to a level of near 'virtual reality' ultimately results in higher product quality [13]. The CAD design process is

[9] The impact of late delivery was highlighted in late 2004, when EADS (parent company of Airbus) was reported to be facing 'growing financial troubles' following expensive delays in the manufacture of the A380 'Superjumbo' airliner [81].

one of continual refinement and improvement. This, coupled with the ability to describe the product much more accurately to the manufacturing process, is the mechanism by which improvements in product quality occur.

Hodgkiss notes that both drawing and product quality is improved [79]. *Jones* suggests that better quality is obtained in two ways: firstly, the overall accuracy of the design is improved (resulting in fewer errors being discovered throughout the product cycle), and secondly that a 'better product' can be designed. *Jones* also suggests that improvements in quality could radically affect the fortunes of an enterprise by "tipping the competitive balance" [80].

Koc & Bosdag observe that improvements to product quality might be realised in terms of performance of the product, a reduction in the cost of its manufacture, improvements to the design (in terms of aesthetics, ergonomics and functional enhancements), tightness of tolerances, inspection performance, material choices and so on [37].

2. Financial Benefits

The financial benefits of 3D CAD systems are extremely diverse and far-reaching. A key benefit is the ability to reduce the cost of production, and ultimately product cost, which is one of the basic determinants of why customers choose a particular product over competing alternatives. *Koc & Bozdag* found that improved manufacturing technologies "play an important role in affecting the cost structure of a product through more efficient manufacturing operations with less waste" [37].

The implementation of 3D CAD (like most technological developments) produces an initial cost saving as basic and mundane tasks are taken over and automated. However, these kinds of savings may not be sustainable - as task complexity increases, automation becomes less viable and manual processing time increases [71]. *Begg* asserts that if CAD tools are to be used in industrial settings, they must provide quick results, as well as good results, otherwise they will be neglected in favour of 'dirty', but time saving, engineering practices [77].

Lee observes that "the cost of engineering goes up exponentially in the later stages of product development and production" [14]. Therefore the advantages offered by CAE, which facilitates early optimisation and refinement of designs, and CAM, which streamlines manufacturing processes, can have a significant impact on overall product development time and cost.

3. Operational Improvements

Software vendors have successfully sold and marketed CAD principally as a way of 'increasing productivity' in the design department. As *Chorafas* observes, this is a vastly over-simplified claim, as productivity can be classified and measured in a number of different ways [32]. Furthermore, vendors imply that productivity gains will be realised naturally, as a feature of the implementation. But as *Chorafas* points out: "with computer-based systems, the equipment itself is a small part of the total; much more important is the applications perspective" [32].

Chorafas also observes that in able use CAD "can improve the productivity of engineers by 400 to 3000 per cent. But such improvements will not come of their own will" [32]. *Gott* also suggests there is now ample evidence that "3D can typically cut product development times in half" [75]. *Medland & Mullineux* have made similar productivity gain observations, including: "a reduction in man-hours to less than a quarter, an improvement in quality and a tenfold increase in 'capture rate'" [71].

Jones identifies two ways in which labour can be reduced: firstly, the reduction in time taken to generate or modify geometry, and secondly, the reduction in labour required in other parts of the company to extract essential information from the design [80].

CAD/CAM also provides potential labour savings and productivity benefits in other areas of the business, across the entire production cycle.

Clearly, productivity increase is not an inherent feature of CAD implementation; organisations must ensure that productivity-enhancing practices are built-in to their overall strategy. *Medland* indicates that modern enterprises are becoming conscious of this - "the idea that a system can be bought on the grounds of more rapidly produced drawings, or the number of drawing office staff it will replace is now, thankfully, long gone" [30]. *Chorafas* asserts that organisational approaches need to 'evolve' in order to realise (and maximise) the potential productivity benefits [32].

4. Product Benefits

CAD systems can offer a range of product-related benefits including: product simplification (leading to improved manufacturability and reliability), enhanced aesthetics and styling, improved ergonomics, higher quality finishing, use of CAE for performance prediction and analysis leading to improved product performance. CAD systems also promote the use of standard / modular components across product ranges which increases process efficiency.

5. Enhanced Flexibility

Diaz et al. emphasised that companies lacking AMTs such as 3D CAD would have fewer strategic options and a narrower scope of action, leading to a failure to develop new capabilities and therefore a loss of competitive advantage [83].

Contemporary market requirements change rapidly and firms need to be able to respond with products which satisfy the needs of their customers. These needs are usually related to the change in both product variety and product quantity. Therefore firms should be flexible enough to respond to such changes in the market by improved manufacturing technology [9].

6. Increased Product Variety

The enhanced speed and ease in investigating new designs offered by 3D CAD systems allows organisations to introduce a wider range of products, which can be tailored to suit individual customer requirements. To exploit this capability, organisations should develop their understanding of customer (market) wants and needs, and focus on the links between marketing and manufacturing.

7. Faster & More Accurate Tendering

The case study implementation (see chapter 4) showed that CAD systems can increase efficiency within the design process, leading to faster tendering. The enhanced accuracy of the product definition created in 3D CAD systems also allows organisations to estimate costs and other design specifications (e.g. weight, cost and time) more accurately.

8. Reduced Product Cost

The financial benefits realised in terms of process efficiency, reduction in mistakes, and access to advanced manufacturing techniques such as CAM can be passed on to consumers in order to enhance competitive advantage.

9. Reduced Product Delivery Time

The influence of 3D CAD systems in terms of reducing design and manufacturing process lead times can reduce product delivery times. *Koc & Bosdag* observe that product delivery on time and earlier than competitors is extremely important for competitive advantage [37].

10. Enhanced Sales & Marketing Capabilities

The increased flow of information across various business functions can lead to enhanced sales and marketing capabilities (see chapter 4). Contemporary CAD systems are capable of producing a range of visual outputs which can be exploited by the sales and marketing function - these include: video animations and rendered still images for use in presentations and publications such as company brochures / product bulletins.

11. Improved Image

3D CAD systems can also contribute significantly to enhancing the 'corporate image' of organisations (see chapter 4). The higher quality presentation of design data, access to 'state of the art' manufacturing technologies and the opportunity to lead technology exploitation within their various sectors can be readily exploited by LTESMEs from a Public Relations (PR) perspective.

3.2.5 Challenges of 3D CAD systems

Figure 11. Challenges of 3D CAD Systems

Despite their many recognised benefits, a number of researchers have observed negative impacts on firm performance arising from the implementation of AMT systems such as 3D CAD [76, 85, 89, 90, 91]. Figure 11 highlights the main challenges identified within the literature which will be discussed throughout the following sub-sections.

Boyer et al. observed "no direct impact of AMT investments on (a) firm's financial performance" [84]. *Jones* cites observations from several AMT studies that failed to recognise differences in terms of growth, profitability or flexibility [80]. *Chung* found that "50–75% of AMT adoptions fail regarding expected benefits like flexibility, quality, and reliability" [85].

1. Control of Data

CAD, CAM, and CAE activities generate massive amounts of data which must be stored, controlled, retrieved and communicated on-demand. Managing this process can pose significant challenges to LTESME managers.

Buxton et al. observe that design, engineering, manufacturing, and maintenance processes "have routinely existed in virtual isolation from one another" [86]. Contemporary AMT systems transcend these traditional boundaries. Effective processes must be in place to ensure that information flows effectively across the business and any changes made are fed through the product cycle in order to keep manufacturing guidance valid and up to date.

2. Interoperability of CAD Data

Interoperability of data between CAD systems is a significant factor in the selection of appropriate software. Organisations can face difficulties in reliably translating geometry from one CAD system into another, leading to communications problems with suppliers. *Buxton et al.* estimated the cost of interoperability issues in US automotive manufacturers at $1 billion per year [86].

3. Displacement of Skills & Knowledge

The implementation of AMTs can lead to the displacement of key skills and useful knowledge within LTESMEs. It is a common misconception amongst LTESME managers that CAD systems can somehow replace the people or skills found within existing design departments. The reality is that CAD systems, like all tools, require direction from an external intelligence [71] and the level of benefit derived from such systems is directly proportional to the ability of the users, and the effectiveness of the systems established to manage them.

The challenge in many cases is that established designers working within traditional design departments find it more difficult to learn and develop CAD skills than younger or more recently qualified individuals who are more familiar with the CAD approach, but who lack valuable experience and knowledge of design standards or manufacturing processes.

Buxton et al. observe that firms may put too much faith in the CAD designer, or make it too easy for the owner-manager to control design at the expense of 'sound engineering principles' [86].

4. Relevance of the Product Definition to Downstream Users

Traditionally, the design process separates those involved in the data creation and analysis phase and those who ultimately rely on the digital product definition for downstream activities such as manufacturing, sales and marketing. However, this separation can severely limit the extent to which the main benefits of AMT systems can be realised, and is in many ways counter-productive.

McMahon & Browne observe that "communication and collaboration between separate design and manufacturing functions is often poor" [87]. This can lead to the development of sub-standard designs, or those which are unsuitable for efficient manufacture. This problem may be exacerbated by the use of younger and less experienced CAD operators, who lack the requisite engineering, technical or manufacturing knowledge.

Buxton et al. observe that within the aerospace industry, the 'user community' for the design definition "extends far beyond company boundaries" [86]. Similar comparisons can be made for LTESME manufacturing firms across other sectors - many such organisations rely on the communication of elements of the product definition 'downstream' to a network of specialised suppliers / third parties.

5. Cost Issues

There is usually a significant start-up cost associated with the implementation of AMT systems. *Jones* observes that this is composed of two components: the initial purchase price and the 'hidden' cost entailed in the initial inefficiency produced by staff having to use radically new methods and skills [80].

CAD systems also have an associated running cost which also has both a visible and a hidden component. The visible cost is the maintenance required on the computers and software, which can be reduced / controlled with careful management and good judgement in balancing risk against cost. The hidden component is the additional time required to manage the installation, which can be minimised with care [80].

6. Effect on Culture & Working Relationships

AMT systems can have a significant impact on organisational culture and working relationships. New technology may lead management to decide that it needs to bring in specialist knowledge (e.g. a CAD/CAM manager). *Jones* identifies one aspect of cultural effects in terms of age discrimination issues with younger staff understanding the technology more easily [80].

7. Limitations of the Hardware & Software

Despite their numerous benefits AMT systems are not without their limitations. *Jones* observes that these may have been overlooked at the evaluation / selection stage [80]. *Hodgkiss* also comments on problems relating to dependence on machinery that could break down or malfunction [79]. Whilst this is still a valid concern, hardware reliability is becoming less of a contemporary problem.

Software limitations may also become apparent when organisations use premature technology that is unreliable [80]. For example, the use of 'Beta-test' software by the author throughout the case study implementation (see chapter 4) highlighted significant problems with reliability (although the enhanced functionality offset the challenges).

Some activities such as reverse-engineering (the process by which 3D geometry is generated by interpreting existing 2D data and/or the geometry of physical components) are inherently difficult. In such cases an inappropriate software choice can be most apparent.

8. Greater Dependence on Individual Members of Staff

AMT systems naturally lead to an increased dependence on individual members of staff. *Hodgkiss* notes that the loss of an individual can mean the loss of all knowledge of a job without a very good standard of documentation [79]. Similarly *Jones* observes that in an engineering department genuinely committed to CAD, failure of the system will not just be 'a nuisance' but it can cause the work of the entire department to come to a halt [80].

9. Implementation & Management Issues

Once SMEs have transcended the crucial initial stages of scoping, selecting and acquiring new technologies, they face the challenge of implementation. Successful implementation aims to leverage the optimum output from the new technology. Training, marketing, finance and investment aspects must be considered.

Jones & Jain refer to the process of 'technology management' - where SME managers approach the implementation of technology in relation to their long-term strategic view for the business, making a conscious effort to monitor and control the impact of the new technology on the businesses competitive position [15]. In all cases, SMEs must effectively manage external relationships in order to ensure success.

3D CAD is not an easy technology for organisations to implement without some prior operational experience. Any organisation considering the implementation of 3D CAD, or the transition from 2D CAD, must be aware of its individual requirements, and exploit this knowledge to select a system most appropriate to their own specific needs. Companies must also be educated (or re-educated) to the extent of contemporary 3D CAD capability, so that they can plan for effective employment of the system, and identify the areas in which it can be applied most effectively.

Begg observes a common failure in organisations that normally use quite sophisticated planning processes to control their product design and manufacturing operations to apply the same discipline to an implementation project. This even occurs with organisations that are extremely familiar with the hardware and software technologies employed in CAD [77].

It has also been observed that companies frequently base CAD implementation plans on assumptions about how the design process operates, rather than what actually happens [30].

Medland & Mullineux suggest that "the 'Unofficial', but vital, channels of communication are ignored. It may, for instance, be assumed that all information is contained in 'the paperwork', even though much information is in fact transferred by means of accepted practices, informal meetings between staff from different areas or a general awareness of events occurring within the organisation" [71].

Information flows within all aspects of the design process need to be determined in order to develop an understanding of a firm's real (as opposed to expressed) needs. However, the complex interactions between the various processes being scrutinised makes it difficult to assess any activity in isolation [71]. Hence companies may be overwhelmed by a wide range of requirements, and need to focus on those which are absolutely essential to success.

9.1 Commercial Off-The-Shelf (COTS) Technology Solutions

Contemporary attitudes to AMT popularise the use of COTS solutions where applicable, in order to avoid the range of implementation problems (including cost and complexity) which are associated with bespoke systems. However, whilst the COTS approach offers advantages in many areas, it can also impose a number of constraints on organisations.

By definition, the use of a generic solution implies companies must modify their existing processes and procedures to fit the new software [33]. This highlights the criticality of the selection of software appropriate to the organisation's real requirements. Implementing an inappropriate system could lead to dissatisfaction and a lack of confidence in implementing technology in the future.

Section 3.3

Linkage Mechanisms for LTESMEs

3.3.1 Introduction

SMEs in particular find it challenging to interface directly with AMTs as a result of their relative lack of technological knowledge and numerous other constraints. The knowledge necessary to successfully implement new technologies is as important as the technologies themselves, and how and where to acquire it is fast becoming an issue of strategic importance.

Lundvall observes that the meaning of 'knowledge' is hard to define concisely, and differs depending upon the context in which it is used [88]. He suggests that in a classical sense knowledge may be thought to describe data, information and wisdom, but that within an organisational context knowledge is comprised of know-what (factual knowledge or information), know-why (understanding or explanation), know-how (skill or capability) and know-who (social awareness).

Bessant et al. observe that "the importance of knowledge to business growth has, in recent years, become well established" [89]. *Rouach* asserts that, in order to remain competitive, SMEs must closely monitor new technology, drawing on a number of sources including government agencies, consultants, suppliers, competitors and customers [21]. However, as has already been shown, LTESMEs lack the resources to carry out effective technology research and monitoring.

In response, a wide range of 'linkage mechanisms' have emerged and are rapidly becoming essential pathways for the dissemination of knowledge and, in turn, new technologies into industry. *Rothwell & Dodgson* found that "successful innovation in firms is associated with the establishment of external technical linkages as well as a variety of business and marketing linkages" and that a firm's ability to forge effective linkages is correlated with its level of in-house technological resources [34].

Brychan identifies two basic linkage mechanisms available to SMEs: 'technology exchange' (technology passed from one SME to another) and 'technology exploitation' (technology transferred to an SME from an external source) [39]. In recent years a broad range of support mechanisms have emerged to assist companies in both activities.

However, despite the widespread availability (and increasing accessibility) of linkage mechanisms, it can be difficult for some LTESMEs to engage successfully with these programmes due to a number of problems including a lack of awareness, poor relationships with other organisations and research institutions, and a lack of in-house skills and expertise [15]. *Kennedy & Hyland* found that SME change efforts through linkage pathways do not always produce the desired results [17].

LTESMEs need greater awareness of the range of available sources of knowledge, and the various linkage mechanisms, in order to select an effective approach. The following section therefore aims to outline the primary knowledge sources and various types of linkages available. In addition, a comprehensive list of useful online information sources for LTESMEs is provided in Appendix 4.

3.3.2 Knowledge Sources

Figure 12. Knowledge Sources

Figure 12 highlights the main knowledge sources identified within the literature, which will be discussed throughout the following sub-sections.

1. Knowledge Pools

Knowledge pools are generally comprised of a range of market, quasi-market and non-market sources and include patents, trade fairs, exhibitions, associations, computerised databases and legislation [16, 24]. Knowledge pools tend towards the supply of 'generic form' information and technological specifications. *Lambert & Barber* found that different industry groups specialise in different elements of the knowledge pools [24]. Hence the range, availability, quality and accessibility of knowledge pools may vary between different industrial sectors.

2. Legislation

Lambert & Barber observe that legislation is an important source of knowledge for SMEs across many different sectors [24]. Legislation includes product standards (available via the British Standards Institution (BSI) [90]) and regulation. For example, the Health & Safety Executive (HSE) can assist businesses implement cleaner manufacturing processes in order to meet stricter environmental regulations [91].

3. Supply Chain & Other Firms

SMEs frequently obtain external advice from private rather than public sector sources. *Lambert & Barber* found that a significant proportion of organisations within 'supplier dominated industries' such as manufacturing cite equipment or materials suppliers as 'very significant sources' of product and process ideas [24]. They also observe that SMEs can be highly dependent on technological progress in their major customer industries.

4. Cross-Sectoral Supports

Cross-sectoral supports include: chambers of commerce, industrial groups, other commercial networks as well as the provision of non-discriminatory grants (e.g. capital, employment (for recruitment of skilled personnel), R&D, marketing and training grants). *Windrum & Berranger* found that SMEs tend to rely on searching within their 'commercial networks' for information, rather than 'government sources' [36].

Vossen suggests that commercial networks comprise: suppliers, private / public agencies involved in the transfer of information, industrial associations, competitors, and consultants providing specialised services or know-how [35].

Organised commercial networking groups are particularly valuable sources of information and usually comprise clusters of companies that are joined informally by meetings where common issues are discussed. An example within the composites sector is the National Composites Network (NCN) [92].

5. Sector-Specific Supports

Sector-specific supports include: targeted research centres, trade associations and other local and national support groups / information networks for companies within specific industrial sectors. Examples within the marine industry include: Marine South West [93], the Cornwall Marine Network [94] and the British Marine Federation [95].

6. Technology Intermediaries

Technology Intermediaries include: research associations, regional technology centres, consultants, members of the science / knowledge base, research councils and external financiers who can act either as direct sources or facilitators / advisers in the process of technology acquisition.

The Science & Technology Council found that SMEs tended to look more towards technology intermediaries for knowledge rather than initiating direct contact with the science base, because the intermediaries could act as 'technology translators' who can "speak the same language" as the SME [16].

7. Government Sources

A number of international, national and regional government initiatives exist to support SMEs in the introduction of new technology. *The Science & Technology Council* observes that in this context, the government's role is to provide 'a framework of policies and instruments' to support businesses [16].

7.1 European Government

Within the European Union (EU) the 'SME Envoy' provides the EC's key interface with the European SME community [8]. The SME Envoy has been instrumental in delivering a range of European-wide initiatives to improve the business prospects of SMEs in response to the challenges identified by the EC's survey of 2005 [8]. This report highlighted 'increased advice and support for organisational development' as one of six key factors which SMEs considered crucial to their continued success. A number of funding initiatives have subsequently emerged to encourage growth[10].

Work in this area has included: education within the field of entrepreneurship, improving access to finance, improvements to funding initiatives, simplification of regulatory issues for SMEs, product standardisation, ensuring fair competition, and assistance with SME efforts to trade and compete internationally [8]. In addition, the Envoy has placed a particularly strong emphasis on the support of research and innovation activities within SMEs.

In the past, SMEs have found it difficult to access many of the funding programmes available for the support of research and innovation due to complicated and lengthy applications procedures [8]. However, recent efforts made by the SME Envoy in collaboration with national and local governments have vastly improved access [96].

7.2 UK Government

The DTI is the government department responsible for trade, business, employees, consumers, science and energy within the UK [97]. It helps people and companies to become more productive by promoting world-class enterprise, innovation and creativity.

[10] An overview of the specific funding opportunities available to European SMEs is available in the EC publication 'European Union Support Programmes for SMEs' [91].

Bessant et al. observe that a significant part of the DTI's activity is now concerned with enhancing business access to, and use of, external sources of knowledge and expertise [89].

The DTI recognises that the UK economy is now exceptionally diverse, and successful businesses in most sectors can demonstrate a capability to add value and use concepts, processes and technologies innovatively [98]. However, supporting those enterprises which are less successful and encouraging their access to, and investment in, research and innovation practices is now essential to secure a prosperous future for both the UK and European economies.

The DTI Innovation Report discusses the need to increase the quantity and quality of business innovation, and the flow-through of innovation from the science base to business. The report also lists several success factors for judging innovation performance: access to sources of new knowledge, capacity to absorb and exploit knowledge, access to finance, competition and entrepreneurship, involvement of customers and suppliers, the regulatory environment and access to networks and collaboration [99].

As a result of their grounding in the knowledge base and links to businesses with strong track records of product and process development, the DTI is ideally positioned to help deliver these objectives [98] and offers a range of business support products including 'Collaborative Research & Development', 'Knowledge Transfer Networks' and 'Grants for Research & Development'.

Lybaert found that Business Link [100] (a cross-government source for business advice which draws on the expertise of key government bodies that deal with business, such as Companies House, the Department for Business, Enterprise and Regulatory Reform (BERR), the Environment Agency, the Department for Education and Skills (now the Department for Children, Schools and Families), the HSE, the Home Office, HM Revenue & Customs) was "the most frequently used public sector source of assistance" [2].

8. Other External Sources

There are numerous other external sources for technological knowledge which are covered briefly throughout the following sub-sections:

8.1 Consultants

Consultancy (from the Latin *consultare* "to discuss") involves working with external firms or private specialists capable of providing technological support, guidance or training on some form of cost-basis. *Robson & Bennett* linked SME growth and the acquisition of external business advice [3].

8.2 The Internet

The internet is an increasingly important source of technological and other knowledge for SMEs. Despite the vast quantity of information there are potential problems with quality and validity. However, there are numerous targeted search engines for high quality scientific and technological information (e.g. Google Scholar [101] and Microsoft Live Academic [102]).

8.3 Scientific Reports, Journals & Conference Papers

Scientific reports, journals and conference papers are also valuable knowledge resources, which are often used to announce new technological developments. A significant source for scientific publications is the British Library [103]. Other HEI libraries are also an excellent information resource, and businesses may be able to gain access to the various collections under some form of agreement.

8.4 Patents

Patent literature is a good source of 'current' information relating to technological developments across many sectors [23]. New web-based searching capabilities and online content has dramatically improved access to detailed information.

8.5 Technology Vendors

Windrum & Berranger found that vendors played an important role in the 'computerisation' of SMEs, and that small businesses tended to rely on vendors to propose alternative ICT options and to provide after-sales service and training [36]. Technology vendors provide the LTESMEs 'main link' with the new technology and are subsequently relied upon heavily to provide guidance, knowledge and advice, even if no formal relationship exists for this purpose.

8.6 Fairs, Exhibitions & Professional Conferences

Porter identified fairs, exhibitions and professional conferences as potential information sources for SMEs [23]. Conferences are usually run by industry associations and are held on a regular basis within most sectors.

8.7 Technology Transfer Networks

TT networks comprise members of private and public sector organisations working together to facilitate the transfer of knowledge, skills and technology. For example, the Materials Knowledge Transfer Network (KTN), which was created to "bring together the views of all in business, design, research and technology organisations, trade associations, the financial market, academia and others in the value network across the materials community" [104]. TT networks are usually segmented by geographical region, industry sector or by technology, and they can work with a mixed sector-technology focus.

Brychan found that TT networks are of particular importance to SMEs, who tend to display relatively low levels of in-house resources and experience [39]. He also notes that they are one of the best forums for SMEs to: learn from each other, reach a common understanding regarding new technologies, share best practices, exchange experiences and diffuse technology quickly. However, there is an element of competitive risk which must be considered.

Brychan found that key success factors for TT networks include: the type and size of the network (particularly the level of 'commonality' between the partner organisations), effective communications and the quality of the relationships between the organisations (e.g. levels of conflict and trust) [39]. He identifies several key mechanisms within TT networks including: information transfer (newsletters and databases), technology transfer (R&D audits), skills transfer (training) and specialist support (financial guidance) [39]. He also observes that 'value for money' of the mechanisms is crucial, and that governments should introduce policy changes that provide SMEs with incentives to overcome their various constraints and pursue new technologies via networks.

9. Higher Education Institutions (HEIs)

Lambert & Barber found that around 15-20% of SMEs are using some information, advisory or other services from HEIs, that this was more amongst manufacturing than service sector firms, and that 10-15% of manufacturing SMEs are engaged in 'more active technology acquisition' from HEIs [24]. They also found a positive relationship between 'in-house innovation resources' and relationships with HEIs, and concluded that the level of involvement with HEIs was broadly connected to the level of internal resources (in terms of finance and employees with graduate-level science and technology qualifications) within SMEs.

In a study of Irish businesses, the *CONVERGE* project found that although SMEs did engage with HEIs for technical training, they were "too small and lacking in internal resources to engage in any meaningful co-operative R&D activity" [105]. Several of the firms within the study indicated that they had identified areas where co-operative research would be beneficial but "they had neither money, time nor skills to pursue such research".

10. Internal Sources

Another important, but often neglected source for knowledge is that which is already available within organisations. Employees with experience of working at other firms may be willing to share information and working methods. Furthermore, recently qualified individuals are likely to have been exposed to 'state of the art' technological concepts and will be familiar with the methodologies for effective internet research. *The Council for Science & Technology* identified a need for organisations to recruit more 'technologically sophisticated' individuals, and foster a 'pro-technology' culture in order to remain competitive [16].

3.3.3 Linkage Mechanisms

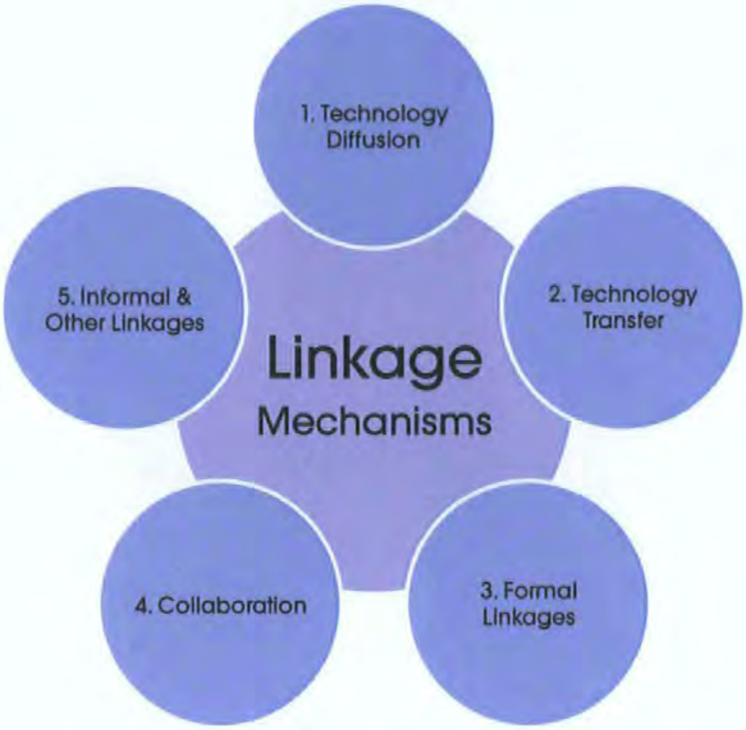

Figure 13. Linkage Mechanisms

Figure 13 highlights the main linkage mechanisms identified within the literature, which will be discussed throughout the following sub-sections.

As has already been proposed, the effectiveness of a given AMT implementation is in-part determined by the appropriateness of the linkage mechanism. Appropriate linkages include those which are inexpensive, efficient, mutually beneficial, low-risk and sympathetic to the constraints of the LTESME.

1. Technology Diffusion (TD)

One of the principal ways in which organisations acquire new technology is via the process of TD [21, 39]. There are numerous definitions of TD within the literature. *Lambert & Barber* define TD as the spread of a new technique from one SME to another [24]. *Martin* describes TD as "the process through which an individual or other decision maker unit passes from first knowledge of an innovation, to a decision to adopt or reject, to implementation of the new idea" [69].

Papaconstantinou et al. highlighted two principal types of TD: 'disembodied diffusion' (the transmission of knowledge and technical expertise) and 'embodied diffusion' (the introduction of machinery, equipment and components incorporating new technology) [106]. *Brychan* observes that "governments today regard TD as an important route to increased competitiveness, especially diffusion into (SMEs) with advantages of flexibility, dynamism and responsiveness" [39].

Lambert & Barber observe that the main types of external sources involved in TD for SMEs are: public and non-profit organisations, Regional and National Development Agencies (RDAs/NDAs), Regional Technology Advice Centres (RTACs) and Chambers of Commerce, private consultants (technology brokers, management consultants, patent lawyers etc.), and Research and Technology Organisations (RTOs) which include: contract research firms, science parks and technology centres [24].

1.1 Rate of Diffusion

Brychan observes that once a new technology has been introduced, the speed at which SMEs adopt may differ widely [39]. *Lambert & Barber* describe this as the 'rate of diffusion', the speed of which will depend on how much greater the improvement over existing technology will be, and the cost of the new technology [24]. *Brychan* identifies five major categories of 'technology adopters':

1. Innovative SMEs (who want to actively explore new technologies)
2. Early adopters (who adopt new technology if it is to their advantage)
3. The early majority (who 'intentionally' adopt new technology)

4. The late majority (who 'sceptically' adopt technology which has already diffused)

5. The laggards (who adopt a technology so late that it has already been superseded)

Brychan found that innovators and early adopters relied to a greater extent on impersonal sources of information from a wide range of 'sources in contact with the origin of new ideas' - for example technical journals [39]. He also suggests that communication within innovative or 'progressive' SMEs tends to be well organised and co-ordinated, and that there will be a willingness to share knowledge with others.

2. Technology Transfer (TT)

TT is widely regarded as a principal catalyst for rapid technological advancement within firms of all sizes. TT is a concept of 'universal appeal' offering a range of diverse benefits to organisations which can typically include: access to new technologies, new processes, techniques, key competencies such as product innovations or new ideas in production, marketing, management or accounting, and the stimulation of innovation and innovative working practices [21].

The origins of the process can be found in the etymology of the phrase:

Greek	**tekhnologia**	'the systematic treatment of an art or craft'	
Latin	**transferre**	'bear across, carry over, transfer, translate'	
		from **trans-** 'across' + **ferre** 'to carry'	[107]

The contemporary meaning of TT varies significantly depending on the scale of the process and the point of view of the observer. In all cases, however, the process involves a principal technology and at least two entities (normally referred to as the transferor and the transferee) working together over a specific timeframe to achieve strategically significant objectives, which are mutually beneficial [25, 69, 108].

Jayaraman & Agrawal observe that the transferor typically has a higher technological capability (or level of technology) than the transferee; thus there is the potential for a 'flow' of technology. In order to be successful, both the transferor and transferee must be aware of, and monitor, the various factors which could stimulate or impede the process [25].

Jung found that the 'quality of communication' was a key success factor for TT - there must be a 'willingness to communicate', sufficient communication channel capacity, and the channels must be easy to use. *Jung* observes that communication can be improved by: removing psychological and other barriers, removing 'leaks' from communication channels, and structuring information so it can be easily understood [98].

Lambert & Barber observe that "the form of TT that is often taken explicitly or implicitly to be the most important as a policy focus is the activation and use of technological knowledge directly from the Science, Engineering and Technology (SET) base" [24] which includes HEIs, Public Research Organisations (PROs), Further Education (FE) Colleges and other RTOs.

Successful TT relies not only on the selection of appropriate technologies or their inherent capabilities, but on the availability of either in-house or external expertise needed to integrate the new technology with the existing working practices, and manage the process of TT. This is usually achieved via some form of formal linkage.

3. Formal Linkages

Formal linkages include collaborative projects with HEIs. For example, the Unlocking Cornish Potential (UCP) scheme [109], which aims to partner small businesses with recently qualified graduates, and the DTI's Knowledge Transfer Partnerships (KTP) scheme [110], which is described in more detail below.

3.1 Knowledge Transfer Partnerships

KTP is one of the DTI's key business support products, and the successor to the Teaching Company Scheme (TCS), launched in 1975 to encourage engineering / manufacturing industries to adopt modern technology [111]. The programme has been widely recognised as one of the world's leading knowledge transfer / business support products of its type [112], with attempts to emulate its success in a number of other countries [98].

KTP was officially launched in June 2003 and now fulfils a crucial role in developing business uptake of knowledge from the UK knowledge base. KTP is principally aimed at SMEs (although larger organisations can also participate) and is ideally suited to the development of new products, services and processes. The DTI estimates that there are about 150,000 businesses within the UK that are of a type that could benefit from KTP [98].

The scheme is designed to deliver rewarding and ongoing collaborations to help innovative businesses improve their competitiveness and productivity through the better application of knowledge, technology and skills, and to accelerate their exploitation of science and new and existing technologies. New technology in this context need not be 'state of the art', just innovative to that particular company. Projects can be undertaken in any sector and in a wide range of areas including: product design, manufacturing, technical innovation, business processes and commercial development.

4. Collaboration with Other Firms

Martin observes that there are numerous benefits to collaboration with other organisations including: the rapid diffusion of new technology, access to new markets, the bypassing of government restrictions and 'rapid learning' from leading firms within a given field [69].

SMEs display different levels of co-operation depending upon the structure of their supply chain, their industrial sector and existing levels of technology. *Martin* showed that high-tech industries such as information technology are more likely to co-operate, whereas low-tech companies are less likely to co-operate [69]. He also found that co-operation usually involves just two firms, and that it can consist of both formal and informal arrangements.

Lee suggests that the extent to which SMEs exploit their social networks is influenced by their internal culture, which can either hinder or encourage the sharing of new knowledge and information [61]. *Windrum & Berranger* highlighted trust as a significant factor in the success or failure of collaborative efforts [36]. *Gable* observes that the manner in which SMEs manage the relationship is a crucial factor determining the benefits of collaborative activity, and that the 'identification and addressing of specific organisational goals' and the 'ability to accommodate evolving project objectives' are key success factors [113].

5. Informal and Other Linkages

In practice, organisations can use any conceivable linkage to assist in the implementation process. There are a potentially limitless number of ways in which organisations obtain external advice and support via 'informal pathways'. One example is through mentoring - in which a close and trusting relationship is developed with an external expert or industry veteran. Mentoring is a highly personal but extremely effective tool for knowledge acquisition. However, as with all informal linkages the quality of the advice and its validity must be taken into account.

Section 3.4

Change Management

3.4.1 Introduction

LTESME managers involved in the implementation of new technologies inevitably face the prospect of dealing with significant 'organisational change' - one of the most widely researched contemporary management concepts. Change within the context of this investigation can be thought of as the process by which LTESMEs must 'adapt' in order to successfully integrate and leverage AMT.

Ludvall observes that in the contemporary business climate "both individuals and companies are increasingly confronted with problems that can be solved only through forgetting old and obtaining new competencies" [88]. Successful AMT implementation relies heavily on increasing knowledge and understanding, and influences many different business areas. Hence the associated change process is heavily focussed on communication, learning and education across all levels of the organisation.

Increasingly, research in this area shows that the key challenges are not necessarily the physical or structural alterations that are made to the business, or the complexity of the knowledge involved, but the way in which people are guided and treated throughout the change process [114].

Leading and managing change has therefore emerged as a key skill for managers, but one that is commonly lacking amongst archetypal LTESME management teams; who tend to concentrate overly on the results and short-term benefits of technology, whilst failing to address how the people in the organisation are going to achieve the results expected, and how they will be managed and developed in order to achieve that [114].

3.4.2 The Design Process & Production Cycle

In order to consider the change management aspects of the implementation of design-oriented AMTs within LTESMEs, the various activities and functions that must be accomplished in the design and manufacture of a product must be briefly examined.

Medland observes that the 'design process' is a network of interrelated activities throughout which a clearer definition and understanding of the proposed product emerges. At the same time, the design process moves progressively towards a more detailed description of the manufacturing process to be employed [30].

Medland & Mullineux and *Medland* observe that in reality, design processes are extremely complex [71] and inherently unstable [30]. Furthermore, that "the design process often appears to defy all efforts to describe or define it. Whilst common elements can be found, the process can only be directly understood in relationship to its effectiveness in creating a particular class of product" [71].

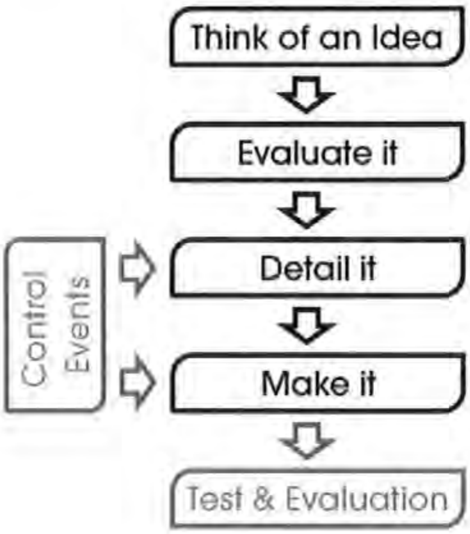

Figure 14. Simplified Design Process [30]

However, some common elements can be identified. Figure 14 presents the 'simplified design process' by *Medland* - in which the test and evaluation stage, and the introduction of control events, are optional [30].

Collectively, the processes of design and manufacture are known as the 'production cycle' [14]. Hence the production cycle describes the series of activities involved in developing a product from its conception to its completion [14, 71].

Most design processes begin with early 'conceptual' activities which are centred on establishing and manipulating the various constraints (e.g. physical, practical and economic) that will influence the final design[11] [30]. Subsequent activities within the production cycle may include: quotation and estimates, analysis and simulation, drawing production, template production, production of: parts lists, construction schedules, catalogue and manual illustration, office and project management, as well as the various manufacturing processes.

Both the design process and the wider production cycle must be carefully studied, monitored and controlled in order that an optimum performance can be achieved [30]. A detailed understanding of how the design process currently operates, and the various relationships with other business functions must be developed as a result of this observation.

This is essential in providing LTESME managers with a more accurate and detailed understanding of how the company actually conducts its design activity. As *Medland* points out: the identification of wasteful processes, and their subsequent rectification, can usually be quite sufficient justification for the work involved [30].

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[11] The influences of 'product-derived constraints' on design processes are examined in Appendix 5.

3.4.3 Managing Change

The capability to effectively lead and manage organisational change is a pre-requisite for LTESME managers involved in the implementation of new technologies. *Browne* observes that leadership and change management are closely linked, and that "the ability to understand, believe in and role model effective leadership behaviours is crucial" [114].

However, implementing technological change is a significant challenge in LTESMEs. The process is inherently disruptive and carries with it a number of associated risks. There will always be 'good reasons' not to change - the human response to a 'new order of things' is often resistance, via a complex combination of both logic and emotion. People's perception of change, and the way in which they are prepared to approach it, varies depending on their past experience and degree of flexibility and adaptability.

Browne comments that a very high percentage (70%) of change programmes fail to meet their objectives [114]. A consequence of this high failure rate, combined with attention from the research community, is that a great deal of detailed case study material is now readily available as an information resource, allowing LTESMEs to learn from past failures, and observe best practices.

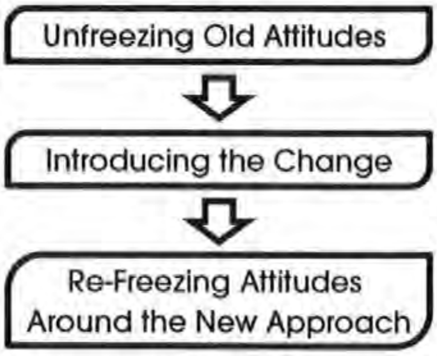


Figure 15. Simplified Change Process [114]

Figure 15 shows the simplified three-step change process proposed by *Lewin* (presented in *Browne* [114]), who focuses on the control of human attitudes (*Lewin's* background is social psychology). In this process, 'unfreezing' is the preparation for change, which should involve greater dialogue with employees - explaining the reasons for change and why the 'status quo' is not sustainable over the longer-term. 'Re-freezing' is the process by which the new behaviours are reinforced to become 'normal running' [114].

Figure 16. Eight Stage Model for Change [115]

Figure 16 shows the eight-stage change management process proposed by *Kotter* [115]. His model places a heavy emphasis on addressing the 'people issues' and highlights the universal nature of change.

Key success factors for organisational change include: a compelling vision of why change is needed, effective and consistent communication, adequate preparation and conditioning, a thorough and lasting implementation process, and effective leadership and management.

Estrin et al. identify several features of successful change management which include: articulating the business strategy (and linking it to specific technological capabilities), base-lining current processes and organisational practices, developing a vision for the future, developing a 'technology adoption roadmap' to eliminate unnecessary tasks, as well as the use of evaluation and selection processes to identify appropriate technologies [33].

There is a strong need to review the company's strategy and working practices. In many cases such findings have implications for the focus of the change effort. *Lybaert* asserts that a difference can exist between "what a business owner or manager's stated wants or expressed needs are, compared with what might potentially emerge from a systematic audit of the strengths and weaknesses of the firm in terms of resources and competence" [2].

Windrum & Berranger found that studies in large organisations have established the importance of 'top management support' in facilitating successful implementation of Information Communications Technologies (ICT) [35]. As has already been discussed, many LTESMEs tend to be owner-managed with relatively 'flat' organisational structures, thereby placing great importance on the levels of support for the new technologies displayed by the MD. Support in this context may include: establishing appropriate technology goals, identifying critical business information needs and allocating the requisite financial resources [36].

Another significant factor affecting the nature of change management practices within LTESMEs is that the changes tend to occur as a result of external pressure, rather than pragmatic decision making. *Kennedy & Hyland* observed that the adoption of management technologies by some SMEs was the result of pressure from government or associated companies or customers [11]. Pressure may also arise from shifting market demands / customer requirements as well as changes in legislation or regulation.

3.4.3.1 Barriers to Change

Despite the widespread availability of guidance information relating to managing change, a vast number of change efforts fail to deliver their anticipated outcomes.

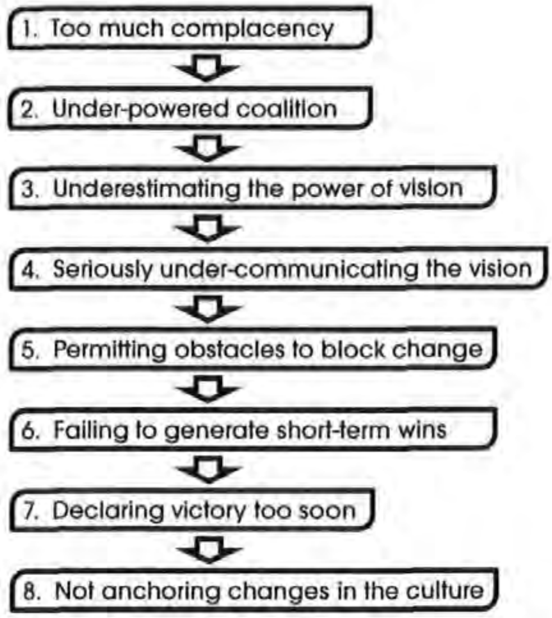


Figure 17. Eight Change Errors [115]

Figure 17 shows the eight common errors identified by *Kotter*, who comments that these can lead to new strategies not being implemented well, long implementation time-scales and high associated costs, as well as the anticipated results not being realised [115].

Browne observes that senior managers often fail to see the importance of having the very people who will have to work in the changed organisation work out the details of how it will actually operate in practice [114]. He also found that many efforts are confounded by a general lack of adequate direction.

Kondo suggests that a 'bottom-up' approach to management (e.g. one which focuses on the needs of the shop-floor workers, rather than the senior management) not only brings wider involvement and hence greater buy-in, but also creates far greater opportunity for new and innovative ideas within the framework of a 'top-down' strategic vision [114].

Employee involvement is crucial - formulation of the 'case for change' is undoubtedly an issue for senior management, but the implementation process itself is one that inevitably involves a much broader range of individuals from across the entire organisation and, in the case of TT, also those outside of it.

The reasoning behind the change needs to be sufficiently reinforced, and articulated in a way which will encourage support and understanding throughout every level of the organisation. Another major barrier is a lack of effective planning, or a failure to communicate the plan (or a timeline for change) effectively throughout the organisation. At a more basic level, not understanding or communicating 'what the change is' can be a limiting factor.

Recognising and celebrating success, and knowing when to stop and 'declare victory' is also important because it is a key part of establishing the new culture as 'normal running' i.e. moving from 'change transition' into 'continuous improvement'.

3.4.4 Related Fields

There are several other areas of academic research and contemporary management thinking which are relevant in addressing the challenges posed by the implementation of AMT. These practices share parallels with contemporary thinking on organisational change - calling for the development of a 'sincere belief and trust in people' in order to achieve success and leverage a competitive advantage.

The main related fields are: quality management and human resource management - which are introduced, albeit extremely briefly, throughout the following sub-sections.

3.4.4.1 Quality Management

A key feature of effectively implemented AMT is the significant impact on quality which can be realised throughout many different levels of an organisation. Understanding and managing quality is an area which has attracted significant academic interest. Much of the research in this area was pioneered by the so-called 'gurus of quality management' - *Deming* [116], *Crosby* [117], *Ishikawa* [118], *Juran* [119], *Shingo* [120] and *Kondo* [121].

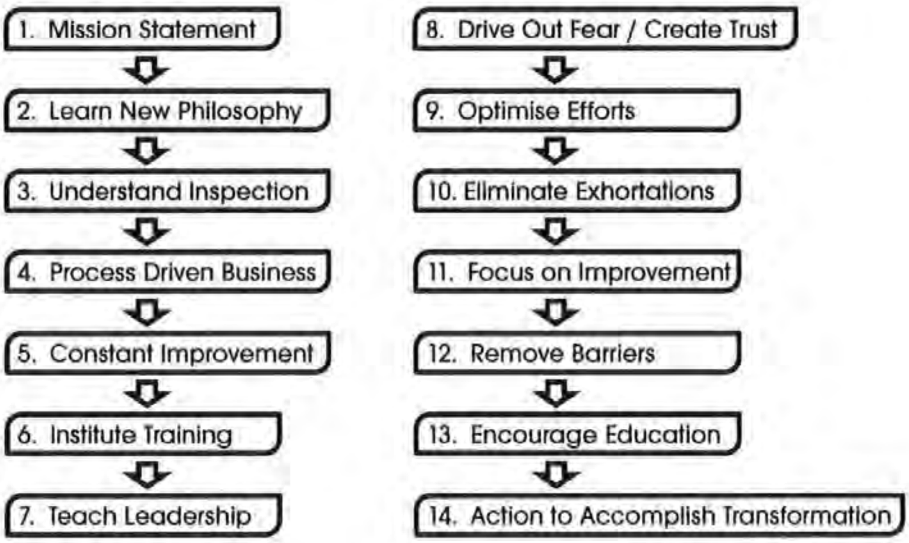


Figure 18. Deming's Fourteen Points [116]

Figure 18 shows the 'fourteen points' which *Deming* considers essential for successful quality management [116]. Other leading quality management principles include: participation and teamwork, continuous improvement, learning as the foundation for improvement, empowerment of the workforce, quality is linked to human relationships, do it right first time, clarify aims and objectives, give people a strong sense of responsibility, make time for generation of ideas, nurture ideas and bring to fruition.

Most approaches to quality management stress the importance of a strong element of control. That is, the ability to continuously evaluate process performance and take corrective action where necessary. Control mechanisms may comprise standards, goals or other means of measuring accomplishment.

3.4.4.2 Human Resource Management (HRM)

HRM is becoming an increasingly important feature of successful business management. Despite this, LTESMEs generally display less of a strategic approach to HR / HRM than their larger counterparts [122].

Leading HR practices include: integrating the HR function with the overall strategic aims of the business, designing jobs to reflect and promote learning and innovation, developing effective performance measuring systems, promoting co-operation and collaboration, empowering individuals and teams to take decisions, investing in extensive training and education, and generally maintaining an environment that supports these philosophies.

Toyota's approach is frequently highlighted as a case study for leading HR practices. They recognise a distinction between 'old thinking' (where people are a part of the process, controlled by managers) and 'new thinking' (where people design and improve the processes, controlled by workers and leaders). The advantages of these practices include: the promotion of trust and co-operation, the development of skills and abilities, increased morale and commitment, and improved creativity.

Section 3.5

Summary of the Literature Review

3.5.1 Introduction

The following section will briefly summarise the main findings of the literature review and identify the areas which appear to have greatest significance for the development of the best practice model. A review / reformation of the original research problem is subsequently presented and discussed.

3.5.2 LTESMEs

Section 3.1 highlighted the limitations of the SME definition and proposed a new classification (the Low-Technology-Enabled SME) which could be used to group small businesses in relation to their potential to successfully implement AMTs. LTESME characteristics include: a general lack of technological experience (and low-levels of existing technology), problems or limitations related to organisational structure, management, behaviour, culture, strategy, processes and infrastructure, and perhaps most significantly, a lack of financial resources.

LTESMEs are generally unable to realise the full benefits of AMT by themselves - requiring direction from an external source to ensure effective implementation. However, a major strength of LTESMEs is their inherent flexibility and agility - and hence ability to respond extremely positively and rapidly to the uptake of AMT.

The general lack of formality within LTESMEs can lead to a focus on day-to-day operations rather than long-term organisational strategy. An essential pre-requisite to managing AMT implementation is the ability to articulate / re-articulate core business objectives, and reflect on strengths and weaknesses, in order to identify the businesses real needs. This promotes the development of a more strategic view of the implementation process, and an extension of the 'planning horizon'.

The implementation process may therefore involve formalising processes and drawing out the hidden 'tribal knowledge' and underlying cultural aspects in order to find out 'what is really happening'. Communication must also be improved across all levels of the organisation. In addition, the business must 'want to change' in order to overcome the inevitable resistance. This involves: conquering fears, changing perceptions and overcoming reluctance to taking external help, whilst concentrating on the facts and demonstrable benefits of new technology (crucially, its potential impact on competitiveness and profitability), which must be viewed as an investment rather than a financial burden.

Skills is a key issue, which can be addressed through training and a capitalisation on the graduate workforce; who are generally receptive, technically able and keen to gain commercial experience. LTESMEs also need to find ways of overcoming their financial limitations - this can be achieved by the sourcing of appropriate technologies, and greater consideration of ROI.

The model must address these issues and promote the acquisition of accurate information, and awareness of the various information sources.

3.5.3 AMTs

Section 3.2 highlighted the importance of technology as a source of competitive advantage amongst firms of all sizes. Design-oriented AMT systems are becoming increasingly accessible and affordable, but despite this there are still significant risks associated with their adoption.

Understanding the capabilities of the various technologies, and generating awareness of the range of benefits available, as well as the associated challenges, is crucial. Benefits can be realised across many different business areas including: communications, processes, operations, products and finances.

The challenges associated with AMT adoption are equally numerous and far-reaching - ranging from issues of data control and storage to hardware and software limitations, interoperability issues and the displacement of skills and responsibility within the firm.

Perhaps the most significant challenge attributed to AMT systems relates to their implementation and management - in other words, leveraging the maximum benefit from the selected system. Linking the planned use of the system to the wider organisational strategy is key - in order to do so, organisations must develop an accurate understanding of their various processes and information flows (both formal and informal).

Thankfully, many of the risks and challenges associated with AMT adoption can be avoided or mitigated by the selection of an appropriate system. It is therefore essential that the best practice model incorporates a mechanism to allow this to occur.

3.5.4 Linkages

Section 3.3 highlighted the potential for linkage mechanisms to allow LTESMEs to circumvent many of their own limitations and interface more effectively with AMT through the acquisition of pre-requisite knowledge and guidance. Linkages are available in many forms, ranging from collaboration with firms in the supply chain to formal TT projects with HEIs.

The sources of information available to the LTESME are extremely broad and diverse. A key challenge is ensuring awareness of the range of sources, and selection of appropriate and credible sources - appropriate linkage mechanisms facilitate this process.

However, despite the obvious attraction and suitability of linkages in supporting technology uptake within LTESMEs, in practice it can be difficult to engage businesses effectively - partly due to a lack of awareness of the range of linkages available.

It is therefore essential that the best practice model addresses the selection of an appropriate linkage or 'knowledge partner' to assist with the implementation process.

3.5.5 Change

Section 3.4 highlighted the importance of managing the changes and adaptations which must occur in order for an organisation to effectively implement AMT, which is an inherently disruptive process. Not only do systems and processes have to be re-evaluated and re-structured, but the people within the firm need to be led and guided throughout the change.

Key to achievement is an accurate understanding of the way in which processes currently operate (rather than how the management 'think they operate') and a clear plan which addresses the desired state of operation once the change has taken place. Implementing design-oriented AMT therefore requires knowledge of the design process and production cycle, and an understanding of the potential impact of the implementation on each.

Overcoming a 'natural resistance' to change is vital. This can only be achieved through awareness of the various barriers to change coupled with effective leadership, support and communication throughout every level of the organisation.

3.6 Contribution to the Development of the Best Practice Model

The findings of the literature review have significant implications for the development of the best practice model, which must seek to address the following issues:

1. Overcome the 'core limitations' of the LTESME (both real and perceived)

2. Co-ordinate the interaction of the LTESME with a knowledge partner

3. Encourage the selection of an appropriate technology

4. Address the implementation strategy, allowing for its refinement and improvement

5. Embed and anchor the changes within the firm

3.7 Problem Review / Reformation

Chapter 2 introduced *Creswell's* observation that the 'research question' is likely to evolve and change throughout an investigation, with new questions emerging [41]. In order to address the question "what factors affect the implementation of AMTs within LTESMEs?" the literature review (chapter 3) has examined the following questions in isolation:

1. "What are the features and characteristics of LTESMEs?"

2. "What are the capabilities, associated benefits and challenges of AMTs?"

3. "What type of knowledge and linkages are available?"

4. "How should the change be managed?"

5. "What key observations can be used to develop the best practice model?"

The problem has therefore so far been approached from a reductionist viewpoint. In order to provide a balanced framework, the problem will now be approached from a holistic viewpoint, using a case study (chapter 4) of an implementation project within a real SME (Kingfisher Boats Ltd.), which will attempt to answer the following questions:

1. "What are the features and characteristics of a real LTESME?"

2. "What AMT system and linkage mechanism were selected, and why?"

3. "What were the results and benefits of the implementation?"

4. "How was the change managed?"

5. "What key observations / lessons can be used to develop the best practice model?"

The relevant findings of both approaches to the investigation will then be combined to develop the best practice model in chapter 5.

Chapter 4 Case Study

Chapter Outline

This chapter aims to study the implementation of a 3D CAD system within Kingfisher Boats Ltd. via a formal linkage - in the form of a three-year KTP project with the University of Plymouth. The basis for the transfer, structure of the project and selection of technology, results and benefits of the implementation, change management aspects and lessons learned are presented and discussed.

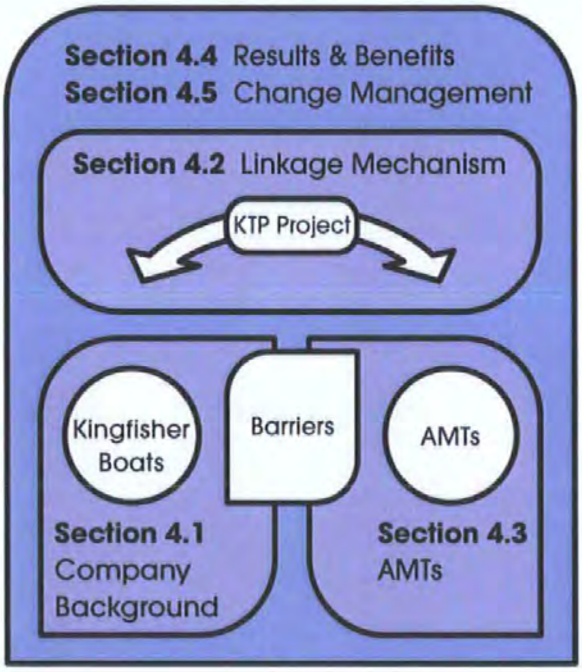


Figure 19. Case Study in Relation to the Research Context

Figure 19 outlines the structure of the case study superimposed on the research context for this investigation. Presenting the case study in this manner is intended to allow the findings of the literature review to be contrasted against the real-world observations, hence contributing to the validity of the investigation, as well as the development of the model and associated guidance.

4.1 Company Background

Kingfisher Boats is a successful family-run, owner-managed business which maintains a good reputation and standing in the industry for the manufacture of high-quality Glass-Reinforced Plastic (GRP) marine craft (commercial fishing vessels and ferries) and associated mouldings. Based in Falmouth, Cornwall, the company employs around 16 full-time members of staff and has been successfully producing boats for over 20 years.

Significant decline in the commercial fishing markets had led to a strong desire to expand into the thriving leisure sector with a new craft, the Kingfisher Sport Explorer, to be based on one of the company's proven 31ft hull forms. Kingfisher recognised that it would need to revise its approach to design and manufacture in order to achieve the improvements in quality and efficiency necessary to realise its market aspirations.

Kingfisher's 'legacy' approach to design relied heavily on the use of outdated methods such as paper-based manual drafting (scale drawings produced by contracted draftsmen) as well as the 'outsourcing' of the majority of critical design activities to third-party naval architects. In addition, much of the historic design information (e.g. modifications to standard builds) resided within MD Ron Coote's head, and had not been formally recorded.

This approach, coupled with Kingfisher's highly flexible attitude to customisation, was causing considerable internal inefficiency as well as limiting the company's ability to communicate design information effectively to its workforce, suppliers and customers. Furthermore, the company was exposed to significant Intellectual Property (IP) risk - with sensitive design data having to be entrusted to third-parties for modification.

The company aspired to bring control of their design process in-house, taking advantage of developments in design-oriented AMTs in order to enhance flexibility, allow a more rapid and controlled response to customisation, improve process efficiency, ensure that modifications to standard designs could be accurately recorded and improve the communication of design data.

Being typical of many SMEs in the marine sector, Kingfisher displayed a number of the LTESME characteristics identified in the literature review. With a limited capacity to undertake internal research and development, a lack of qualified staff with the pre-requisite knowledge and expertise necessary to achieve the successful implementation of new technologies, relatively few links with the knowledge base and low levels of involvement with other organisations in the local business community, the company acknowledged that it would need to take advantage of one or several linkage mechanisms in order to succeed.

4.2 Linkage Mechanism

In November 2004, a three-year KTP project was established with the University of Plymouth with the aim of implementing a new 3D CAD system in order to enhance Kingfisher's design capability, bring the design function in-house, and take advantage of a number of associated CAE / CAM technologies.

The selection of a KTP as the main linkage mechanism was eminently appropriate, representing a relatively low-risk solution offering mutual benefits to the various project stakeholders. The scheme provided relatively inexpensive access to a graduate to manage the project who would be supported by academics at the University of Plymouth, which has a strong record of excellence and innovation across teaching, research and enterprise activities[12].

[12] Working in support of the South West of England Regional Development Agency (SWRDA) and the Government Office for the South West, the University of Plymouth is eager to be seen as an organisation that actively supports economic and social regeneration - primarily via the transfer of technology to SMEs.

Based full-time at the Kingfisher Boats site, the author's responsibilities throughout the project were to:

1. Review the company's product range and existing design capabilities
2. Identify, select and acquire an appropriate 3D CAD system
3. Transfer existing design data / geometry into the new system via reverse-engineering
4. Produce 3D models of both the company's existing and developing product range
5. Exploit CAD/ CAM / CAE across design, manufacture and marketing functions
6. Implement drawing office procedures to manage the new design data
7. Review / re-engineer manufacturing processes and generate new guidance material
8. Record and document the new procedures and systems to ISO9000 standard
9. Embed the new techniques and processes culturally within the organisation

4.3 Advanced Manufacturing Technology

The first step in the AMT selection process was to gather information. An initial investigation focussed on two main areas: firstly, identifying company needs and requirements and secondly, researching and evaluating the range of available technologies.

4.3.1 Company Needs & Requirements

Establishing the company's needs and requirements involved working closely both with the management of Kingfisher Boats (to discuss overall strategy and the various ways in which AMT could be applied to support it) and the shop-floor staff (to establish levels of dissatisfaction with the current state and their views on the areas in which AMT could offer benefits). The technological capabilities of the other organisations within the company's supply chain were also considered to establish interoperability requirements.

The design data generated by the new system was ultimately to be used by the shipwrights and boat-builders for reference during construction - design intent therefore needed to be communicated intelligently and completely throughout the entire production cycle. Potential strategies for the use of existing 'legacy' design data were also evaluated, with options including: complete conversion, conversion of critical elements only, or maintaining of the current system alongside the new solution.

The software available at the University of Plymouth, together with the software experience of the supervisory staff there was also taken into consideration as it raised compatibility and data exchange issues. In this case, the operational CAD expertise of the academic staff was not considered to be a critical factor as the KTP Associate had already demonstrated a reasonable level of competency and was unlikely to need direct supervision in this area.

The main conclusions were that the company required a powerful, flexible, affordable and easy to learn design solution that could span the entire design process, from initial idea through to design implementation and preparation for manufacturing and production. Achieving full exploitation of the system and a positive ROI[13] were also highlighted as essential.

4.3.2 Range of Applicable Solutions

Evaluating the range of applicable technologies involved significant internet-based research, close involvement with the various technology vendors, and contact with other organisations both from within and outside of the marine sector. Many issues arose

[13] For this reason, so-called 'high-end' solutions (which are traditionally much more expensive, but more functional) were not dismissed on the basis of cost alone. Potential ROI on many of these systems can be substantial.

throughout this process including: claims of capability or performance against competitors products being distorted or inaccurate, salespeople providing recommendations before they had an accurate idea of company requirements, the availability of data on some products being extremely limited, the reluctance of some companies to discuss their methods or working practices and, in contrast, the openness of others (e.g. Sunseeker [123]) in discussing their techniques.

The market for 3D CAD software considered suitable for marine design was found to comprise a wide range of systems including: integrated, database-driven ship design solutions for very large commercial craft (e.g. Tribon [124]), yacht design and hull fairing packages for high-quality surfacing (e.g. ProLines [125]), non-industry specific Product Lifecycle Management (PLM) systems (e.g. CATIA [126]), general purpose parametric[14] solid modelling systems (e.g. Solidworks [127]) and general purpose surface / hybrid modellers (e.g. Cobalt [128]).

It was initially assumed that the 'marine-specific' packages (e.g. Maxsurf [129]) would provide the most appropriate solution. However, it was soon discovered that the majority of these programs concentrate solely on individual aspects of the marine design process (e.g. hull design, stability analysis, performance prediction etc.). This is somewhat inflexible, not accommodating the completion of the wide range of production cycle activities on one system. Contact with other marine sector organisations indicated that such programs are commonly implemented in combination (e.g. Maxsurf for hull design alongside AutoCAD [130] for 2D drafting).

The software review also highlighted several potentially applicable products which were not considered to be 'mainstream' solutions. These were ultimately discounted on the basis of a

[14] For further information on parametric capability see Appendix 6.

number of associated risks and challenges. For example, potential problems with a lack or small number of professionals proficient in the software (and a lack of suitably trained graduates), limited access to local resources for training, technical support and consulting services, lower levels of testing, quality assurance and innovative development, little or no support for critical third-party add-on solutions or compatibility issues surrounding non-standard data formats.

4.3.3 The Selected System

Having been presented with the findings of the selection process, in the form of a detailed report and executive summary recommending an appropriate combination of hardware and software, the project stakeholders ultimately agreed a 3D CAD system comprising a Windows-based Dell [131] workstation and the following McNeel software:

Rhino 3D	3D NURBS[15] modelling	www.rhino3d.com
Flamingo	Photorealistic rendering	www.flamingo3d.com
Penguin	Non-photorealistic rendering	www.penguin3d.com
Bongo	Animation	www.bongo3d.com

The software evaluation showed that at the time of the investigation there were very few, if any products that competed directly with Rhino in terms of both functionality and accessibility. Rhino is designed to run on 'ordinary' Windows PC's, requires very little Random Access Memory (RAM) and no dedicated graphics card. Rhino also supports a wide range of different file types that transcend the boundaries of CAD, CAM, CAE, multimedia, illustration and graphics applications, and is capable of performing file conversions between formats - ensuring high compatibility with suppliers' systems.

[15] Non-Uniform Rational B-Spline (NURBS) is the mathematical model used for generating and representing curves and surfaces in Rhino.

Rhino was found to be used across a vast range of industrial sectors, on applications as diverse as the modelling of an artificial heart valve to the design of bespoke jewellery. It was particularly popular within the field of marine design (most evident in countries with significant marine leisure markets e.g. Australia and New Zealand), ensuring that there could potentially be a ready supply of operators with relevant skills and expertise. Rhino's popularity within the marine industry also increased the potential for interoperability with customers, suppliers and other manufacturers within the company's commercial network.

4.3.3.1 Training Aspects

A significant advantage of Rhino over competing products was its reputation for being intuitive and easy to learn. McNeel offers a wide range of training activities (including some industry-specific courses) at numerous locations worldwide. In addition, a large number of independent user groups and communities have evolved, offering access to discussion forums and a vast range of 'unofficial' modelling tutorials. Furthermore, as a result of networking, a number of private consultants and training providers with commercial experience in a range of industries were identified.

4.3.3.2 Support Aspects

The author observed that McNeel maintains an outstanding reputation within the CAD industry for 'market-leading' customer support. A worldwide network of offices, affiliates and resellers provide direct end-user telephone assistance, online 'newsgroups' also provide 24-hour access to advice and assistance from developers and expert users worldwide. All products are supported by extensive literature and the Rhino 'Wiki' [132] also provides a number of useful articles and links. In addition, products are updated in response to customer feedback via electronic 'service-releases' - downloaded automatically from the internet.

Rhino is also supported by a vast selection of third-party applications and plug-ins, many of which are tailored for use in specific industrial sectors. Within the field of marine design, for example, plug-ins such as Rhino Marine from Proteus Engineering [133] can help to support the boat design process by facilitating weight estimation and the hydrostatic analysis of NURBS hull forms. The ability to tailor the system in this way allows organisations access to a bespoke suite of applications dedicated to their marine design needs as opposed to an 'off-the-shelf' product intended solely for mechanical engineering or mechanical modelling.

4.3.3.3 Cost Aspects

Cost was a significant factor in the technology selection process. The budget available for equipment was limited to approximately £4000 and the company did not have funds available for extra investment. This ruled-out some of the high-end solutions for immediate purchase, although they were not discounted for possible future implementation.

Rhino was found to be highly affordable - the standalone program was available for £700 for a single commercial license, with the full suite of Rhino and companion products Flamingo, Penguin and Bongo available for £1250. Other products with similar NURBS tools and functionality (e.g. CATIA, Solidworks, SolidEdge etc.) can cost more than £3000 (some as much as £20,000) for an equivalent licence, and many companies charge an additional yearly subscription. Despite Rhino's relatively modest cost, vendors were found to be willing to negotiate - in some cases offering additional training and resources.

4.3.3.4 Functionality Aspects

Functionality was a key consideration in the selection process. Rhino is not marketed as an all-encompassing CAD product - McNeel stress its status as a 'standalone modeller' suitable for complementing other parametric feature-based modellers as well as rendering, animation, CAM and Finite Element Analysis (FEA) software. However, it is capable of producing renderings, illustrations, dimensioned drawings and animations when used in combination with various plug-ins and companion products, and was therefore considered capable of handling the complete range of production cycle activities at Kingfisher Boats.

Rhino uses four fundamental geometric entities: points, NURBS curves, NURBS surfaces and polygon meshes. Modelling is principally undertaken with NURBS curves and surfaces, 'downstream activities' such as rendering, animation, stereo lithography, Virtual Reality Modelling Language (VRML) output and finite element analysis tend to require a conversion to polygon mesh objects.

As well as tools for geometry creation, Rhino offers a number of powerful tools for geometry analysis which are crucial in ensuring the production of high quality surfaces. Rhino lacks parametric functionality, but the benefits of the history-based parametric approach were (at the time) determined to be extremely limited for this implementation.

4.4 Project Results & Benefits

The KTP delivered against its original objectives within the agreed timeframe and various project budgets. Kingfisher has experienced a step-change in capability, and now competes technologically with some of the industry's leading organisations. The 3D system has had a significant impact on the business, having been used for a variety of purposes including: reverse engineering, output to sales and marketing, internal and external communication of design data, CAM, CNC, CAE, assembly modelling / virtual prototyping, animation, and the production of manufacturing drawings and guidance. It has subsequently continued to be applied in a variety of innovative ways to add value to both the organisation and its products.

Exploiting the 3D CAD capability on numerous manufacturing projects, including the development of the brand new Sport Explorer, demonstrated dramatic gains in efficiency, accuracy and quality throughout the production cycle. The implementation also resulted in a 'tightening' of tolerances within manufacturing processes. As a result of these improvements the company has been able to increase overall production capacity.

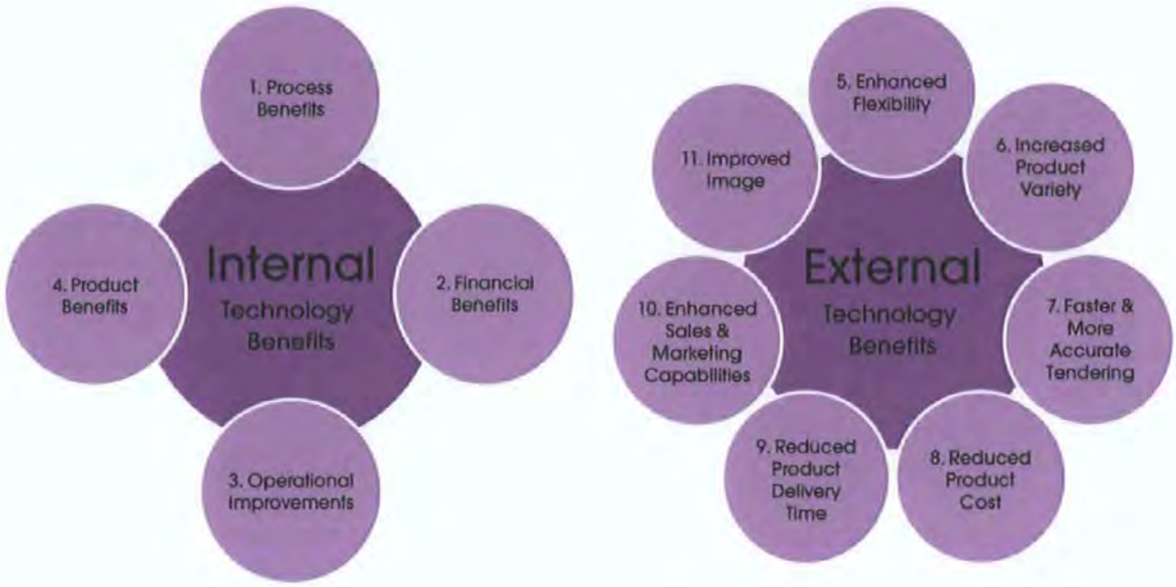


Figure 20. Internal & External Benefits of AMT within the Case Study

Figure 20 highlights the main internal and external benefits of AMT that were identified within the literature review. The benefits of the case study implementation, in each of these areas, will be examined throughout the following sub-sections.

4.4.1 Process Benefits

The implementation of 3D CAD significantly enhanced design, manufacturing and purchasing processes at Kingfisher. Lead-times for the production and modification of drawings / technical illustrations were reduced to a fractional level (in some cases exceeding the 8:1 productivity increase proposed in the literature review) although it was difficult to quantify these improvements meaningfully - partly due to a lack of historical data.

All of the design data for the Sport Explorer was collated into a 'technical construction manual' containing part and assembly drawings, laminate schedules, build instructions, annotated CAD representations, fit-out / finishing instructions and photographs, as well as a 'bill-of-materials' spreadsheet thoroughly detailing each component. This was a novel approach for the company, who had previously relied upon a combination of archived drawings, physical templates and the undocumented knowledge of the shop-floor staff.

To produce the manual, all of the major manufacturing processes were examined and documented using a combination of digital photographs and written records. These were then pooled with drawings and other key pieces of information in order to produce 'process sheets' which could be copied and distributed to staff. These outlined the materials required (including part names, descriptions and product codes), inter-relationships between components as well as supplementary procedural information.

The manual provided a permanent, accurate record of the Sport Explorer's construction. The information within was kept up to date and amended in response to any problems encountered in manufacturing the boats. Because manufacturing guidance was always distributed directly from the manual, consistency was maintained in the production of components. The manual also embedded the information generated within the 3D system by transferring it to a 'universal format' (i.e. hard-copy scale drawings).

This approach ensured a high level of parity between the CAD data and manufacturing guidance, led to high quality control in the manufacturing processes, dramatically improved the communication of design data (both internally and externally), facilitated a more rapid and controlled response to customisation (with more repeatable results) and contributed to a reduction in mistakes throughout the production cycle.

The effectiveness of this approach was highlighted when, in order to address a potential overload of capacity and meet a tight deadline for the 2006 Southampton International

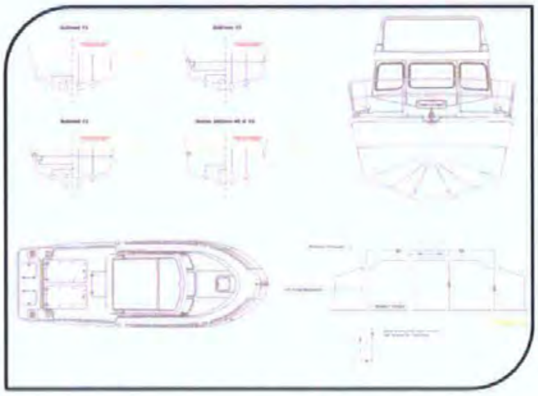
Boatshow, Kingfisher worked in partnership with Bridgend Boat Company of Plymouth, Devon, on a collaborative venture whereby a semi-completed set of mouldings and some mould tools for the Sport Explorer were supplied to Bridgend for assembly and fit-out.

Kingfisher also supplied a complete copy of the Sport Explorer construction manual and a DVD containing over 2000 digital photographs of the boats produced so-far. All of the 'off the shelf' fittings and components for the boat were ordered, using the 'bill of materials' spreadsheet, in a single day. A copy of the list of components was also supplied to Bridgend providing an inventory of components against which deliveries could be recorded, and stock could be controlled.

The construction manual enabled Bridgend to construct the boat with very little input from Kingfisher Boats - indicating that the overall aims of creating a comprehensive resource for the manufacture of the boats had been achieved.

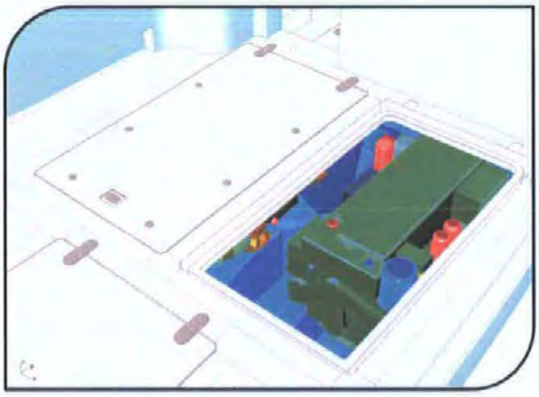
The traditional approach to design at Kingfisher Boats: scale-drawings produced by contracted manual draftsmen.

Using a rotary laser-level to mark the inside of the hull mould: providing a vertical reference datum to measure against.



New 2D Data produced directly from 3D model: ensuring 100% accuracy and incorporating the laser-line datum system.

Drawings in use on shop-floor: promoting consistency in the manufacturing process and reducing the propensity for mistakes.



Level of detail of the assembled CAD model: representing a 'virtual prototype' of the completed Sport Explorer.

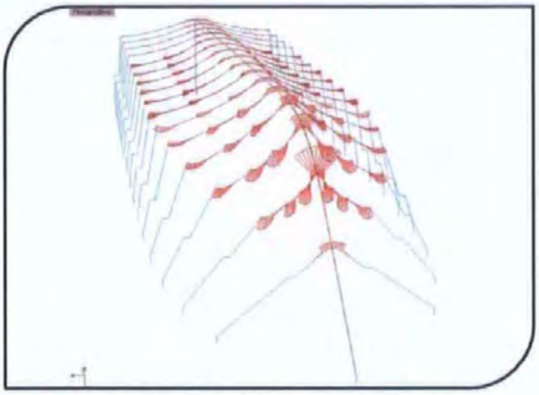
High parity with real-life geometry: essential due to complex inter-relationships between components and equipment.

Figure 21. Examples of Process Benefits

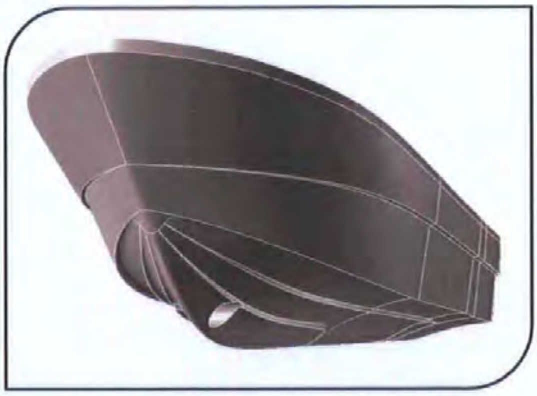
Figure 21 shows a number of areas in which the new CAD system has been successfully used to enhance manufacturing. The main challenge was controlling the manufacturing process in order to ensure parity between the model and real-life geometry.

4.4.1.1 CNC Manufacturing Applications

Throughout implementation, the application of CNC manufacturing techniques to support the development of various products and components yielded significant benefits.



Hull lines transferred to 3D from original hand-drawn lines plan - data is rapidly optimised / improved using analysis tools.



3D surface model generated from hull sections - used now to evaluate the design, and later to develop the virtual prototype.

CNC-cut 'hull sections' produced using 3D data, assembled in workshop using laser alignment strategy developed in-house.

Datum and numbering system developed in-house to facilitate rapid and accurate construction (assembled in 2 days).

Hull plug surface finished by hand using traditional methods - geometry found to be exceptionally accurate / high quality.

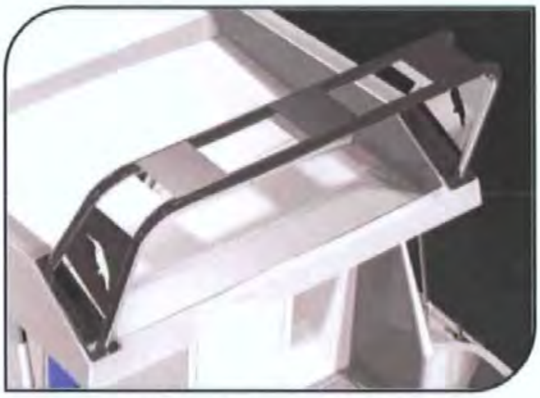
Hull plug subsequently used to manufacture tooling, which was in turn used to produce the finished fibreglass hulls.

Figure 22. CNC Manufacturing for K45 Hull Tooling

Figure 22 outlines one particularly successful application of CNC - to assist the rapid development of composite tooling for a brand new hull design. The technology was selectively applied, supporting the traditional manufacturing processes by removing tedious elements whilst significantly increasing accuracy. As well as improving manufacturing efficiency, the process ensured that the 'real-world' hull geometry represented the CAD model to an extremely high tolerance (less than 3mm over 45ft).

Aesthetic / functional layout generated in Rhino and full-size paper template produced to verify accuracy.

CNC-cut Carbon fibre panel (manufactured off-site): allows for rapid and accurate installation of gauges and instruments.

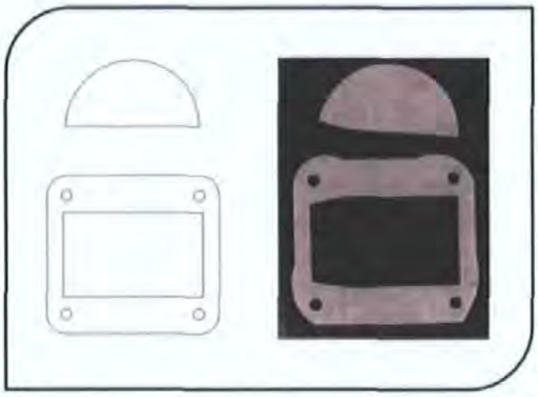


3D concept for spoiler modelled in Rhino and used to 'sell the concept' to senior management and fabricator.

Waterjet-cut panels, including Kingfisher logo cut-outs, assembled off-site by fabricator using associated CAD guidance.

Figure 23. Other CNC Manufacturing Projects

Figure 23 shows some other areas in which CNC was exploited. The company was able to form links with CNC-enabled suppliers from the local area (who had not been known / identified prior to the KTP project). Furthermore, despite a move to produce as many components as possible using the technology (with the advantages of speed, cost, quality and consistency / repeatability), relationships with less-technologically-enabled suppliers were not disrupted - in many cases they were actually strengthened. For example, Kingfisher was able to supply pre-cut raw materials (which were guaranteed to fit together) and higher quality assembly instructions.



Discrepancy between the submitted CAD file (shown on left), and the received laser-cut components (shown on right).

Description of the problem (including original files) posted to Rhino newsgroup: numerous helpful replies were received.

Figure 24. CNC Manufacturing Problem

Despite these successes, some problems were encountered. For example, figure 24 shows a major discrepancy between the CAD data submitted to a third-party laser-cutting firm, and the components which were subsequently received. This raised a number of issues, most importantly: *the question of liability for the erroneous components.*

The author posted a description of the predicament to the Rhino newsgroup - resulting in a number of valuable responses which were used to build the company's case. Ultimately, the issue was resolved after the author negotiated with the supplier to have the components re-cut free of charge. The fault was later determined to be a data translation issue with the laser-cutting firm's CAM software (although both parties had a defensible position).

The thread provides an excellent example of the effectiveness of the newsgroup, and is currently available online [134].

4.4.2 Financial Benefits

The new system lowered the cost of production and enabled cost avoidance through the elimination of third-party involvement with design and manufacturing activities. ROI was achieved rapidly as the system was brought into operation. For example, the application of CNC for the production of the K45 hull tooling realised a project time saving of four weeks, equating to a labour cost saving of the order of £8000. To give this some context: the original equipment and consumables budget was £4500, initial outlay for the CAD software and associated hardware was approximately £3250, spend to date (with 3 months remaining) was £4103.

Financial benefits were also realised through the avoidance of formal 3D CAD training, which is notoriously expensive (in excess of £400 per day). By selecting a system with an outstanding support network, identifying and undertaking free self-teach training exercises and tutorials as well as developing an informal network of experienced operators who could be contacted to resolve technical queries at no cost, zero expenditure on either CAD support or training was achieved.

The production of a 'bill of materials' for each Sport Explorer led to detailed and more accurate record keeping and a greater understanding of the true cost of each vessel. As a result, the company has been able to monitor cash-flow more accurately and identify areas in which to save money via the use of more competitively priced components and suppliers.

4.4.3 Operational Improvements

The company has benefited from an enhanced understanding of AMTs, including knowledge of how and where technologies can be exploited in order to leverage competitive advantage. In addition, all project outcomes have been comprehensively recorded and integrated with the company's ISO9000 quality management system.

Communication of both design and other data has been significantly improved, allowing the company to work more easily with a wider network of suppliers. Meanwhile, this has not negatively affected links with existing suppliers, who are provided with much better design information than was previously possible. Relationships with several key suppliers have been significantly strengthened - the capabilities of the 3D system have been shared / transferred, allowing mutual benefit through increased accuracy, purchasing efficiency and reduced wastage.

Working with suppliers to co-ordinate orders for bespoke components of the Sport Explorer highlighted the importance of communicating design intent accurately. Considerable attention was paid towards written and verbal consultation with suppliers to ensure quality levels were maintained.

To check that custom manufactured items were produced within tolerance they were inspected on delivery against the original design data. On major projects the task of inspection and comparison involved a number of parties, typically including: the author, MD and any shop-floor staff involved in the fitting or assembly of the products. Key geometric features were compared with those submitted, and verification was sought that revisions or modifications to the design had been taken into account.

This essential monitoring ensured that the design process worked effectively, and that clear communication was maintained. The findings of inspection usually indicated conformance with the supplied data, but when a non-conformance was recorded a subsequent process of fault-tracking was required. This may have indicated a shortcoming in the information originally submitted, in which case the fault was corrected for subsequent submissions and the manufacturer was notified but not held accountable, or a failure on the part of the supplier, in which case the data submitted may have been used as the basis for a potentially legal / liability dispute over the non-conformance.

4.4.4 Product Benefits

The new system has facilitated the rapid modification of designs and as a result has allowed more design alternatives to be investigated in the time available (ultimately leading to more manufacturable products, of a higher quality). The ability to 'virtually prototype' and explore conceptual new designs before committing to manufacture was the main mechanism by which product benefits were realised.

Original design data for *Sport Explorer* - previously, presentation of all design work was limited to this basic 2D format.

3D Virtual Prototype produced for extended wheelhouse variant of Sport Explorer - before any manufacturing work had begun.

Level of detail of the 3D model: staff, customers and suppliers now have access to a high-accuracy product definition.

One of the first boats manufactured using the new systems and processes - high performance: capable of over 40kts.

Figure 25. Examples of Product Benefits

Figure 25 highlights the influence of the new system on product development activities. Both customers and the workforce are now more involved in product development, resulting in highly refined products which are more suited to customer requirements.

4.4.5 Enhanced Flexibility

The new system has allowed the company to display greater flexibility by responding rapidly to changing customer demands. For example, feedback from customers indicated that the original Sport Explorer would benefit from a reduced aft-deck and larger cabin. The CAD system was quickly used to generate a virtual prototype of the proposed design revision, which was subsequently presented to potential customers. This approach stimulated a culture of 'participatory product development', which proved very effective.

It was essential to work closely with customers, and subsequently suppliers, to ensure that their requirements were met. The 3D system was pivotal to this process as it allowed the generation of near photo-quality representations of the finished product to facilitate unambiguous discussion and unanimous agreement of requirements.

4.4.6 Increased Product Variety

The new system allowed an extensive 'virtual product range' to be developed, thereby increasing product variety. Despite this, the company has not had to commit to full-scale development of any products which are not actual customer orders (previously the company invested in full-scale mock-ups for product development).

4.4.7 Faster & More Accurate Tendering

As a result of the increased speed and ease in accessing data and implementing design changes, the company is able to respond much faster to customer enquiries and tendering opportunities. Furthermore, as a result of the enhanced product definition provided by 3D CAD, other organisations within the company's supply chain are able to quote for their contribution to proposed manufacturing projects more accurately.

4.4.8 Reduced Product Cost

The improvements in terms of process efficiency, reduction in mistakes and use of more cost-effective CAM techniques (such as CNC) have contributed to a reduction in the cost of producing each vessel, which could also be passed on to consumers in the form of more competitive pricing.

4.4.9 Reduced Product Delivery Time

A reduction in product delivery time has principally been achieved via improvements in both design and manufacturing productivity, which has increased significantly - not only within the design function, where the lead-time for the production of designs, manufacturing drawings, data retrieval etc has been reduced to a fractional level (in some cases exceeding 8:1 in comparison with manual methods), but also within manufacturing, where the new guidance material has allowed people to work faster, more consistently and with a lower propensity for mistakes. This has contributed to a reduction in the overall 'time to market' for the company's products.

4.4.10 Enhanced Sales & Marketing Capabilities

Using the 3D CAD system to produce a wide range of rendered images and other visual outputs ultimately brought the majority of marketing activities in-house, resulting in significant cost savings, higher quality output and greater control over IP. For example, the production of marketing materials for the Southampton International Boat Show in 2006 realised cost savings in the order of £3500.

Splash-screen for auto-run CD sent out in response to customer enquiries - included CAD images + animations of product range.

Brochure produced in-house for 2006 Southampton International Boat Show - printed before boat had been completed.

Figure 26. CAD Contributions to Marketing

Figure 26 highlights some of the areas in which CAD outputs have been exploited in-house to support the marketing function.

4.4.11 Improved Image

The intangible benefits of the implementation have been equally significant. The new technological capability has helped to build the company's reputation for innovation and creativity throughout the local business community. Company links with the knowledge base have been significantly strengthened - the author arranged company visits / factory tours for students from several HEIs and Falmouth Marine School.

As a result of its success, the project was highlighted as a case study for the South West Regional Development Agency (SWRDA) and Knowledge Exploitation South West (KESW). The author was also invited to publicise the success of the project by delivering presentations on behalf of: the University of Plymouth's Department for Research and Innovation (RIO), SWMAS, McNeel, Unlocking Cornish Potential (UCP), the Cornwall Engineering Group (CEG) and Combined Universities in Cornwall (CUC). A video of one presentation is currently available online [135].

4.4.12 Benefits to the HEI

The University has benefited from the project in several areas. The KTP has facilitated the feedback of expertise and knowledge of real industrial challenges. The author also delivered several lectures to undergraduates and delegates on University short-courses, and worked closely with several undergraduates, and other KTP Associates employed by the University, in order to provide case studies and other relevant input to related projects.

4.4.13 Benefits to the Author

The author has benefited significantly, having gained experience in: the running of projects, implementing new technology / managing TT, manufacturing process control and optimisation, CAD/CAM/CAE/CNC and advanced composites manufacturing techniques as well as gaining a deeper appreciation of cultural issues, company processes and relationships between key business functions and individuals.

The experience has helped to develop ability in analysing information rapidly to support key decisions, in an environment where time is at a premium. The author has also been funded to undertake this MPhil, as well as number of other training activities and qualifications including: three week-long residential modules, an NVQ Level 4 in Management, and the Chartered Management Institute's 'Chartered Manager Award'.

4.5 Managing the Change

Introducing the new system involved challenging traditional working practices, requiring careful change management and awareness of the significant cultural implications of the project. The technology, which was initially perceived as a threat by the workforce, was ultimately fully embraced across the organisation. This was largely achieved by developing the workforce's understanding of the capabilities of the new system and encouraging them to identify new opportunities to apply the technology, whilst providing the technical expertise necessary to put their ideas into practice.

It was essential to involve staff at every level in: articulating a compelling case for change, developing a shared vision of the future and creating the conditions for success. This was achieved by working closely with management to shape and develop a competitive strategy that addressed the businesses needs, and meeting with staff 'on their own ground' to discuss how the new technology could be applied across the organisation, as well as the wider implications of the change.

As a result of this involvement the author was able to produce a Specific, Measurable, Achievable, Realistic and Time-bound (SMART) project plan that:

1. Addressed the strategic needs of the business and supported its competitive strategy

2. Demonstrated how the changes could be delivered within the desired timeframe

3. Included project milestones and defined indicators / measures of success

4. Would be confidently supported throughout the organisation by staff at every level

Staff were regularly updated on progress, via both formal and informal pathways, allowing them to track developments and relate their individual contributions to the overall success of the project. It was particularly important to remain flexible, responding quickly and decisively to the continuously changing strategic needs of the business in order to maintain direction and focus.

4.5.1 Communication

Effective communication was vital throughout the change process. The needs of the various project stakeholders (who each had different levels of interest and involvement) had to be carefully balanced. To achieve this, a number of separate communication channels were established, each of which was appropriate to individual stakeholder needs. These included: monthly 'technical meetings' involving the immediate project team, weekly progress meetings involving the company management team, open / conference phone calls and emails, formal reports (both full and executive summary), company-wide change bulletins and presentations. In addition, four-monthly Local Management Committee (LMC) meetings (which involved representatives from the company, University and the DTI) were built into the KTP project structure and provided an opportunity to review project progress against the strategic aims of all parties. Succinct communication was key: a great deal of information needed to be communicated in a short period of time and it was important to focus on the 'bigger picture' rather than the 'day-to-day' detail.

Equal importance was placed on 'upstream' communication with management and 'downstream' communication with the workforce - this was essential, not only to provide clarity and keep people informed, but also to receive their vital feedback. There was a strong need to maintain regular contact, even when the news was bad, as a lack of information could quickly lead to potentially damaging speculation. Responding effectively to concerns and offering support and guidance was also vital.

4.5.2 Strategy

Adopting a strategic approach to the project, with the principal aim of improving and sustaining high levels of both personal and organisational performance, was fundamental in delivering successful change.

This was achieved throughout the project by: consistently engaging with both staff and management to keep abreast of company developments and changes in strategy, identifying constraints (and developing ways of both challenging and working within them), considering wider implications, appreciating other people's points of view, and remaining vigilant as to continuously changing strengths, weaknesses, opportunities and threats that could affect the business (not just immediately, but over the short and longer-term).

In practice, this involved 'asking the difficult questions' to ensure the real business needs were identified and articulated. The most poignant example of this was the issue of project closure - the message that the company potentially faced a skills-gap unless operational knowledge of the technology was embedded had to be strongly reinforced.

4.5.3 Opportunities for Change & Development

Many of the improvements and refinements made to the implementation strategy were suggested by the company employees who were directly affected by the new technology. It was therefore essential to foster a culture of open and honest communication - encouraging staff at every level to identify and discuss opportunities for change and development. For example, a significant amount of work was undertaken to optimise the new manufacturing processes and techniques - this involved working closely with the workforce to gather feedback and evaluate the processes as well as encouraging individual members of staff to take the responsibility and ownership necessary for a 'continuous improvement' environment.

4.5.4 Support & Development

A number of staff development activities were undertaken throughout the project, these included training both individuals and teams in the new techniques and processes as well as educating staff in the capabilities of the new system in order to enhance their understanding. It was important to manage relationships on several different levels, from the management team's strategic interest in the technology, to the shop-floor staff's direct involvement with the CAD outputs and new manufacturing processes.

Despite operational knowledge of the technology being beyond the scope of most roles within the organisation, it was considered crucial that the system's 'internal customers' (i.e. the people who worked with the drawings, or assembled components produced via CAM/CNC) should understand, and to some extent influence, what happened 'upstream'.

4.6 Observations & Lessons Learned

The author's unique opportunity to directly observe the issues facing a contemporary LTESME in its adoption of AMT, whilst simultaneously influencing and shaping the implementation strategy, has provided a fascinating insight into the real-world challenges.

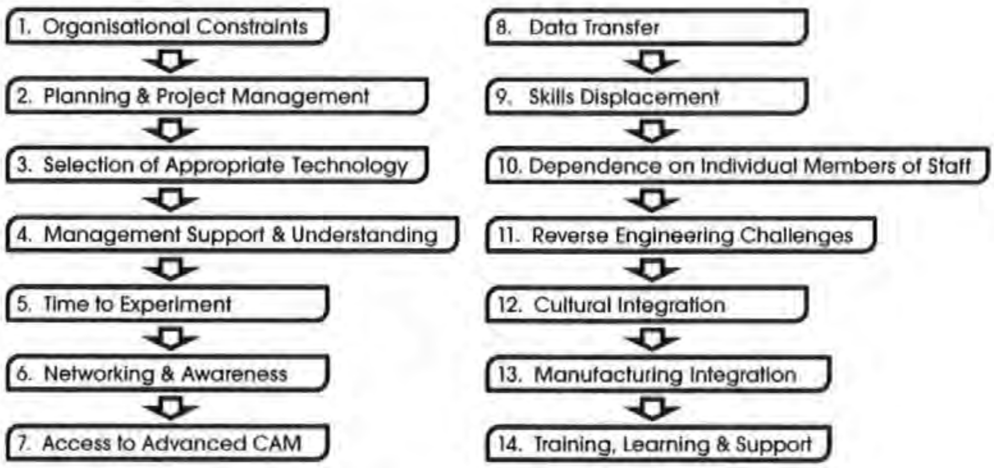


Figure 27. Factors Identified by the Author

Figure 27 shows the fourteen factors identified by the author as having a significant influence on the success of the AMT implementation. A number of important lessons have been learned - these are summarised throughout the following sub-sections and will be used to contribute to the development of the model in the next chapter.

It should be noted that whilst these observations are highly 'internally valid' they are seen from the perspective of the author and as a result it may be difficult to differentiate between opinion and fact. These findings (and the subsequent development of the model) therefore comprise the 'introspective reflection' described in the research methodology.

1. Organisational Constraints

A number of organisational constraints hindered the technology implementation process. Limitations were commonly related to a relative lack of collaboration, both internally, between different business functions (and notably between the company management and shop-floor employees), and externally, between organisations in the supply-chain.

Formal relationships between key business functions were not always clear - things seemed to 'just happen' rather than following a well-defined process. This lack of formality conflicted with the disciplined approach necessary to ensure parity between the CAD data and the real-world components, and therefore became a source of frustration throughout the project.

The strong emphasis placed on day-to-day problem solving and visibly value-adding business processes meant that there was insufficient time to bring people together to collectively plan the application of the new technology. There was also found to be a lack of understanding (and in some cases an initial lack of interest) about what the technology was capable of achieving - so a lot of time was invested in re-educating rather than strategically planning.

It became clear that the technology could not be used to replace the judgement of skilled / experienced designers, rather, that it was a complementary addition. Implementing new technology therefore requires commitment across the entire organisation, clear and careful planning (clear aims, objectives and achievements) and effective support and evaluation.

2. Planning & Project Management

Effective planning and project management were crucial in guiding the implementation and providing focus for the various stakeholders. One highly effective approach was to use the new technology relatively early on a project of high strategic value for the company (a 'critical pilot project') in order to demonstrate value and inspire confidence.

The highly structured nature of the KTP scheme was particularly effective - regular team meetings involving all stakeholders ensured that a realistic project plan was followed throughout the implementation, and that changes in strategy were responded to swiftly.

3. Selection of Appropriate Technology

The selection activities undertaken early on in the project proved to be highly effective in delivering an eminently suitable solution. Key metrics for software selection included: functionality, interoperability, capability and complexity. It was initially assumed that a less expensive solution would be less functional in operation. However, this was definitely not the case. Appropriateness was found to underpin the requirements for software selection - and is perhaps the single most important factor for successful technology uptake.

Another related observation is that the level of detail of the model within the CAD system needs to be determined early in the design process. This is important because the modelling process itself was also found to be extremely time-consuming. It was found that Rhino was both intuitive and relatively easy to learn. Furthermore, the software could be applied very 'freely' and innovatively across the business - this is in stark contrast to many of the traditional misconceptions that CAD is a 'rigid' and restrictive tool.

4. Management Support & Understanding

The support of both the project and company management teams was essential to the success of the implementation. Ultimately, management control the resources within the organisation - it is therefore paramount that they are aware of the key issues, with an informed (and ideally detailed) understanding of both the function and capability of the new technology, and that they support the various implementation activities[16]. Management must be patient, acknowledging that successful implementation relies on allowing adequate time and committing adequate resources.

5. Time to Experiment

Allowing adequate time to experiment and 'play' with the software (on non-commercial projects / exercises), in order to develop an advanced level of competency, was perceived to be a key contributing success factor. This approach required a significant investment of time and resources, but the rewards were significant. The experience highlighted the criticality of the relationship / interaction between operator and system, and the importance of recruiting staff capable of adequate (but ideally expert) operation.

6. Networking & Awareness

Building awareness of the implementation project throughout the wider business community was important. The author's presence at a range of industry events led to the

[16] *Jones & Jain* identified 'upper management support' as a key success factor in the implementation of new technology, and suggested that there needs to be a "conscious effort to think about the impact of technological change on the market position of the firm" [15].

development of an influential commercial network - able to offer support, advice and mentoring in numerous areas. Presentations delivered throughout the implementation were extremely well received and helped to raise national awareness of the project as well as the wider KTP scheme. For example, the author maintained close contact with developers at McNeel and was invited to present at the UK Rhino User Meeting - the opportunity was used to promote the project, and highlight what can be achieved to an audience of over 100 SME managers and technologists.

7. Access to Advanced CAM

One of the major benefits of the 3D CAD system was anticipated to be the ability to exploit 5-Axis CNC production methods, which would have allowed for the construction of 'organic' sculpted surfaces for mould tooling: potentially a source of significant competitive advantage for the company. However, in reality 5-Axis CNC was determined to be cost-preventative for a business of this size / type. This limitation must be overcome in the longer-term by developing relationships with other organisations / technology partners who could provide more cost-effective access.

8. Data Transfer Limitations

Despite selecting a CAD system with exceptional interoperability, the transfer of data to and from different formats was found to be problematic when dealing with some suppliers - particularly those with a lower technological capability. It is difficult to say how this might have been improved, although supply chain management practices could address this issue.

9. Skills Displacement

The displacement of core-skills was found to be a significant problem in the implementation of 3D CAD at Kingfisher Boats - primarily the naval architecture / marine engineering competencies that had been previously provided by the contracted manual draftsmen. Building awareness of this issue, and ultimately recruiting new staff to bridge these 'knowledge gaps' will be essential over the longer-term.

10. Dependence on Individual Members of Staff

The implementation has also naturally led to a greater dependence on key members of staff - particularly those with a developed technological understanding and ability. Whilst this has been somewhat unavoidable, it does pose a significant risk to the business which needs to be addressed, and minimised.

11. Reverse-Engineering Challenges

One of the most challenging aspects of the implementation was ensuring the CAD data accurately represented the mould tooling and other components on the shop-floor. In many cases there was a lack of formally recorded design data (either 2D drawings or CAD data) available for the various mouldings and components. A great deal of effort was therefore required to reverse-engineer geometry, drawing on any data available, or carrying out surveys of the real-world components to generate new reference information.

A comprehensive 3D survey of the Fastcatch hull mould was undertaken by the author: using a 'dumpy level' and theodolite.

Survey data (red dots) plotted in 3D against lines-plan data (white dots) in order to validate the hull model.

Figure 28. Reverse-Engineering / Surveying Activities

Figure 28 shows a typical approach to reverse-engineering, involving a survey of the real-world geometry to generate a data set comprising Cartesian (X,Y,Z) co-ordinates, which could be plotted in the 3D environment as a guide. The reverse-engineering of the Fastcatch hull was a particularly challenging project - there were three sources of data: an original hand-drawn lines plan (which had been used in the past by the shipwrights to construct the hull plug, and subsequently the tooling) a 'digitised' lines plan created by a Naval Architect who had worked with the company in the past (this had been generated using the hand-drawn lines plan as a guide) and the real-world geometry of the hull tooling and various hull-mouldings which were available on the shop-floor. These conflicting data-sets had to be resolved in order to generate a model which accurately represented the real-world geometry, to within an acceptable tolerance.

Despite having been successfully relied upon within the conventional manufacturing process, the 2D design information available at Kingfisher was generally found to be of limited value for the purpose of reverse-engineering. Although there was evident use of logical / conventional drawing practice, the three individual views of components very rarely resolved in all three dimensions.

Reverse-engineering aspects are discussed further in Appendix 7.

12. Cultural Integration

Integrating the system culturally throughout the entire organisation was found to be extremely important for effective technology exploitation. This process involved educating and inspiring the workforce to think about the range of possible applications for the new technology, whilst providing the technical expertise necessary to put their ideas into practice. An open and honest culture was perceived to be a key factor in promoting successful technology exploitation.

13. Integration with the Manufacturing Process

Effectively operating and managing the 3D CAD system would not have been possible without a detailed understanding of 'downstream' manufacturing processes. Integration of design and manufacturing processes was therefore crucial to the success of the implementation. The CAD system offered support to the manufacturing process in a myriad of different ways. For example, detailed drawings or 1:1 scale templates could be printed on an ad-hoc basis. Use of the system was particularly effective in 'convincing' senior management of design or manufacturing proposals. Some problems were experienced in terms of keeping drawings and models current (both within the system and on the shop floor).

14. Training, Learning & Support

It became clear throughout the early stages of implementation that the most effective form of learning (once a base-level of competency had been established) was to attempt to apply the software in the real commercial setting. Only then would the areas in which the user required further training become apparent. There must be an optimum balance between learning and achievement. Organisations need to recognise that non-value-adding activities can significantly improve performance in the long-term.

Engaging with a number of online communities (e.g. the Rhino newsgroup) enabled the author to rapidly obtain targeted advice and guidance from a broad audience of users and industrialists. It was observed that the most effective way to use newsgroups was a pro-active approach - where possible providing a detailed file demonstrating an attempt to solve the problem under the operator's own initiative. This tended to result in helpful, practical guidance and usually a 'fixed file' containing the solution.

Chapter 5 Development of the Model

Chapter Outline

This chapter describes the development of a best practice model intended to enlighten and guide LTESME decision makers / operational managers involved in the implementation of AMT whilst illuminating the subject area for subsequent research.

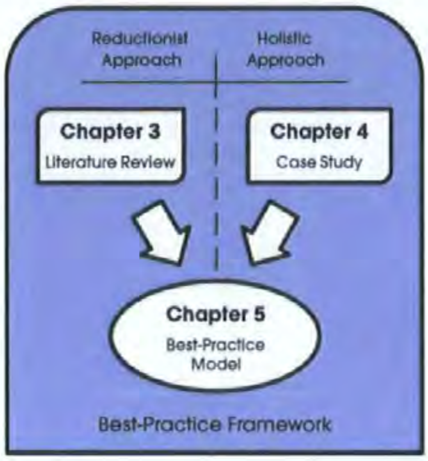


Figure 29. Focus of the Investigation **Figure 30. Development of the Model & Framework**

Figure 29 illustrates the conceptual framework around which this investigation has been based. So-far, the various components of this framework have been examined using two distinctly separate approaches – reductionism: through the literature review, and holism: through the case study.

Figure 30 shows how the findings of each approach must now be combined, or 'triangulated' [42], in order to develop the best practice model. This process is highly interpretive and therefore represents (along with the observations from the case study) the 'introspective reflection' described in the research methodology – influenced by the author's own 'naturalistic generalisations' [41].

5.1 Introduction

As both the literature review and case study have shown; the implementation of AMT within LTESMEs via linkages involves the management of a number of complex inter-relationships between various project stakeholders and, crucially, requires an appreciation of the factors which are likely to affect success.

LTESME managers might start by reviewing the findings of the literature review, particularly the various characterisations attributed to LTESMEs, and evaluate the extent to which these apply to their particular organisation, in order to understand their own limitations[17]. However, managers should take care not to focus overly on any one aspect.

5.2 Best Practice

Increasingly, businesses are recognising that the way in which people actually carry out work activities usually differs from the 'documented / prescribed approach' and are therefore replacing the traditional approach of 'training and development' (based on existing practice) with 'learning activities' at organisational, team and individual levels to investigate examples of 'best practice' from other sources. In order to develop the model, it is first necessary to examine what 'best practice' means in this context.

Mathaisel et al. define best practices in a relatively simplistic manner, suggesting that they are the various ways in which organisations have successfully addressed a particular problem [136]. They also observe that identifying best practices within other organisations is a relatively easy task in comparison to 'transplanting' them within one's own firm.

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[17] Although not addressed by this investigation, the development of a system to allow managers to undertake a quantitative evaluation of the extent to which LTESME characteristics apply to their organisation would be an excellent area for future study.

There are other common definitions of best practice. For example: that it represents a 'standard way of doing things' which can be used by organisations to achieve success, that it is 'the best way' of achieving a particular objective - in other words, an approach which is 'more effective' than any other, or that it is the 'most efficient' way of addressing a particular problem. In the context of this investigation, 'best practice' is intended to represent a series of discrete actions most likely to lead to the desired results in a given implementation of AMT.

It is crucial to observe that although best practice can be considered as an effective route to addressing the various implementation challenges, it is essentially a philosophy which logically contradicts that of innovation (the successful exploitation of new ideas). If no-one ever looked outside the best practice framework for solutions, then by definition there would be no innovation. Organisations are therefore encouraged to remain vigilant of opportunities to challenge the following model, and develop new ways of thinking.

5.3 A Best Practice Model for the Implementation of AMTs within LTESMEs

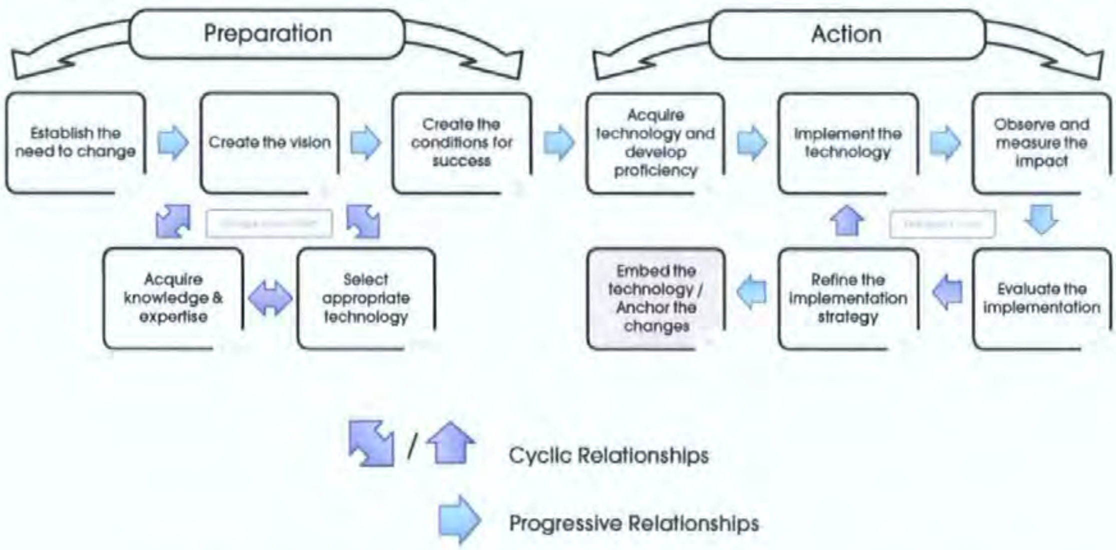


Figure 31. A Best Practice Model for the Implementation of AMT within LTESMEs

Figure 31 illustrates the proposed best practice route for the implementation of AMTs within LTESMEs. The model draws on the findings presented in section 3.6 of the literature review, and section 4.6 of the case study in order to addresses both the physical / structural changes which need to occur as well as the key cultural, managerial and behavioural issues.

By analysing the model and understanding the interconnectedness of the various components, LTESMEs managers should be able to: develop their own unique implementation strategies, explicitly planning the actions most likely to lead to the desired results (linking a clear path of implementation activities to a successful outcome), understand and visualise the 'boundaries' of a particular change effort and respond effectively to changes in circumstances throughout an implementation.

Whilst progressing through the model (which is presented as an iterative cycle rather than a linear process) organisations should focus on the use of SMART objectives. The model has not been related to timescale, which will vary depending on many different factors including: the significance of the change, strategic issues, market forces, organisational constraints, availability of funding, availability of (and access to) linkages.

The model should be applied in a manner appropriate to the scope and significance of the proposed changes. For example, there is little value in applying extremely complex and time-consuming strategies to a relatively simple change (e.g. the upgrading of existing CAD software to a later version with similar functionality). In contrast, the implementation of radical technology with far-reaching implications for the organisation would warrant a more thorough and detailed approach.

The following sub-sections will review the main stages in more detail.

1. Establish the Need to Change

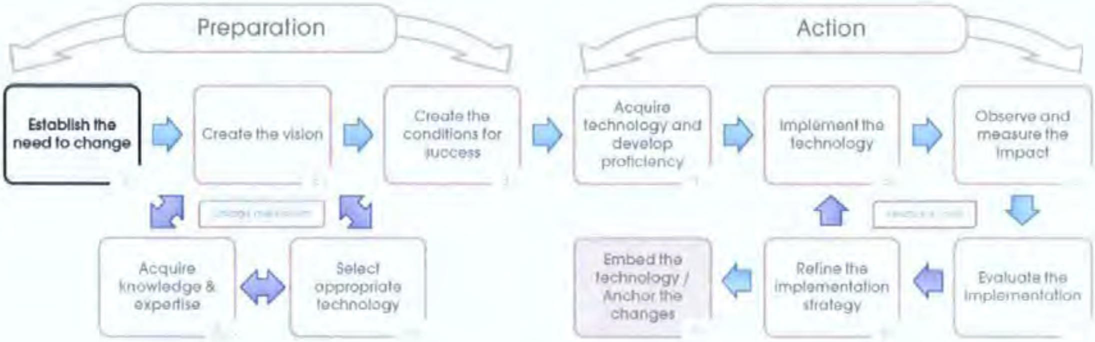


Figure 32. Stage 1 of the Model

Figure 32 highlights the position of stage 1 within the model. The first step in any organisational change effort is for the management to develop a strong sense of self-awareness and clarify: exactly why the business needs to change, and what the various barriers and constraints to achieving success are likely to be.

This is achieved by developing a clear understanding of how the company (or a relevant sub-section) currently operates, examining the contemporary features of its internal and external environments, and anticipating the short and medium-term changes (in terms of environment, market, technology, personnel, legislation etc.) that are likely to affect the business's ability to compete effectively.

The key here is to generate factual evidence of the need to change - this stage should result in a clear identification of driving and resisting forces. Despite this, logical information alone is rarely sufficient to drive through changes and this is therefore a preliminary step.

1.1 Characterise the 'Current State'

This process aims to develop a succinct description of how the business currently operates, and the positive and negative features of this condition. It is essential that the core characteristics of the business are understood in terms of purpose, business model, operations, roles, activities, values, opinions and culture. The range of activities within the existing production cycle, including the various information flows and interactions between functions should also be examined. This knowledge is essential in order to understand what the organisation is actually trying to achieve, and what will need to change in order to realise that.

1.2 Define / Articulate the Business Model

The 'business model' is a conceptual tool used to describe the operation of an organisation via the definition of its core structure, features and processes. Business models come in various forms, and contain varying levels of detail. At its most basic level the business model must contain the following aspects: a value proposition, a target market, an infrastructure, revenue generation mechanism/s, a position within the value network (i.e. competitive position) and a competitive strategy.

Techniques such as 'process mapping' may be useful in order to develop a clear understanding of the core business areas and to identify potential focus areas for the change effort. For further information on the concept of business models see [137-140].

1.3 Develop a Mission Statement

The mission statement is a useful tool for describing, in clear and succinct terms, the purpose for the business, the activities of the business and the values of the business (including desired levels of performance). It is important for organisations to articulate this information at this stage, even if they cannot say for certain how the specifics of the mission might change in response to the selection of new technologies.

1.4 Undertake a SWOT Analysis

The SWOT analysis can be used to audit the businesses strategic position. The analysis considers both internal factors (the strengths and weaknesses of the organisation) and external factors (the opportunities and threats presented by the external environment). Despite being a powerful tool, the SWOT analysis tends to produce subjective results if used in an 'abstract' manner. The analysis should therefore always be undertaken in reference to a stated objective or desired end-state.

In this context the SWOT is intended to be used to determine the extent to which each of the main organisational barriers and constraints identified in 3.1.3 are present within a given implementation - thereby allowing for the development of an approach which can be tailored to overcome these limitations.

1.5 Undertake a PEST Analysis

A PEST analysis audits the businesses environmental influences and considers Political, Economic, Social and Technological factors. The PEST analysis can be used to develop a detailed understanding of past, present and future market trends, market forces, establish market growth or decline and assist in business positioning and operations planning. It therefore has important implications for influencing organisational strategy. PEST factors can be classified as the 'opportunities and threats' in a SWOT analysis.

1.6 Undertake a Competitive Analysis

A competitive analysis identifies the businesses main competitors and assesses its strengths and weaknesses in comparison with those of the competition. The competitive analysis can allow the business to benchmark its current performance, and will inevitably help to identify areas where changes (e.g. new technology) could create a competitive advantage.

1.7 Undertake a Cultural Audit

A firm understanding of the organisation's culture is essential in delivering effective change. The 'cultural audit' is an attempt to identify and measure a range of cultural attributes. It should focus on: power distribution, management style and key values. Other attributes which can be measured as part of the audit include: risk tolerance, degree of hierarchy, reward structure, collaboration, values, and innovation versus adaptation.

1.8 Engage with the Workforce

The need for change must be felt deeply throughout the entire organisation in order to ensure that the implementation is well supported. In fact, within SMEs suffering from cultural or communication problems the need for change may already be felt throughout many areas of the business to the exclusion of the management.

Management should therefore engage with the entire workforce to identify and discuss 'dissatisfaction with the current state'. Ultimately, the people best positioned to identify problems or weaknesses with various organisational processes are the individuals who work within them. If there is a need to change then the findings will show that the current state is unreasonable / not viable as a long-term strategy.

This stage is extremely influential because it allows people to think freely about the prospect of a better way of working - there may be opportunities to let people build their own case for change. This is also an opportunity to encourage open and honest communication, in order to develop common agreement, create a 'compelling case' for change, provide evidence, reinforce urgency and explain the consequences of not changing.

2. Create the Vision

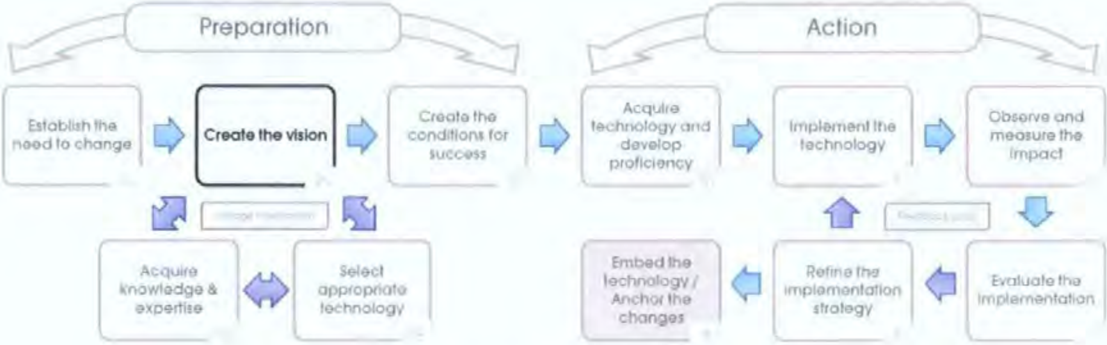


Figure 33. Stage 2 of the Model

Figure 33 highlights the position of stage 2 within the model. In order for the implementation to move forward successfully, the management needs to build on the work carried out during the first stage of the model in order to identify, and articulate, exactly how the business intends to address 'the need to change'.

A 'vision' or 'image' of the future is required, supported by a well-defined change programme / implementation strategy with clear outcomes, valuable enough to make the change effort worthwhile. The vision should address the urgency for change, and the consequences of not changing. A strong vision allows the people within an organisation to get involved in the change, rather than simply imposing a new way of doing things

2.1 Characterise the Desired State

This process draws on the feelings and opinions of project stakeholders in order to develop a succinct description of a viable future state of operation. This should involve staff from every level to some extent - open and honest communication should be promoted in order to encourage 'buy-in'.

2.1.1 Develop a Vision Statement

The vision statement is a useful tool for describing, in simple terms, 'where the company wants to be'. As the vision is used to create and drive the changes, it must be both easy to understand and communicate, and inspirational, using clear language and powerful images.

In order to begin to define the vision, organisations need to ask the following questions:

1. "Where are we now?"
2. "Where do we want to be?"
3. "How are we going to get there?"

At this stage, organisations may only be able to answer questions 2 and 3 at a strategy level - identifying those technologies or systems which are appropriate for taking the business forward will almost certainly involve further research or collaboration.

2.2 Develop the Project Plan

Achieving the vision and requisite changes requires a strong 'project-managed' approach. The implementation cannot be handled by one person - the formation of a 'guiding coalition' to lead the project is therefore essential. This group should comprise team members from a variety of relevant backgrounds, whose skills and experience are complementary to the aims of the implementation.

The plan should identify 'who will do what, and by when' and hence outline the project stakeholders and address the approximate timescale for the proposed changes, including milestones and defined indicators / measures of success in order to allow progress to be tracked and measured. The project plan will normally contain at least the following elements: aims, strategic objectives, key tasks, milestones, deliverables, performance criteria, timeline, risk assessment, logistics and budget. ***Browne*** observes that there will almost certainly be broader elements, such as: organisational structure, scope, roles and responsibilities, selection / recruitment, implementation plans, progress review and methodology [114].

There must also be a clear definition of who is leading the change process and who will approve the actions to be taken. The planning stage should consider the financial implications of the project, and include budgets for indirect costs such as training - there should also be some realistic contingency funding provided.

2.2.1 Undertake a Stakeholder Analysis

It may also be useful at this stage to review the project stakeholders' 'initial position' with regard to the potential change. This is useful in determining who will be affected and how well supported the change is likely to be, as well as identifying potential problem areas / sources of resistance.

2.2.2 Undertake a Pareto Analysis

The Pareto principle is the idea that in any project, 80% of the advantage can be generated by doing 20% of the work (when applied to quality improvement, the principle shows that the majority of the problems are produced by a few key causes). The Pareto principle can be applied to the planning stages of new technology implementation to estimate the potential benefits of a range of technological applications in order to select the most effective focuses and actions.

2.3 Identify Change Champions

It is essential to identify the key members of the organisation who will take a pro-active, leading role in driving the technology across the business. *Browne* observes that champions are those members of the organisation or project team who are able to approach an implementation with positivity, and to use the right constructive and visionary language in order to make lasting change happen [114]. Champions can be from any level within the organisation and should be sufficiently 'empowered' to take appropriate action.

2.4 Identify Technology Gatekeepers

Windrum & Berranger describe the role of a 'technology gatekeeper' - an experienced technologist working within the firm as part of the implementation team to facilitate the process by 'shaping realistic expectations' regarding the likely benefits of the new technology [36]. The gatekeeper assists in 'translating' the strategic objectives of the firm into specific technological solutions, as well as providing in-house technical support, user assistance and basic training. They observe that 'codification' and the transmission of information relating to the technology (such as the production of user manuals, operational or process guidelines and systems documentation) may also be carried out by, or with the assistance of the gatekeeper [36].

Windrum & Berranger's definition is a strikingly accurate description of the author's own position within the case study implementation.

2.5 Establish Communication Networks

Effective communication networks must be established in order to ensure that both the case for change and various updates on progress throughout the implementation process can be communicated both frequently and consistently throughout all levels of the organisation (inconsistencies will be seen by employees as signs of uncertainty and confusion). This can be achieved via a number of formal and informal pathways (e.g. memos, change bulletins, newsletters and meetings). Ultimately, it is the effectiveness of communication, and not necessarily the implications of 'good' or 'bad' news which is important. Ineffective communication presents one of the biggest barriers to organisational change efforts: perception is key. Careful management is required in order to provide clarification, address concerns, and avoid misunderstanding and resistance.

2.6 Address Change Management Issues

This stage is about changing mindsets, which is inherently very difficult. Mindsets include a combination of values, knowledge, expertise and information - people need to understand their own perspective in relation to the change, become receptive to new models, describe how they need to change, and receive feedback on their own flexibility.

In many ways this stage is about removing the traditional borders of the organisation - this tends to produce powerful reactions, and for this reason it is one of the most challenging aspects of the change. Some people will display excitement at the ending of a familiar way of working. At the other extreme some people will experience the five psychological stages of major loss: denial, anger, bargaining, depression and acceptance.

Personal issues such as job security need to be handled sensitively. People should be given time and opportunity to 'disengage' from their old ways of working. However, it is possible to provide incentives to encourage this process - management have the opportunity to recognise and reward desired behaviour in making the transition between states.

Overcoming resistance to change is crucial throughout all stages of the model, but efforts to minimise resistance at this early stage can have the biggest impact on overall success. It is paramount to focus on the opportunity to win the support of the workforce / power groups within the organisation, and overcome scepticism. Resistance is often founded on inaccurate information - so re-educating should be a key theme to overcome it.

2a. Acquire Knowledge & Expertise

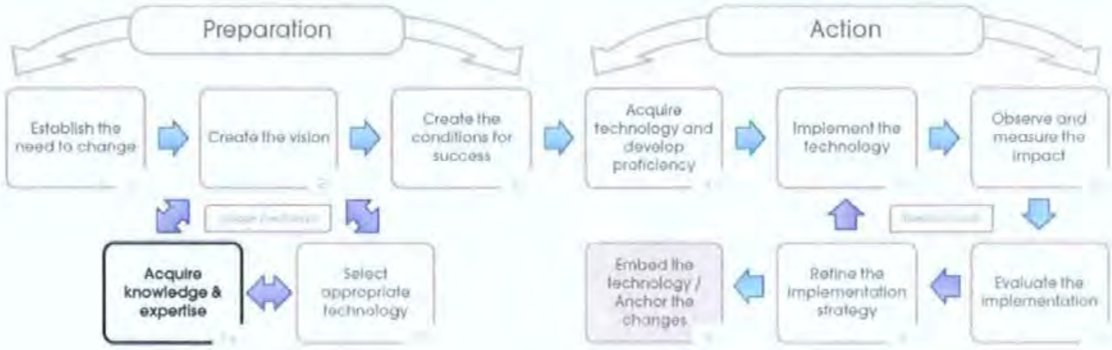


Figure 34. Stage 2a of the Model

Figure 34 highlights the position of stage 2a within the model. In order to develop their vision, organisations first need to acquire knowledge and expertise in order to understand where and how the new technology can be applied, and what the likely implications are in terms of structure, management and behaviour.

If the knowledge is not available in-house, organisations need to engage with one or several 'knowledge partners' via a suitable linkage mechanism. In this context 'knowledge partners' are defined as those individuals and organisations external to the business, who are willing and able to transfer their own relevant knowledge and expertise in order to increase the effectiveness of the host company's AMT implementation, and assist in the identification of commercial applications for the new technology. Linkage mechanisms are either formal or informal arrangements which promote the transfer of knowledge, technology, skills and expertise between the partners.

It is essential to ensure that both the knowledge partners and linkage mechanisms are appropriate. Knowledge partners should be selected on the basis of their suitability, in terms of capability, experience, culture and access to resources. Appropriate linkages are those which are inexpensive, efficient, mutually beneficial, low-risk and sympathetic to the constraints of the LTESME.

2b. Select Appropriate Technology

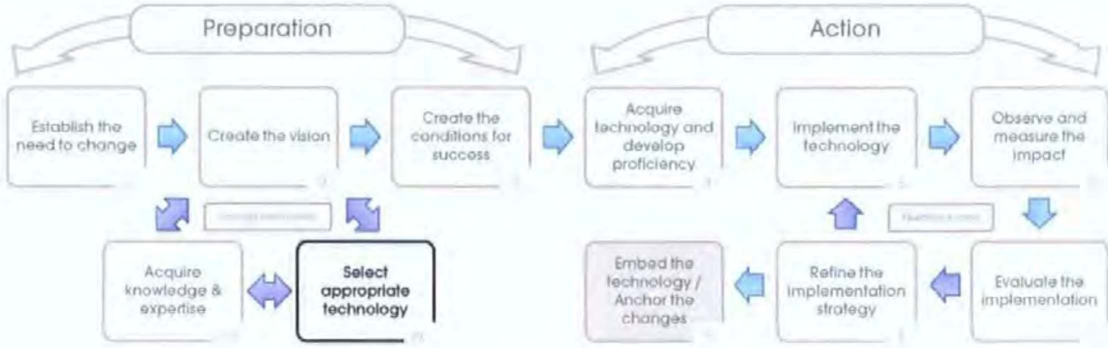


Figure 35. Stage 2b of the Model

Figure 35 highlights the position of stage 2b within the model. In order to be able to create their vision, LTESMEs must reflect on the 'need to change' identified in stage 1, and draw on their newly-acquired knowledge and expertise in order to select an appropriate[18] technological solution.

2b.1 Technology Selection Process

The technology selection process begins by examining the specific needs and requirements of the business at both strategic and operational levels, alongside the range of potentially applicable technologies. The findings of this investigation should be presented to the project stakeholders with a recommendation for an appropriate combination of hardware and software.

2b.1.1 Establish Technology Needs & Requirements

This is achieved by working closely with the management (to discuss how the new systems will support the competitive strategy and production cycle), and the shop-floor employees (to discuss shortcomings in the existing technologies / working practices, capabilities of the

[18] In this context, appropriate technologies are those which are affordable, well supported, relatively easy to learn, and most importantly, feature the pre-requisite capability / functionality to support organisational objectives.

new technologies under review, and how these could be applied to enhance performance). The technological capabilities of the other organisations within the company's supply chain should also be considered. The implementation team should also refer back to the characterisations of the production cycle, 'current state' and 'desired state' (identified earlier in the model) in order to establish the requisite capabilities.

2b.1.2 Examine the Range of Applicable Solutions

The range of available technological solutions should be characterised / categorised in terms of: training, support, cost, functionality and their associated challenges and benefits. To achieve this, organisations should undertake research using the various 'knowledge sources' identified in the literature review. The investigation should be inclusive, and consider the complete range of possible solutions.

2b.1.3 Address Training Issues

The majority of modern CAD programs require a significant investment in training in order to achieve optimal results and full exploitation of the software. Some packages are known to require months or even years of experience to gain a sufficient level of proficiency. It is therefore necessary to examine the range of training options available for each software package in order to develop an understanding of the level of support provided, as well as the associated costs.

2b.1.4 Address Support Issues

CAD users must be supported throughout the early stages of learning and experimentation in order to advance their skills more rapidly. It is often the case that software operators with new systems exercise a very small portion of the software that they feel comfortable with. The first step in using software support is to try something new - if this yields unexpected or unwanted results then the user can access support to address the problem and resolve it. It is therefore essential that the support mechanism is natural, 'user-friendly' and accessible.

There are many potential sources for support: the first is a structured vendor support hotline. This is not offered on all systems and can take considerable time and effort on behalf of the user in order to resolve the issue. The second possible option is direct support from an engineer of a local reseller. Users may feel more comfortable with this solution but it is not always available or accessible. The third and most popular solution is to post a question to a user group or web discussion board: either general or industry-specific.

2b.1.5 Address Cost Issues

CAD software is usually purchased on a perpetual licence for a relatively large upfront fee, with annual maintenance for support and upgrades being charged on a rolling basis. Once purchased and paid for the company owns the license forever. This purchasing method does not always suit the project-oriented nature of modern design work - with some projects requiring higher or lower numbers of operators or even team members from outside the organisation itself. Regardless of the type of licence required, the full cost of implementation and maintenance, which is sometimes known as the Total Cost of Ownership (TCO), needs to be estimated. There may be opportunities for organisations to exploit 'bargaining power' or the prospect of mutually beneficial arrangements with vendors in order to reduce the purchase cost, or increase the value of the technology package.

2b.1.6 Address Functionality Issues

It is essential that organisations closely match their commercial requirements to specific technological capabilities. The system needs to be capable of performing in all of the ways envisaged by the 'vision' identified in stage 2. If compromises must be made, the consequences should be considered very carefully.

Products with limited or 'mismatched' functionality can lead to numerous problems including: a need to purchase extra software to achieve a specific functionality, a severe shortage of trained operators (or high-cost operators), heavy reliance on (potentially costly) support and difficulty communicating with other organisations.

This is one of the most important facets of the technology selection process, as it can be very difficult for non-specialists to appreciate their own functional requirements whilst they still have relatively little experience with the technology. The 'knowledge partners' should therefore be heavily relied on to provide quality advice and steering. LTESMEs are particularly vulnerable to the risk of inappropriate selection - commonly as a result of misleading advice from technology vendors and other low-validity information sources.

2b.1.7 Evaluate & Select Technologies

Once the range of potential solutions has been identified organisations must begin to evaluate the information available, in order to establish the respective merits of each system. This can be achieved in a number of ways including: internal internet-based research, contact with technology vendors (to seek answers to concerns), contact with 'technologists' from other organisations.

There should be a strong element of collaboration with the 'knowledge partners' to interpret the findings and evaluate the results in order to select an appropriate system. The technological experience of the 'knowledge partners' should be considered - although it is not a pre-requisite that the partners share common hardware or software platforms (it may be sufficient that they use a similar type of technology, as opposed to an identical system).

3. Create the Conditions for Success

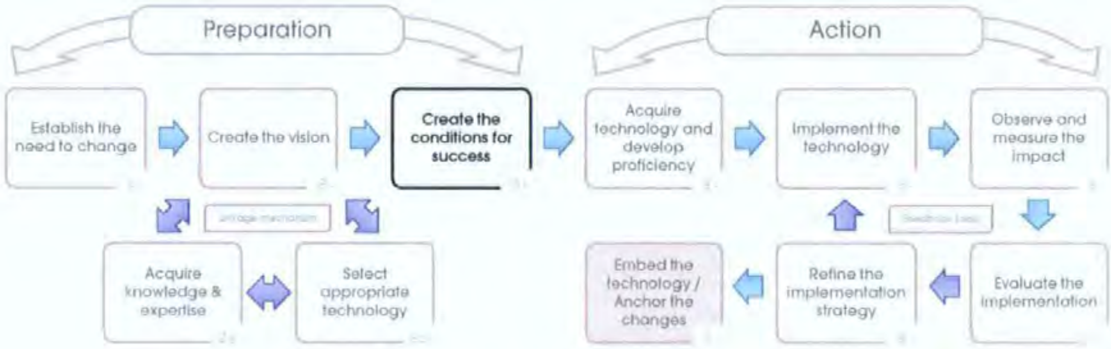


Figure 36. Stage 3 of the Model

Figure 36 highlights the position of stage 3 within the model. This stage is concerned with creating the right 'climate' for change by aligning the businesses internal structures, processes and informal networks to support the implementation, and removing any obstacles and barriers. This is important because there is a tendency to focus overly on technological capabilities rather than the environment in which they will be applied - *Nepal et al.* observe a parallel that in developing countries, greater attention is usually given to the physical hardware element as opposed to creating the conditions required to use the technology efficiently and effectively [141].

3.1 Remove Obstacles & Barriers to Change

This stage represents the transition from 'preparation' to 'action' and as such it provides the last opportunity to draw out objections and concerns before the technology is formally brought into the organisation. Everybody should be prepared to accept the prospect of imminent change. 'Winning-over' objectors is essential, and the promotion of co-operation and collaboration is crucial in achieving this - stakeholders should feel involved and engaged with the challenge as a team, confident that the right decisions have been made so-far, and ultimately prepared and empowered to deal with the various problems which will inevitably emerge throughout the subsequent implementation.

By this stage there should be a clear understanding of who is organising the implementation, and what their specific roles and responsibilities are. This is also the last opportunity to address serious weaknesses in any aspect of the implementation. All of the activities from the previous stages must now be complete, in order to ensure that the relevant information is known, and the business is 'poised for success'.

3.2 Focus on Team Development

With the strategic plan in place, management needs to focus on the people 'on the ground' that will ultimately be responsible for delivering and driving the changes. The most effective way of approaching this task is to focus on the development of small, high-performing teams, each with clear roles, responsibilities and direction, featuring built-in linkages between individual objectives and organisational success. Measuring and monitoring systems should be implemented which include clear performance targets.

3.3 Role Model Leadership Behaviours

It is essential that leaders within the organisation role-model the kinds of behaviours that reinforce the change message. The behaviour of senior figures within the organisation has a very significant effect on attitudes, opinions and confidence with respect to the implementation process. LTESME managers should be prepared to support those members of the organisation who are likely to experience difficulty in accepting the change. For this to be effective, management must be seen to be trustworthy and credible.

3.4 Engage with the Workforce to Negotiate Changes to the Strategy

The implementation of new technology, and its impact on the organisation should result in a win-win situation for all parties involved in the change. In order to ensure this, management needs to engage with individual team members in order to match their personal development goals with the opportunities provided by the changes. 'Engagement' is the process by which people become personally implicated in the success of a strategy, change, transformation, or everyday operational improvement. Participation and 'ownership' greatly increase the effectiveness of this process - it is much easier for people to support something they have a stake in.

4. Acquire Technology & Develop Proficiency

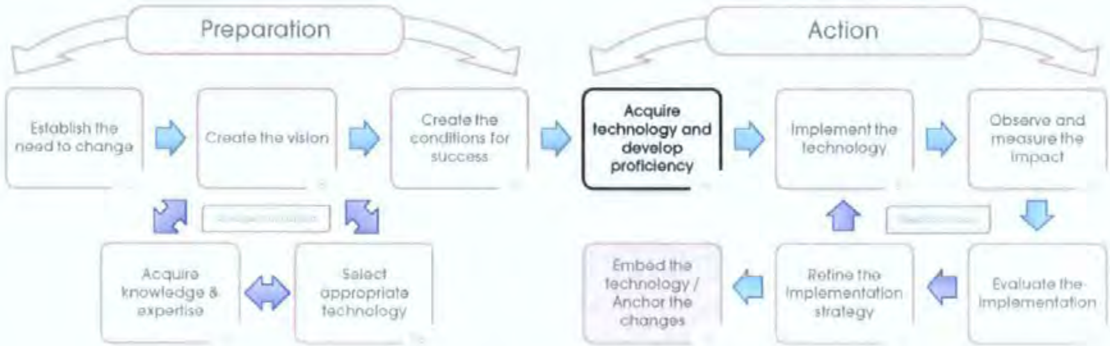


Figure 37. Stage 4 of the Model

Figure 37 highlights the position of stage 4 within the model. This stage focuses on re-educating and training staff, to develop a level of operational proficiency amongst those who will ultimately be responsible for 'driving' the new system, prior to the technology being rolled-out across the entire organisation. This provides an opportunity for staff to start to work with the new systems in a familiar environment, but without the pressure of a commercial workload.

There is likely to be a desire to keep this stage as short as possible, because of it is comprised primarily of non-value-adding activities. Nevertheless, it is essential that potential problem areas are identified early, and that operators are given sufficient time to explore the full range of capabilities of the new system in order to prepare for the impending implementation phase.

4.1 Commit Adequate Resources

A significant commitment of time and resources is required in order to allow people to familiarise themselves with the new technology, learn and practice the new techniques and overcome early frustrations. Organisations can draw on their 'knowledge partners' to assist with training and guidance, as well as exploiting the range of 'knowledge sources' identified within the literature review.

4.2 Implement Training

Training is essential to equip the implementation team with the ability to effectively operate and control the new technology. The research carried out in stage 2b should have identified the range of available training sources. Organisations should focus on using a combination of formal and informal training pathways to develop technological competency and proficiency.

Traditional 'classroom based training' is becoming harder to implement within many companies for various reasons: it is often very expensive (perhaps as much as the software itself), it is very disruptive to the operation of most design offices to have absentee employees, and critically, it is difficult to schedule training within a project's life to enable users to start using the new tools immediately.

The training provided by vendors is usually high cost and not always at a particularly advanced level. A stronger approach may be to review a range of informal sources such as online tutorials and advice sought through newsgroups. LTESMEs should also seek to develop relationships with independent technology specialists who may be able to offer bespoke (and perhaps free) advice and guidance.

Management should maintain a positive and supportive learning environment throughout this stage.

5. Implement the Technology

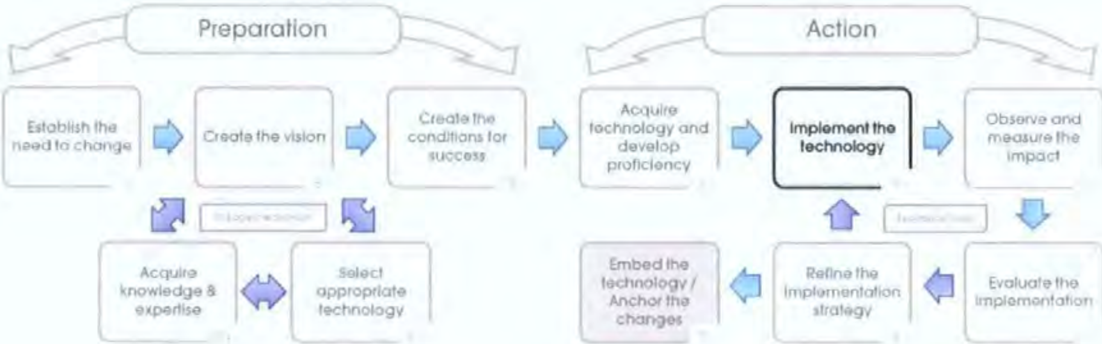


Figure 38. Stage 5 of the Model

Figure 38 highlights the position of stage 5 within the model. The implementation stage involves the introduction and 'rolling-out' of the new systems across the organisation. This should be carried out in a highly structured manner, beginning with a suitable pilot-project, and subsequently scaling up the new processes throughout appropriate areas of the organisation. It is essential to monitor the progress of the implementation regularly against the plan, making appropriate adjustments as the project progresses.

5.1 Focus on Quick Wins

It is crucial to focus on achieving some 'quick-wins' in order to build confidence and add some credibility to the new techniques as early as possible in the implementation. This can be achieved via the selection of small, but vital commercial projects which can be used to demonstrate the effectiveness of the new system.

It should still be possible to respond early to difficulties and revert to traditional working practices to complete these tasks if serious problems are encountered. However, if this happens it could be very damaging for confidence in the new techniques. The main aim of this stage is to carefully select projects which in reality have a high likelihood of succeeding, but that depend on the new technology.

5.2 Scale-Up the Implementation Across the Organisation

Based on the successful completion of the pilot projects, and once any initial concerns / problems have been addressed, the technology is ready to be rolled-out across the entire organisation. This should be carried out in line with the implementation strategy identified in stage 2. It is crucial to ensure that adequate resources are committed at this stage.

There should be visible support for (appropriate) experimentation. People must be sufficiently empowered to respond appropriately to unforeseen problems. The management should provide strong, visible leadership and support throughout.

The focus should be on maximising the cost-effectiveness and productivity benefits of the new technology whilst ensuring value-adding outputs into sales, marketing and other areas are exploited as fully as possible.

5.2.1 Obtain Feedback & Evaluate

Although this stage is heavily focussed on 'action' it is crucial that effective feedback mechanisms exist and are able to provide the project stakeholders with accurate information concerning the implementation. The management should feel 'connected' to the changes occurring throughout the rest of the organisation. This relies on open an honest communication, and a focus on 'factual evidence' rather than personal opinions.

5.3 Keep the Workforce Informed

Because this stage is potentially the most disruptive, it is essential to develop an effective communications strategy to keep everyone up-to-date, informed and motivated. This should include honest feedback on the challenges and difficulties which have been encountered, and crucially, how these have been addressed. Communication is also vital to reinforce messages about where in the implementation process the company currently is.

For example, everybody should be clear about when 'transition' should evolve into 'normal running'. There are numerous tools and pathways available to managers including the establishment of 'change bulletins' company newsletters, the open celebration of reaching key milestones, company-wide meetings and presentations.

5.4 Stage 5 Considerations

The implementation phase will highlight how accurate initial assumptions about the design and production processes were, and the presence of skills or capability gaps may begin to emerge. At this point in the implementation it is likely that formerly simple tasks may take longer, and in many cases may appear more difficult. As a result, this stage is where resistance is most likely to arise - this needs to be handled effectively and quickly to prevent the spread of pessimistic attitudes or 'scaremongering' which could threaten the success of the implementation.

The risk of failure needs to be accepted without apportioning blame - the organisation needs to learn from early challenges, and accept their presence as part of the learning process, rather than an indication of problems inherent in the new technology or the overall approach.

6. Observe & Measure the Impact

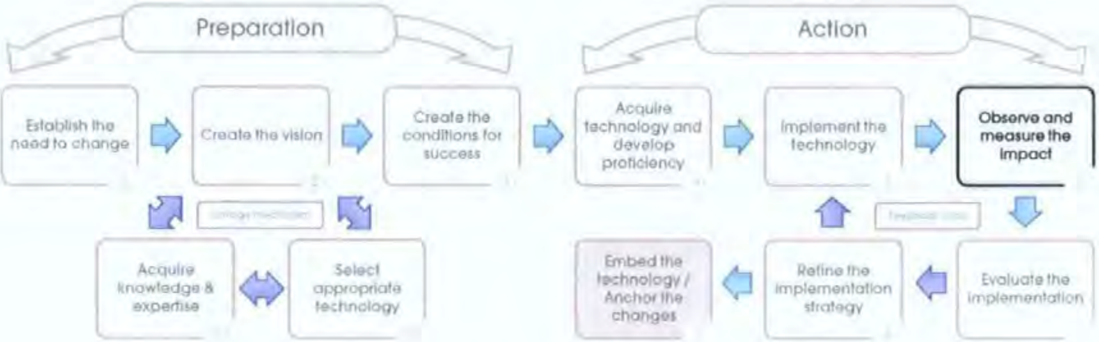


Figure 39. Stage 6 of the Model

Figure 39 highlights the position of stage 6 within the model. This stage is intended to provide the management with a clear picture of how the business operates following the implementation i.e. in the 'changed condition'. To achieve this, the characterisation of the 'current state' of the business which was developed in the first stage of the model needs to be updated in order to reflect on, and quantify, the changes which have occurred.

Like the first stage, the focus here is on gathering 'factual evidence' rather than drawing conclusions - 'dealing in fact' is important because it allows people to understand 'what is actually happening', rather than speculating on 'what they think is happening'.

6.1 Monitor & Review Performance

In order to establish how the business has changed, the management needs to review the original performance criteria, and implement a range of associated monitoring strategies. The aim is to establish whether the results achieved are higher or lower than those which were originally anticipated. The impact on the supply chain should also be considered in terms of data communication issues, financial impacts (engage the accounting / purchasing functions for this), interoperability of data, and effects on working relationships.

This stage requires open and honest communication. Regular team meetings and reporting mechanisms should be established in order to track progress, measure achievement against the original performance criteria, discuss key issues such as process and structural changes and skills displacement. This will involve engaging with the workforce to gather opinions / observations in order to establish the 'cultural impact' of the changes. The data collected in this stage needs to be collated and formally presented to the guiding coalition.

7. Evaluate the Implementation

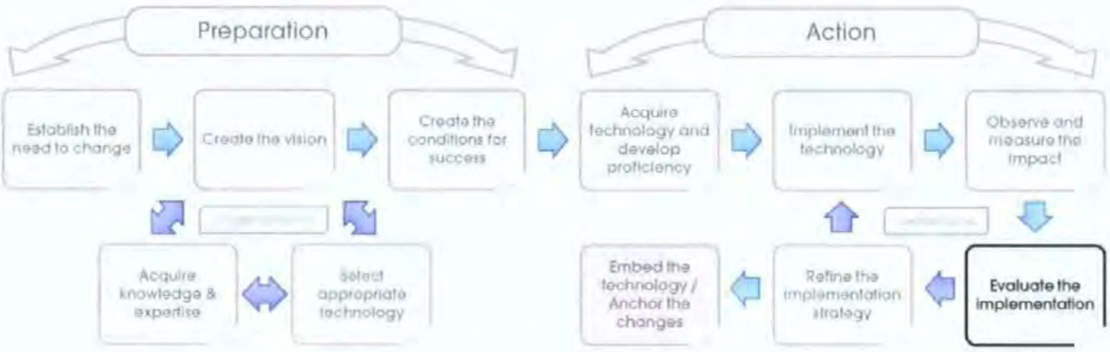


Figure 40. Stage 7 of the Model

Figure 40 highlights the position of stage 7 within the model. The evaluation stage draws together the observations made throughout the implementation so-far, in order to summarise the key changes in organisational performance, explain how these can be attributed to the new technology and compare these findings against the original project aims and objectives. This stage also represents an opportunity to suggest improvements to the implementation strategy which have become apparent, and to review emerging business needs and technological trends.

The ultimate aim of the evaluation process is to improve organisational performance, and crucially, to improve the performance of subsequent implementation projects.

7.1 Compare 'the Vision' with 'the Reality'

A number of qualitative and quantitative indicators should be used to compare the 'vision' developed in stage 2 with the 'reality' observed in stage 6, and to determine the value of the changes that have occurred. It is important both to identify and, crucially, to explain any variance between intended and actual outcomes.

Effective project evaluation relies heavily on open and honest discussion with staff from all levels of the organisation - it is important to identify why and where problems occurred, and to recommend corrective improvements not only to organisational processes and procedures, but to the overall strategy.

7.2 Review Financial Aspects

At this stage it should be possible to review the actual costs involved with operating and implementing the new technology - this may include the various 'hidden costs' which have emerged throughout the implementation (e.g. software or hardware costs which were not immediately apparent). This work should contribute to an accurate understanding of the TCO of the new technology and associated processes.

7.3 Stage 7 Considerations

It is essential that the purpose of the evaluation phase is clearly understood throughout the organisation - it is tempting for people to consider the implementation successful without understanding 'why it is successful'. The technical competencies required to collate and analyse data must be available, and adequate resources (i.e. time, money, equipment, and people) must be committed to achieve this.

It can be difficult to evaluate accurately due to issues with 'real world complexity' - in other words, there may be numerous other factors contributing to changes in organisational performance which cannot be attributed directly to the technology, although it may appear that they are related. Problems with evaluation can also arise when the objectives of the evaluation process are not clearly articulated or are not readily measurable.

8. Refine the Implementation Strategy

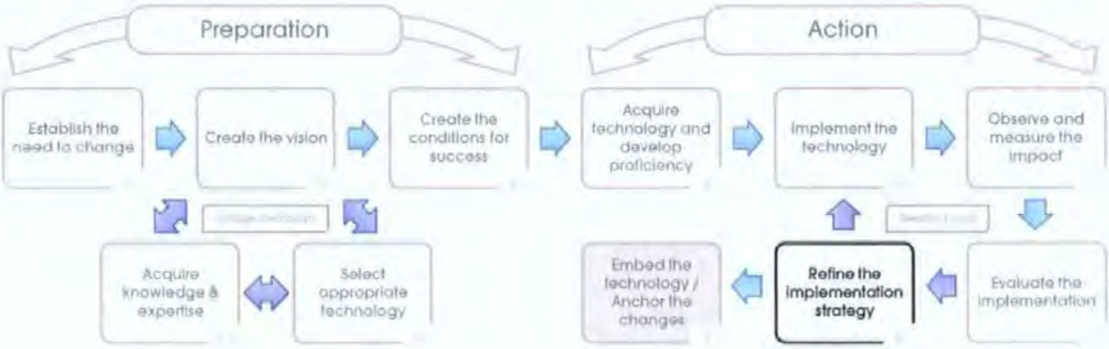


Figure 41. Stage 8 of the Model

Figure 41 highlights the position of stage 8 within the model. The refinement stage provides a 'feedback loop' in order to address the less-successful elements of the implementation and to improve the quality of the activities contained therein. Successful processes may be optimised and the gains consolidated to achieve yet further change.

This stage involves engaging with the workforce to identify opportunities for process improvements / corrective initiatives. Refinements may include: reducing operational and other costs, developing process improvements, reducing cycle times, removing inefficiencies, changing roles or responsibilities, and in some cases the justified discarding of certain aspects of the initiative which cannot be made to work effectively.

Transparent communication is essential. Management should be prepared to discard aspects of the implementation that aren't working out, whilst successful processes should be optimised and the gains consolidated to achieve more change.

9. Embed the Technology / Anchor the Changes

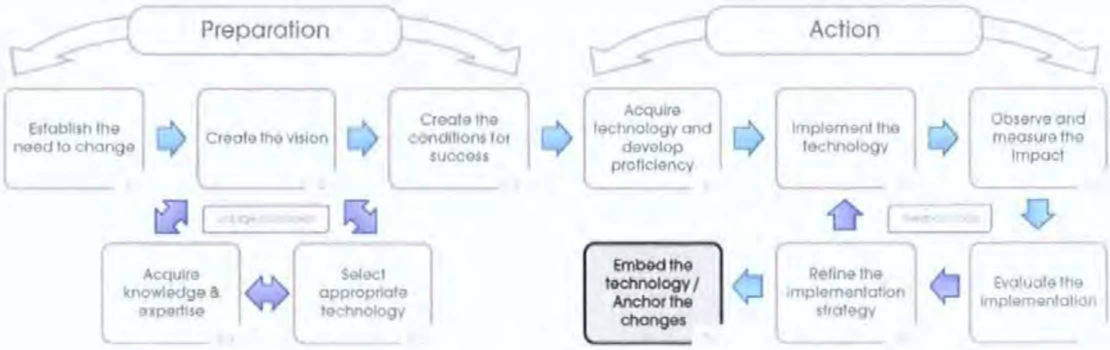


Figure 42. Stage 9 of the Model

Figure 42 highlights the position of stage 9 within the model. This stage focuses on crystallising the successful elements of the implementation in order to move from 'transition' to 'normal running'. The changes need to be 'institutionalised' to prevent the organisation reverting to the 'old way'. The language, behaviours and actions of those leading the change (at every level) should acknowledge the completion of the major challenges, and a move towards 'self-sufficiency' in the operation of the new technology.

At this stage any outstanding documentation or 'codifying' of the new techniques and processes must also be completed. This might include the production of process charts and procedures, and the updating of induction documents to reflect the new practices.

It is important to openly recognise those who have performed well throughout the implementation, highlighting clear linkages between individual achievements and organisational success. It is equally important to 'declare victory' in order to 'draw a psychological line' under the achievements, and secure acceptance and commitment.

The attention of the management should turn to maintenance of the new technology and continuous improvement (Kaizen) activities across the organisation. Formal linkages with the 'knowledge partners' can be disengaged and evaluated - although relationships should be maintained to seek out future opportunities for collaboration.

The business should also establish an ongoing commitment to learning - including the establishment of technology scanning practices (to keep abreast if new developments), whilst preparing itself for the inevitable future changes.

10. Continuation of the Model

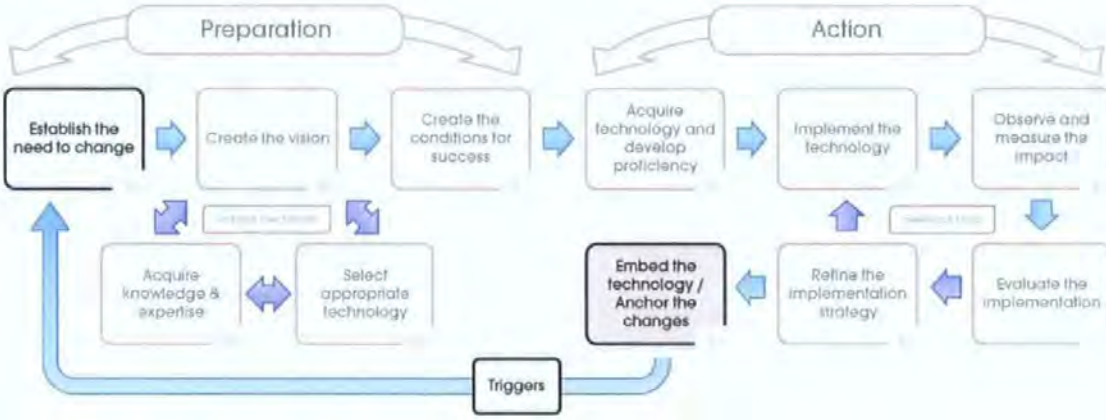


Figure 43. Continuation of the Model

Having successfully implemented the new technology, the company should be in a position to 'self-sufficiently' continue with its day-to-day operations without further external assistance. However, the completion of the implementation process really represents an opportunity for new change to begin - there will always be room for improvement.

A number of 'triggers' may lead back to the first stage of the model, as highlighted in figure 43. Triggers may be comprised of various internal and external influences including: changes in market conditions, legislation, competitive factors, the emergence of new technologies, loss or gain of staff with relevant expertise, and opportunities for collaboration.

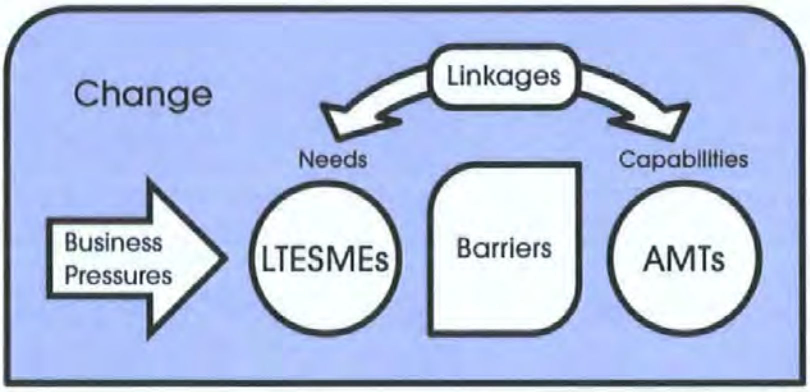
LTESMEs should actively monitor many of the developments that may act as triggers by engaging with the various knowledge sources identified in the literature review. For example, a good understanding of the 'state of the art' in terms of technology for specific industrial sectors can be maintained by attending industry meetings and focus groups.

Chapter 6 Discussion & Conclusions

Chapter Outline

This chapter summarises the key findings of the research and discusses the investigation's contribution to the research cycle. The implications for both LTESMEs and researchers are considered. The thesis concludes with a discussion of the limitations of the investigation, as well as a series of recommendations for further work in this field.

6.1 Introduction



LTESMEs *Low-Technology-Enabled Small & Medium Enterprises*

AMTs *(Design-Oriented) Advanced Manufacturing Technologies*

Figure 44. Reviewed Research Context

In answering the question "what factors affect the implementation of AMTs within LTESMEs?" this investigation has examined the features of contemporary AMTs, LTESMEs and the various linkage mechanisms available to them, leading to the development of a best practice model and framework. Effective change management has been found to underpin successful implementation, and figure 44 shows the original research context, modified to reflect the significance of this underlying component.

6.2 Summary of the Investigation

This investigation has been successful in accomplishing its main objectives:

1. LTESMEs have been characterised in terms of technology, structure, management, behaviour, infrastructure and processes, culture, strategy and access to financial resources. The various ways in which these features can manifest themselves as barriers or constraints to the uptake of AMT have also been examined.

2. The features, characteristics, capabilities, benefits and associated challenges of contemporary design-oriented AMTs (and the various ways in which these can be leveraged by SMEs to gain competitive advantage) have been examined.

3. The primary knowledge sources and various types of linkages available to assist in the dissemination of AMTs into LTESMEs have been identified and discussed.

4. The concepts of change, human resources and quality management have been briefly introduced, and the implications for LTESMEs discussed.

5. The implementation of an AMT system within one SME manufacturing firm via a formal linkage with an HEI has been presented as a case study.

6. A best practice model and associated guidance has been developed to assist LTESME managers in the implementation of AMT.

The investigation has been primarily 'interpretive' and qualitatively-biased, drawing on a combination of reductionist and holistic approaches, and yielding some valuable insights into the issues associated with new technology adoption in SMEs. The body of knowledge gained throughout the investigation, in combination with the best practice model, provides a reference to help LTESMEs avoid many of the pitfalls associated with implementing AMTs, whilst streamlining their efforts, and improving their overall chances of success.

6.3 Contribution to the Research Cycle

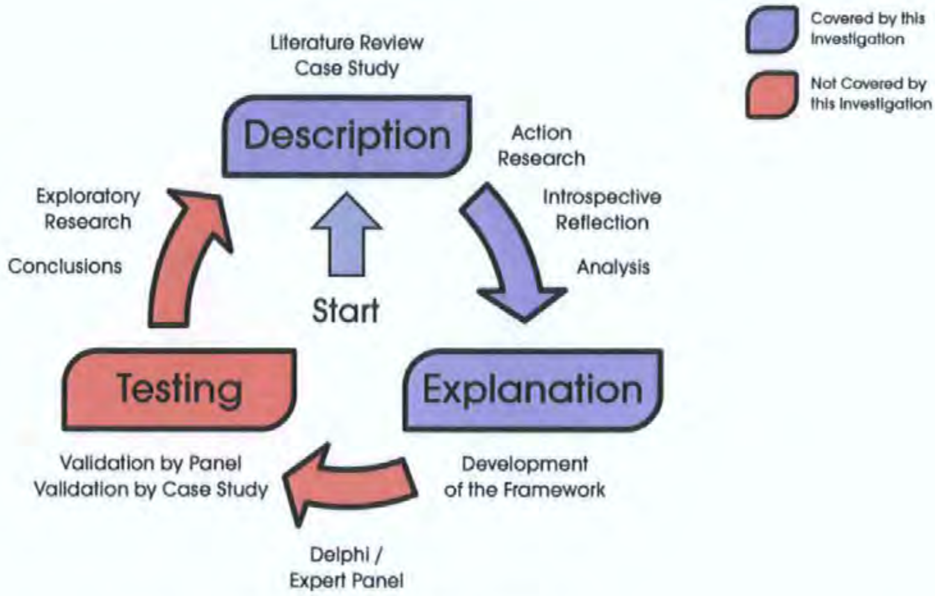


Figure 45. The Research Cycle [42, 43]

Figure 45 shows the research cycle proposed in chapter 2, which has provided a logical framework on which to structure this investigation. As has already been acknowledged, the investigation has not covered a complete revolution of the cycle. A testing phase (undertaken as part of a separate future study) will be essential in further validating the proposed best practice model. Some ways in which this could be achieved, and other possible extensions to the research are proposed in section 6.6.

6.4 Main Conclusions

This investigation has highlighted the importance of SMEs, showing that they represent a vital component of both the national and global economies. Despite their celebrated diversity, SMEs are united by a common need to innovate[19] in order to remain competitive in an increasingly challenging business climate. As technological innovation processes continue throughout industry, the level of pre-requisite knowledge required increases.

[19] In this context, innovations include: the implementation of new technologies, improvement programs, new processes, advanced management practices and the development of external relationships.

Organisations lagging behind in terms of technological progression are faced with the prospect of an increasingly uncomfortable and radical change in order to survive.

Dosi identifies four 'innovation characteristics' - uncertainty, reliance on academic research, complexity, and the importance of learning by doing [142]. *Lambert & Barber* highlight the importance of 'absorptive capacity' in terms of pursuing technological innovation [24]. Despite offering an 'optimal environment' for innovation (SMEs tend to be lean, agile flexible and passionately managed organisations - capable of absorbing significant disruptive change), many firms experience difficulties.

This investigation has highlighted the inadequacy of the SME definition in terms of identifying varying levels of technological sophistication, or other factors which could influence a firm's ability to innovate successfully - proposing a new definition, the LTESME, which can be used to group small firms in relation to their potential to successfully implement AMTs.

The various LTESME characteristics, particularly those attributed to the owner-manager, provide a fascinating insight into the factors that contribute to poor innovation performance. The investigation has shown how these become manifested as barriers and constraints to technology uptake. A *Scientia* study concluded that the barriers are "more basic than most people realise" [48] including fear: of failure, technology or 'the unknown', and a lack of: knowledge, commitment, training, skills, finances or time.

A key finding of the investigation was that 'appropriateness' underpins the successful adoption of new technologies, particularly via linkages. This creates a logical paradox for LTESMEs - in order to know what kind of technology they need, they must be able to articulate what they want to do with it - this is of course impossible, because they don't know what it can do, and lack the resources to find out. It is this process which can lead to the self-perpetuating skills and knowledge gap found in many LTESMEs.

One of the most important ways in which this can be overcome is through self-awareness of the inherent limitations of the LTESME, and the development of organisational learning strategies to identify and overcome the various challenges. It is therefore essential that firms strive to create an environment which is conducive to, and supportive of, learning activities.

Managers within such organisations need practical 'common sense' advice and guidance, in a language they can understand, in order to successfully engage new technology. And they need this fast - rapid developments in technology create new opportunities for innovative firms to capture market share, and spearhead new directions and trends within their respective industry sectors. *Lundvall* highlights the increasing importance of the emerging 'learning economy', where the "ability to attain new competencies is crucial for the success of individuals and for the performance of firms, regions and countries" [88].

Linkages have been shown to offer the solution - bridging the 'knowledge gap' and allowing LTESMEs to access technology (and the pre-requisite knowledge) whilst mitigating or eliminating the associated risks. Furthermore, the linkage process itself stimulates learning and development within the host firm, leading to self-perpetuating innovation, and greater long-term growth and sustainability.

Despite the effectiveness of linkages, there is nothing 'extraordinary' about the way in which they deliver results. In fact, the principles behind the majority of linkage mechanisms are so elegantly simple that it is hard to believe that organisations have not considered undertaking the various activities before, and in some cases why it has taken the involvement of people from outside the organisation to act as a stimulus.

The most obvious implication of this research is that implementing new technologies almost always involves significant organisational change. *Brychan* observes that the speed at which technology can be diffused is determined by the willingness of SMEs to 'make adjustments' and respond to change [39]. Identifying the need to change early (before it becomes an imperative) is crucial. In simple terms 'it is better (for organisations) to jump than to be pushed'. Once a decision has been taken, it is the way in which the change is managed that to a great extent determines success or failure. In turn, change management has been shown to rely heavily on effective leadership and strategy.

Change is a formidable challenge for organisations of all sizes, and requires determination, commitment and the ability to establish trust through openness and honesty. Success or failure in delivering change depends entirely upon how people are managed, how well-informed they are, how well they understand the need to change and how well they support the 'change vision'. A structured linkage (or a 'knowledge partner' with change management experience) gives organisations the best chance of achieving success.

Although this research has focused on innovation through the implementation of design-oriented AMTs (3D CAD/CAM/CAE), the underlying principles of successful technology uptake and the management of the associated change process, which have been uncovered by this investigation probably have much wider application.

In assessing the extent to which the research community addresses the needs of LTESMEs it has become apparent that very little (of the reviewed literature) is of real practical value to the organisations themselves - not because it is incorrect, but because it is simply 'inaccessible' to the managers (typically owner-managers) responsible for implementing new technologies within their businesses.

The reality is that the majority of small business management teams are too busy to philosophise on their various problems, or read academic papers and journals, and are instead focussed on the immediate tasks to hand - reacting to problems, with little time for planning and strategy. However, as *Kennedy & Hyland* observe, "small firms will continue to struggle to compete while they are either unwilling or unable to invest in improvement programs and activities and new technologies" [11].

Despite their inherent problems, small businesses, with their relatively flexible structures, pragmatic owner-managers and frequent exposure to high-risk business activities are ideally positioned to deal with the pressures of change. In fact, LTESMEs have many significant advantages over larger, more inertially-driven enterprises - and therefore need to gain confidence in their ability to 'out-perform the competition' through embracing technology.

6.5 Limitations of the Investigation

Despite having been successful in achieving its original objectives, this investigation has contributed to an understanding of the subject area in a limited way. The following limitations have been acknowledged:

1. The best practice model was developed largely through interpretation by the author. Therefore, without further testing, the model should be used cautiously.

2. The literature review could have been more critical, with a greater emphasis on identifying any gaps and deficiencies. Furthermore, the review was based on a finite number of references and it is therefore entirely possible that some valuable sources of information / research were overlooked or have only recently emerged.

3. The case study / action research was largely based on qualitative data, and was naturally biased by the views and opinions of the researcher. The use of a single case study limits the investigation's 'external validity', which could be enhanced through a broader analysis.

4. As has already been acknowledged - technological developments tend to occur rapidly, hence the validity and relevance of the findings of this investigation may diminish as new technologies emerge.

5. Despite their value, the findings of this investigation are presented in a relatively inaccessible format for most LTESMEs. Practitioners within such firms would benefit from an abbreviated interpretation (e.g. a workbook or website).

Referring back to *Creswell's* comments on qualitative research - this investigation has been 'fundamentally interpretive', with a focus on substantiating the research problem, and perhaps more useful for those seeking a 'broad panoramic view' of the subject, rather than a 'micro analysis' [41].

6.6 Extensions to the Research

As the scope of this investigation was extremely broad, it is acknowledged that it is unlikely that each issue has been examined or validated to the fullest possible extent. Therefore, it is essential to propose ways in which the 'research cycle' should continue with further description, explanation and testing, thereby increasing the validity of the findings.

The following research questions are proposed to extend this investigation:

1. "To what degree do LTESMEs agree / disagree with the proposed framework?"
2. "To what extent could the best practice model apply to larger organisations?"
3. "How can the model be refined and validated?"
4. "How can the effectiveness of the model be quantified?"
5. "How can the various components of the model be prioritised?"
6. "How can the model be translated into a format more suitable for practitioners?"
7. "How can the model be contextualised for specific industrial sectors?"
8. "How can LTESME awareness of / access to knowledge and linkages be improved?"
9. "What alternative approaches could be used to develop the model?"
10. "Should change management and technological aspects be addressed separately?"

There are numerous directions in which this study could be extended. However, to maintain the proposed 'research cycle' for this investigation, the initial focus of any future study should be to support the testing and validation of the concepts proposed so-far.

1. The Nature of Learning

Effective learning is a fundamental component of successful research. In an academic context, learning is an 'intentional process' involving the progression from an initial assumption or observation of a problem or phenomenon to a valid assertion, which can benefit from the application of a structured approach - examples of which can be found in the literature:

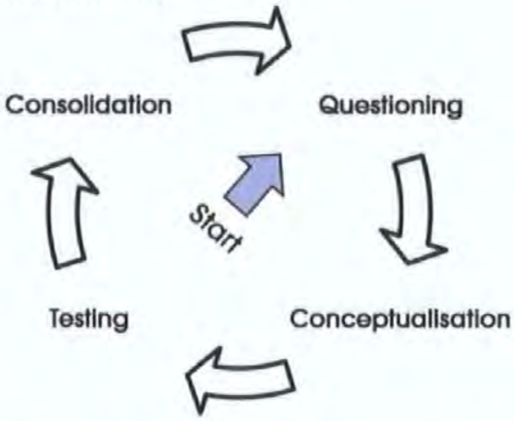


Figure 46. The Learning Cycle [143]

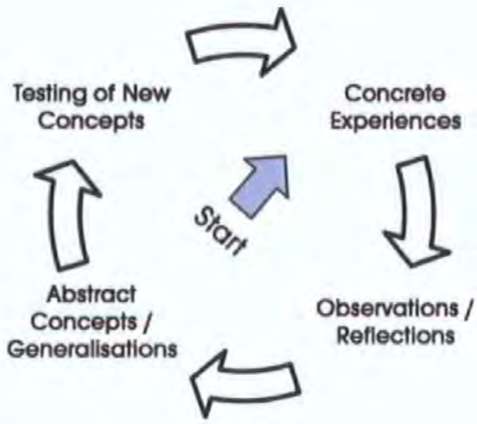


Figure 47. The Experimental Learning Cycle [144]

Both *Handy* (figure 46) and *Kolb* (figure 47) conceptualise structured learning as an ongoing 'cyclic' process. Their views echo *Creswell's* observations of the evolving nature of questioning, and also reflect experiences in the real-world: attempts to answer one question often lead to the emergence of new and previously unforeseen questions.

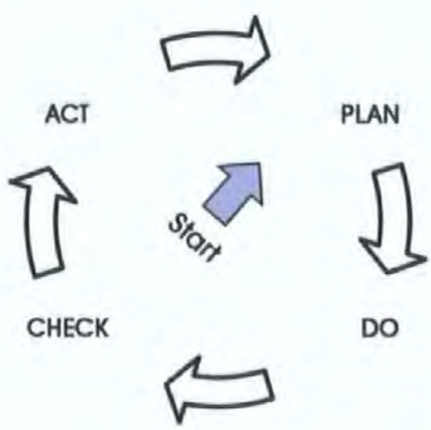


Figure 48. The PDCA Cycle [116]

Both cycles are driven by inquisitiveness and rely on testing for validation. They can be simplified / approximated to *Deming's* iterative problem-solving cycle (figure 48) which, although deceptively simple, is considered to underpin successful continuous improvement.

1.2 The Nature of Research

Academic researchers combine both structured learning and problem solving techniques to design investigations which can answer their research questions. Research is a process in itself, and it too can benefit from the application of a structured approach - examples of which can be found within the literature:

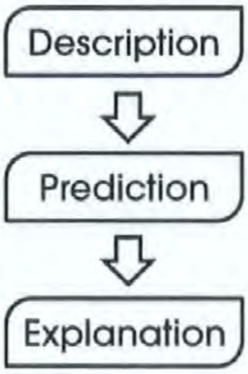


Figure 49. The Research Process [145]

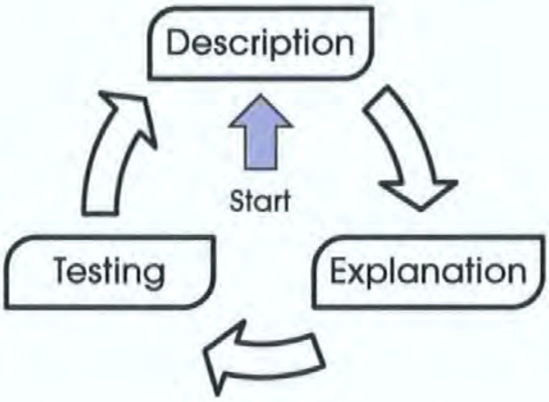


Figure 50. The Research Cycle [42]

Emory (figure 49) proposes that research consists of 3 sequential main tasks in which the description of a phenomenon allows concepts to be formulated which can be used to predict behaviour, hence offering an explanation for what is happening.

Meredith et al. (figure 50) expand on this concept, proposing a repeating 'research cycle'. Originally developed within the field of operational management, their cycle has since found much wider application, and supports prior observations by *Creswell*, *Handy*, *Kolb* and *Deming* - that learning, problem solving and research are iterative, non-linear processes.

According to *Meredith et al.* descriptive research is concerned with the reporting of key elements / variables within situations or events, and tends to result in a well-documented characterisation of a subject. Having undertaken the descriptive phase, it may be possible for the researcher to postulate some initial concepts and begin to develop an understanding of a given situation by attempting to explain the observations [42].

Subsequently, testing[20] focuses on the analysis of the generated concepts to see which are correct, which are false, and how to expand or modify them [42]. This in turn leads to further 'exploratory research'- where a particular aspect of a problem is investigated more fully, perhaps in isolation, in order to gain a better insight and understanding. This leads to further explanation and once again to testing - hence the research cycle continues.

In reality the boundaries between the stages (and even the order in which they are undertaken) may be different. Furthermore, an individual research study may not involve all stages. However, as *Meredith et al.* observe, "a description which does not explain, although research, is incomplete" [42]. Hence the validity and 'realism' of a particular study is significantly affected if the key stages are not undertaken in a justifiable order, or if the process overall is incomplete [48].

1.2.1 Research Outcomes

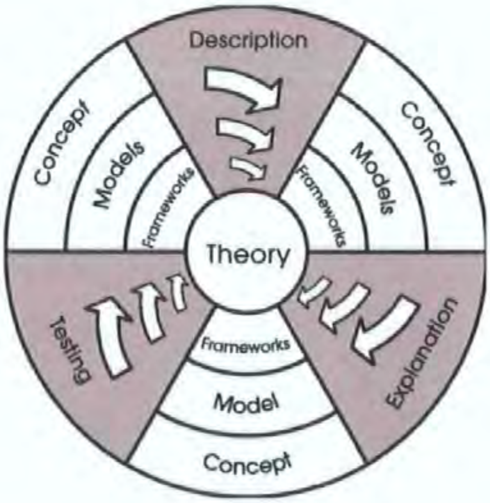


Figure 51. The Normal Research Cycle [45]

Figure 51 (which is adapted from *Meredith*) shows the various levels of understanding of a phenomenon that can be developed as the research cycle progresses. At the periphery are

[20] *Meredith et al.* note that testing typically consists of prediction, based on the findings of previous stages, followed by observation to see if the prediction was correct. They also hold that a prediction may be formulated and checked against observations already made or included in the description [47].

concepts or abstract generalisations which appear to offer some explanation for cause and effect within the phenomenon under investigation. As the cycle continues, it may be possible for the researcher to construct a theoretical model which attempts to capture the processes operating within the phenomenon.

Meredith et al. observe that "if a complex, relatively closed set of relationships appears to be operating, a framework may be constructed to explain the dynamics of the situation" [42]. Frameworks attempt to create a "conceptual frame of reference to help researchers design specific research studies, interpret existing research and generate testable hypotheses" [42]. *Hobbs* observes that frameworks have more 'explanatory power' than models [43].

Taking this concept further, and with more testing, a framework may become a theory - these consist of a set of general principles that explain the observed facts and interrelationships between the variables in a given system, and must include some criteria that define the boundaries or scope.

1.3 Research Validity

Meredith et al. observe that "arguments frequently arise about whether the best research is that which proposes knowledge or that which validates knowledge" [42].

According to *Joppe*, validity "determines whether the research truly measures that which it was intended to measure or how truthful the research results are" [146]. The validity of a research investigation therefore refers to the 'soundness' of its design and methods, the way in which it is executed, and the nature and analysis of the data collected.

Seliger & Shohamy observe that "any research can be affected by different kinds of factors which, while extraneous to the concerns of the research, can invalidate the findings" [147]. Identifying and controlling these factors is therefore a primary concern for researchers.

Depending on the nature of the investigation, researchers can select from a number of validation tools and methods. Popular approaches include activities such as expert panel consultation (used to identify commonalities or differences in opinion between individuals in response to research findings) as well as structured / unstructured interviews.

In order to select an appropriate method of validation, it is necessary to examine the two main types of validity within research investigations: internal and external. The extent to which an investigation is either internally or externally valid is affected by: the size and nature of the population used in the research, the time dedicated to collecting data, the way in which data is collected, environmental effects and influences, as well as timescale [147].

1.3.1 Internal Validity

Internal validity describes the extent to which the findings of a particular research investigation determine the cause and effect relationships between two or more variables. Internal validity may be threatened if the outcomes were found to have been affected by factors other than those thought to have caused them or if the interpretation of data by the researcher is not clearly supportable [147].

1.3.2 External Validity

External validity describes the extent to which the findings of a particular investigation can be 'generalised' and applied to a different setting or context. *Seliger & Shohamy* describe external validity as the extent to which "an experiment's results hold across different experimental settings, procedures and participants" [147].

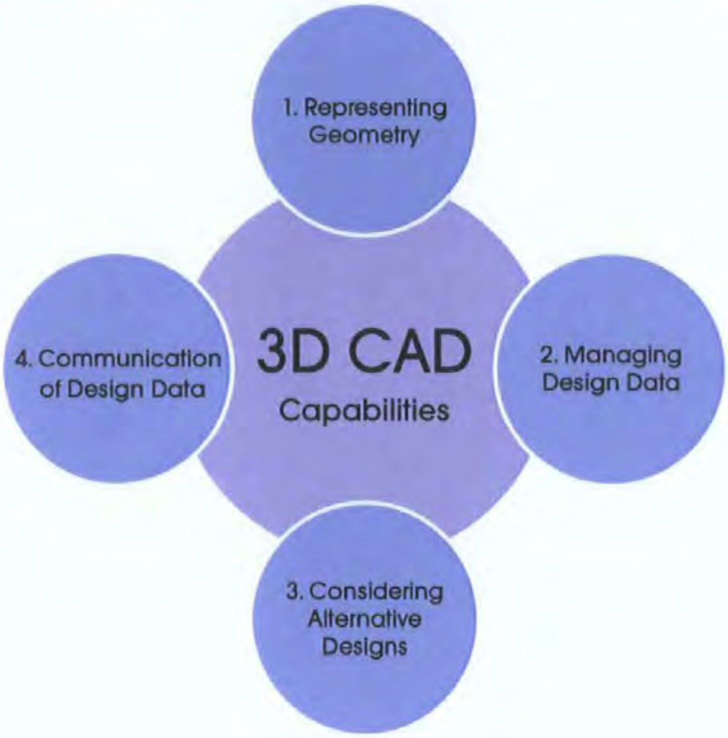


Figure 52. Capabilities of 3D CAD Systems

This section aims to identify the main capabilities of 3D CAD systems in order to assist LTESMEs in understanding how the technology can be applied in practice. Figure 52 highlights the areas which will be examined throughout the following sub-sections.

1. Representing Geometry

3D CAD systems allow the complete geometric modelling of products or components within a software environment ('legacy' CAD systems and traditional approaches to design (e.g. manual drafting) have typically focused on the 2-Dimensional representation of geometry). As *Medland & Mullineux* observe; there are clearly many advantages to be gained from the use of a system that allows designs to be generated in three-dimensions [71].

Contemporary CAD systems handle the representation of geometry via numerical values and their interconnection without consideration for the underlying ideas and purposes. These have to be inferred by the CAD operator, guided by their observations, knowledge and experience [30]. This is a common feature of most computer-based systems, which are restricted to performing transformations on information in a solely deterministic way, which is nevertheless extremely fast, flexible and versatile [80].

There are a number of different systems available, which can be loosely categorised as: wireframe modelling systems, surface modelling systems, solid modelling systems and hybrid (non-manifold) modelling systems in order of their evolutionary development [14].

1.1 Wireframe Modelling Systems

Wireframe modelling uses characteristic lines and end-points to describe the shape of objects. The visual model is therefore a wire-frame drawing of the shape, and the associated mathematical model comprises the list of curve-equations, co-ordinates of the end-points, and the connectivity information pertaining to each [14]. Despite its ability to provide the user with three-dimensional shape data, wireframe modelling is severely limited in terms of visualisation - the representation of characteristic lines is ambiguous and does not allow, for example, for the calculation of mass-properties.

1.2 Surface Modelling Systems

Surface modelling is an evolutionary development of the wireframe system; in addition to the characteristic lines and their end-points, the mathematical description includes surface data (i.e. the shape data bounded by each surfaces edge curves). This allows for the aesthetic evaluation of the model, as well as the generation of CAM outputs (e.g. 'tool-paths' for use downstream by CNC machines).

1.3 Solid & Hybrid Modelling Systems

Solid modelling systems are used to model a shape having a closed volume, termed a 'solid' [14]. Operations may be carried out on the features of the solid object (for example the 'filleting' of an edge to a specified radius) which are reflected in the model. Hybrid (or 'non-manifold') modelling systems allow a mixture of surfaces and solids. In such systems, a relationship between the number of discernable surfaces that bound a solid object's volume is described (the system is able to consider a collection of surfaces as a solid).

2. Managing Design Data

Most modern 3D CAD systems are capable of supporting either designs which consist of a single component, or a complex assembly with multiple subassemblies [76]. This is a significant feature as managing complex assemblies using manual drafting methods or 2D CAD systems has traditionally been (and continues to be) an extremely challenging task.

When products or components are designed within 3D CAD, a vast amount of data (i.e. form, shape, position and orientation) is implicitly captured in the 3D model. This is a significant benefit, because it allows the designer to focus on the design, without worrying about the underlying mathematics or presentation aspects. *Chorafas* sees CAD as a "way to augment the range and depth covered by our brain", and suggests that as processes and products become increasingly complex, the human designer simply "cannot handle all the details and integration requirements" [32] in their mind.

This capability can be of particular benefit to the investigation of modifications to a standard product, or integration of third-party components into a design. To varying degrees most CAD systems can be used to check fit and function of components. Specifically, systems may be used to check for interference in a complex assembly; moving parts can be investigated throughout their full range of motion to check for collisions or other design flaws. This ultimately results in higher product and process quality through the reduction of errors.

3. Considering Alternative Designs

CAD takes advantage of the processing capabilities of computers in order to carry out design calculations - because they are done faster with less human effort, more alternative cases can be examined in the time available. This allows for the investigation of a number of possibilities including alternative materials and processes that could be incorporated to lighten the design or reduce manufacturing costs [71]. *Gott* observes that this provides a "greater potential for engineering analysis" [75] which results in increased product innovation and quality.

In marine design, for example, it is common to investigate several different engine options for a given vessel. Using manual drafting for this purpose is extremely labour intensive, slow and inaccurate - in contrast, the CAD approach allows for digital drawings of each engine to be downloaded from the respective manufacturers' websites, and comparisons to be made within minutes.

4. Communication of Designs

Hamblin observes that (to varying degrees) the range of contemporary CAD systems available on the market offer the capability for companies to produce professional grade communications in terms of drawings and other CAD outputs in a quick and efficient manner [148]. Data can be output in a variety of useful formats. For example: Scale drawings can be plotted / printed for use on the shop-floor (including full-size or 1:1 templates), CAD files can be sent electronically to suppliers (via email or fax), images and animations can also be produced to assist in the unambiguous communication of designs.

Most CAD systems also allow for the export of data in native format (where the data can be opened and used by any third-party with the same software) as well as several of the 'intermediate data exchange' formats (file formats which are common to several different software systems). Several of the most popular intermediary formats have been so successful that they are now regarded as quasi industry standards - for example, the AutoCAD Drawing Interchange Format, or Drawing Exchange Format (DXF) which is relied upon across many different sectors for the consistent interchange of 2D CAD data, and the Initial Graphics Exchange Specification (IGES) which is a neutral data format which allows for consistent interchange of 3D CAD data.

3D CAD therefore significantly enhances the SMEs ability to communicate design data both internally with the workforce and externally with customers and suppliers.

CAD systems can be broadly classified as 2D (generation of electronic drawings in a two-dimensional environment), and 3D (generation of CAD models in a three-dimensional environment) in order of their evolutionary development.

The use of 3D CAD technology within industry is spearheaded by the aerospace and automotive sectors. In a report discussing the use of 3D CAD systems in the development of the Boeing 777 airliner, *Buxton* comments that the prototype aircraft's various components, many of which were outsourced for manufacture by third-parties, "fit together so precisely (largely due to the use of CAD/CAM techniques from 10 years ago) that the number of discrepancies needing redesign was substantially less than what had appeared to be an extremely optimistic early prediction. Rather than the multiple mock-ups needed for previous models, the 777 manufacturing mock-up flew as part of the flight certification process. Similar stories exist in the automotive and other industries" [86].

CAD emerged as one of the first computer graphics applications in both academia and industry [86] in the early 1960's, and has developed rapidly over the last twenty years [30]. Early developments in the field included applications such as 'Sketchpad' (Ivan Sutherland, Massachusetts Institute of Technology) and DAC-1 (General Motors) [86], which were the first competent and commercially viable CAD solutions.

Buxton observes that the automotive and aerospace industries led the development of their own CAD applications throughout the late 1960's / early 1970's [86]. These were delivered on complex multi-user mainframe computers. The 1980's saw the emergence of 'turnkey' CAD systems comprising bundled hardware and software, designed to deliver a comprehensive computer-based design solution [86]. Contemporary 'mainstream' CAD systems comprise powerful software applications which can be run on a variety of different hardware configurations; including desktop PC's.

CAD's primary function is to describe the geometry of products or components, including the provision of technical information pertaining to their manufacture. For many years, the engineering drawing was the only accepted means of conveying this information to the workshop. As companies began to exchange engineering drawings with each other it became necessary to agree on a common, unambiguous means of representing the geometric data contained in the drawings. Various standards thus emerged [71].

The purpose of the engineering drawing is therefore to communicate, as efficiently as possible, technical information relating to the product or component which can be used to assist its manufacture. There has been a historical trend amongst design engineers, as observed by *Medland:* "to behave as if the drawing were the end product of the design process. As a result ... far too much emphasis is placed on the style of the drawing rather than on how efficiently and effectively it conveys the necessary engineering information" [71]. Drawing office procedures are therefore required to regulate the design process (with respect to the production of drawings) and ensure that all relevant information relating to the product or component is communicated clearly and unambiguously [71].

Drawings are limited as a communication medium. In the same way that CAD systems assist the designer with the development of a product or component without providing any cognitive input, manufacturing drawings provide the geometric details of a single chosen embodiment of the designer's original concept, without explicitly conveying its function. None of the ideas behind the design are directly presented - if it is necessary to discover the purpose or role of the object, this will have to be deduced from its features and the way in which they are related to each other or to features of other objects [71].

Engineering drawings are therefore only semi-pictorial representations of products or components, and are not intended to convey an exact visual impression [71]. The two-dimensional views which are developed for the engineering drawing are representations of a three-dimensional object. How these views are laid out on the engineering drawing is dictated by convention and various applicable standards [71]. Manual drafting techniques have popularised the approach of a three-view construction (front, profile and plan) in order to provide the clearest interpretation of an object which exists only in his / her mind.

Early 2D CAD systems offered the ability for draftsmen to develop drawings electronically. These systems greatly increased the speed at which drawings could be produced, as well as the accuracy of the information contained therein. The drafting process itself remained largely unaffected; drawings were developed in a similar manner to those produced using manual techniques, albeit more quickly.

Medland acknowledges that with the advent of 3D CAD, it has become possible to reverse the way in which drawings develop: two-dimensional views can be derived from a three-dimensional model [71]. The CAD model provides the true-representation of the object, and the views, from any chosen position, can be selected to provide the best display of those features which are relevant to any particular purpose.

The role of the engineering drawing has therefore changed. *Medland* notes that drawings no longer provide the primary product definition; they now serve to translate the definition 'captured' within the CAD system via the transfer of "discrete parcels" [71] of process-specific information to downstream manufacturing operations. Despite this, he observes that many manufacturing organisations are still producing drawings to 'conventional' specifications, although those who have begun to explore the wider possibilities in this area have reported "spectacular productivity gains".

It is commonly suggested by 3D CAD software vendors that the very concept of dedicated 2D CAD has been superseded, and that continuing to use manual drafting techniques or 2D CAD "puts any business involved in mechanical design, engineering or manufacturing at a disadvantage to their competition" [76].

In the long-term, it seems plausible that the engineering drawing may be at some point completely superseded. *Medland* categorically states that "this will not be the case" [71], arguing that although the form may change, it will continue to perform an important role in communicating information about the design to those involved in the manufacturing process (even if there is no reliance on the information for the process i.e. all manufacturing is via CAM).

In the same way that the CAD system needs to be able to define product geometry, but not necessarily to understand its role or function, the engineering drawing needs to be able to communicate only that information relevant to the manufacture of the product, non-essential detail simply adds unnecessary complexity to the product cycle. Thus, with the emergence of powerful CAD systems, which are accessible to the SME, the potential for innovative approaches to design communication throughout the product cycle has increased.

Appendix 4 Recommended Information Sources for LTESMEs

The following organisations are recommended for the provision of general assistance and information to LTESMEs involved in the implementation of AMTs:

Government Sources

Confederation of British Industry (CBI)	www.cbi.org.uk
Department for Trade & Industry (DTI)	www.dti.gov.uk
Institute of Directors (IOD)	www.iod.com
Business Link Network	www.businesslink.gov.uk
Home Office	www.homeoffice.gov.uk
Companies House	www.companies-house.gov.uk
Europa - European Union	www.europa.eu.int
The Small Business Service	www.sbs.gov.uk
Foresight	www.foresight.gov.uk
Local Government Association	www.lga.gov.uk
National Statistics	www.statistics.gov.uk
Government Information & Services	www.direct.gov.uk
Training and Enterprise Councils	www.tec.co.uk
Health & Safety Executive	www.hse.gov.uk
HM Treasury	www.treasury.gov.uk
UK Parliament	www.parliament.uk
Office for Science & Technology	www.ost.gov.uk
Inland Revenue	www.inlandrevenue.gov.uk
BERR Innovation Unit	www.innovation.gov.uk
UK Patent Office	www.patent.gov.uk
Council for Industry & Higher Education	www.cihe-uk.com

EC Commission	www.europa.eu.int
EU Framework Programme	www.cordis.lu
Department for Business, Enterprise and Regulatory Reform	www.berr.gov.uk
Engineering and Physical Sciences Research Council	www.epsrc.ac.uk
Department for Innovation, Universities & Skills	www.dius.gov.uk

Other Sources

British Standards Institution (BSI)	www.bsi-global.com
Small Business Group	www.smallbusinessgroup.org.uk
Small Business Europe	www.smallbusinesseurope.org
Growing Business Awards	www.growingbusinessawards.co.uk
Investors in People	www.iipuk.co.uk
Queen's Awards for Enterprise	www.queensawards.org.uk
Small Business Journey	www.smallbusinessjourney.com
BSI small business website	www.standardswork.co.uk
Design Council	www.designcouncil.org.uk
Innovation Exchange	iexchange.london.edu
United Kingdom Accreditation Service	www.ukas.com
International Organisation for Standardisation	www.iso.org
European Committee for Standardisation	www.cenorm.be

Design processes vary between organisations, depending upon the types of product being manufactured. In this sense, 'product types' can be classified (in the simplest possible manner) into two distinct groups: those which are technically over-constrained, and those which are under-constrained [30].

Medland observes that over-constrained products tend to exist in the high-technology markets. A prime example of an over-constrained design situation is the development of an aircraft structure. The preferred solution for a component design here would be one that had zero mass, and infinite strength; as neither is achievable (or should be attempted at the expense of the other) an over-constrained system exists [30]. He notes that the over-constrained design process thus revolves around the analysis of a range of alternative proposals, until the correct (or most acceptable) compromise is found, and that by their very nature, over-constrained design situations lead to the development of analytical techniques to solve them.

Medland also observes that under-constrained products tend to exist in 'ideas-centred' or 'skills-centred' markets (where company activities are centred on bringing products out simply to satisfy market demands). An example of an under-constrained design situation is the development of an office chair. The preferred solution for a component design here is not immediately obvious, and there is a large variety in the range of conceptual designs that could satisfy the specification. A number of factors such as aesthetic character, ergonomics, weight, comfort, durability, ease of manufacture and many others need to be considered in evaluating the design. Somewhat inevitably, the under-constrained design process tends to revolve around manufacturing capability. Thus, by their very nature, under-constrained design situations lead to the development of communication links with the manufacturing function to solve them [30].

Medland claims that at present, there are very few CAD products which can significantly aid and improve the ideas-centred (under-constrained) design process [30], but this is a vague observation. He is perhaps suggesting that CAD is a technology lending itself to the resolution of well-defined and understood constraints. However, CAD also offers immense capability to those involved in the free-form 'organic' design of products in the under-constrained design process, delivering improvements in a number of areas including speed, accuracy and visualisation.

CAD software can be classified further still into two groups: systems that are 'parametric' and 'non-parametric'. Parametric modellers use the concept of 'design intent' to develop models of products and components according to their function. Objects and features created within parametric systems are numerically controllable. This can facilitate the rapid modification of designs (although the potential for modification is limited in its scope by the 'design intent' with which the model was created). Despite their obvious potential, *Elliot* observes that parametric modellers are not necessarily superior to non-parametric modellers for a given application [149], providing two 'obvious reasons' for this:

1. Generally, CAD operators need to be familiar with the historical content of a given CAD file in order to benefit from it. In a small company with a limited design team this may pose no obstacle, as the original CAD operator (who is familiar with the history) can be used to manipulate his / her design. A problem becomes apparent when the original designer moves on in their career and leaves the company unable to amend a critical design issue by its history [149].

2. Parametric modellers excel where there is predictability in design intent (for example the design of a range of shoes in standard UK shoe sizes). Provided the design intent is well conceived, and religiously adhered to throughout the design process, a set of parametric 'rules' can be established to cater for logical variations to a design within the constraints of those rules governing design intent. However, practical experience shows that more often than not, design intent is rarely that well conceived at the outset of a 'creative' design process. If it were, the process would not be that creative, it would simply be engineering [149].

Therefore parametric modellers tend to be used in engineering applications and non-parametric 'free-form' modellers tend to be used in creative design.

Variations in design intent are natural throughout the evolutionary design process. In the case of a boat, for example, it would not be unusual for a customer to decide (perhaps fairly late in the design process) that they don't really need the large capacity offered by the proposed fuel tank design, and that a smaller tank, which reduces the overall weight of the boat and increases the storage capacity of the hold within which it is located would be better suited to their needs. The draughtsman may find a last minute alteration such as this an unwelcome burden, but there is little technical challenge in implementing the design revision; this would also be the case if the boat had been designed in a free-form surface modeller. However, if this change in design intent had not been anticipated in the early stages of a parametric design process, the prospect of modifying the fuel tank geometry may actually involve the re-modelling of the surrounding geometry, or in the most extreme case the entire craft.

Parametric modellers are therefore of limited value in design scenarios where there are likely to be significant departures from the original design intent (particularly when these are late in the design process). The design of bespoke, non-production or low-volume boats is one such scenario. Short-run designs are intrinsically unique; they rarely contain modular features or components that are re-used in other designs, and so the value of a parametrically constrained assembly model tends to diminish.

Appendix 7 Reverse-Engineering Aspects of the Case Study Implementation

The ability to reverse-engineer existing geometry and design information from a real component into accurate 3D CAD data is a fundamental requirement for any organisation implementing the technology for both new *and* existing designs.

Kingfisher has a large product range and therefore a high number of individual mould tools. Many of these have been built to manufacturing drawings but some have inevitably been constructed to a verbal and undocumented specification.

It was therefore necessary to review the range of existing data, which included legacy CAD drawings (from several different sources) which had been retained by the company on disc following various contracts involving external Naval Architects, as well as a large archive of hand-drawn paper plans and hard-copy CAD plots.

Existing manufacturing drawings assisted the reverse-engineering process to some extent; providing easily understood information which could be used to facilitate the rapid construction of CAD geometry.

For example, one of the most significant CAD projects was the reverse-engineering of the Fast Catch hull form, which was the first step in the development of the Sport Explorer concept within the 3D CAD system. It was crucial that the hull data represented the geometry of the real mould tool as accurately as possible.

There were two sources of existing design data: firstly the original hand drafted hull lines (in the form of a lines plan / manufacturing drawing) and secondly some subsequently produced 2D CAD data, which was a product of reverse engineering by one of the external Naval Architects working with the company.

An initial attempt was made to resolve the existing 2D CAD data within the 3D system, by orienting the respective views of the hull in each of the 'construction planes' within Rhino. It was immediately apparent that the views would not resolve in 3D, posing a significant problem: either disregard the data, or assume the significance of one particular view over the others - neither of which is a particularly attractive option.

The implications were that a design developed solely from the existing CAD data would be possible but inherently inaccurate. It is interesting to observe that with the 2D system, the same data had been used successfully throughout the design and production of many tens of vessels.

Reverse-engineering seems to call into question the validity of existing information, despite the fact that the same information is used successfully to manufacture products. The process itself was found to be extremely laborious and generally difficult for the operator - demanding judgement to achieve compromise between conflicting sets of data. Fundamentally, the difficulties encountered with reverse engineering at Kingfisher are related to the tolerances of the information, and the associated systems and processes.

References

1. European Commission (2005) "The New SME Definition" [http://ec.europa.eu/enterprise/enterprise_policy/sme_definition/sme_user_guide.pdf], [Accessed 09/09/06].

2. Lybaert, N. (1998) "The Information Use in a SME: Its Importance and Some Elements of Influence" Small Business Economics, Volume 10, Number 2, Pages 171-191.

3. Robson, P.J.A. and Bennett, R.J. (2000) "SME Growth: The Relationship with Business Advice and External Collaboration" Small Business Economics, Volume 15, Pages 193-208.

4. Walker, B., Bode, S., Burn, J. and Webster, B. (2003) "Small Business and the use of Technology: Why the Low Uptake?" Presented at the 16th Annual Conference of the Small Enterprise Association of Australia and New Zealand, Ballarat.

5. Storey, D.J. (1994) "Understanding the Small Business Sector" London: Routledge.

6. Landström, H., Frank, H. and Veciana, J.M. (1997) "Entrepreneurship and Small Business in Europe - Economic Background and Academic Infrastructure" Entrepreneurship and Small Business Research in Europe, Pages 1-13, Aldershot: Avebury.

7. European Commission (2005) "Implementing the Community Lisbon Programme Modern SME Policy for Growth & Employment" [http://www.madrimasd.org/proyectoseuropeos/futuroPoliticalnv/docs/SME_policy_en.pdf], [Accessed 11/01/07].

8. European Commission (2006) "Enterprise & Industry" [http://ec.europa.eu/enterprise/smes], [Accessed 08/12/06].

9. Levy, M. and Powell, P. (1998) "SME Flexibility and the Role of Information Systems" Small Business Economics, Volume 11, Pages 183-196.

10. Theng, L.G. and Boon, J.L.W. (1996) "An Exploratory Study of Factors Affecting the Failure of Local Small and Medium Enterprises" Asia Pacific Journal of Management, Volume 13, Number 2, Pages 47-61.

11. Kennedy, J. and Hyland, P. (2003) "A Comparison of Manufacturing Technology Adoption in SMEs and Large Companies" Presented at the 16th Annual Conference of the Small Enterprise Association of Australia and New Zealand, Ballarat.

12. Goodman, M.B. (2004) "Meeting the Global Challenges of the Contemporary Business Environment" Lecture to the Royal Society for the Encouragement of Arts, Manufacturing & Commerce, New York, 01/10/04.

13. Willows, P. (1983) "CADCAM Management Awareness" in "Efficiency in the Design Office" London: Mechanical Engineering Publications.

14. Lee, K. (1999) "Principles of CAD/CAM/CAE Systems" Harlow: Addison-Wesley Longman.

15. Jones, M. and Jain, R. (2002) "Technology Transfer for SMEs: Challenges and Barriers" International Journal of Technology Transfer and Commercialisation, Volume 1, Part 1, Pages 146-162.

16. The Council for Science & Technology (2000) "Technology Matters - Report on the Exploitation of Science and Technology by UK Business" [http://www2.cst.gov.uk/cst/reports/files/technology-matters/mainrep.pdf], [Accessed on 03/01/07].

17. Ghobadian, A. and Gallear, D. (1997) "TQM and Organization Size" International Journal of Operations & Production Management, Volume 17, Number 2, Pages 121-163.

18. Cagliano, R., Blackmon, K. and Voss, C.A. (2001) "Small Firms Under MICROSCOPE: International Differences in Production/Operations Management Practices and Performance" Integrated Manufacturing Systems, Volume 12, Number 7, Pages 469-482.

19. Corso, M., Martini, A., Paolucci, E. and Pellegrini, L. (2001) "Information and Communication Technologies in Product Innovation within SMEs – The Role of Product Complexity" Enterprise and Innovation Management Studies, Volume 2, Number 1, Pages 35-48.

20. Hayes, R.H. and Upton, D.M. (1998) "Operations-based Strategy" California Management Review, Volume 40, Number 4, Pages 8-25.

21. Rouach, D. (2003) "Technology Transfer and Management - Guidance for Small and Medium Enterprises" Tech Monitor, May–June, Pages 21–28.

22. Barber, J. (2007) "Presentation on Innovation" [http://www.oecd.org/dataoecd/63/40/27237765.pdf], [Accessed on 10/10/05].

23. Porter, M.E. (1990) "The Competitive Advantage of Nations" New York: Macmillan.

24. Lambert, R. and Barber, J. (1994) "Technology Sources for SMEs" [Email from john@barber43.plus.com], [Sent on 12/06/05].

25. Jayaraman, V. and Agrawal, R. (2001) "Determining Optimal Partnership in Technology Transfer - A Theoretical Framework" Presented at the International Conference on Management of Engineering and Technology, Portland, USA.

26. Asheghian, P. and Ebrahimi, B. (1990) "International Business" New York: Harper & Row.

27. Meredith, J. (1987) "The Strategic Advantages of New Manufacturing Technologies for Small Firms" Strategic Management Journal, Volume 8, Pages 249-258.

28. Jonsson, P. (2000) "An Empirical Taxonomy of Advanced Manufacturing Technology" International Journal of Operations & Production Management, Volume 20, Number 12, Pages 1146-474.

29. Gideon, H. (1998) "Production Management Issues for the Next Century" Production Planning & Control, Volume 9, Number 8, Pages 735-741.

30. Medland, A.J. (1992) "The Computer Based Design Process" 2nd Edition, London: Chapman & Hall.

31. South West Manufacturing Advisory Service (2005) "Fact Sheet - Manufacturing Processes: Advanced Manufacturing Technology" [http://www.mas.dti.gov.uk/pluto-resources/1130156183430.pdf], [Accessed 04/01/07].

32. Chorafas, D. (1987) "Engineering Productivity through CAD/CAM" London: Butterworths.

33. Estrin, L., Foreman, J. and Garcia, S. (2003) "Overcoming Barriers to Technology Adoption in Small Manufacturing Enterprises" [http://www.sei.cmu.edu/pub/documents/03.reports/pdf/03tr012.pdf], [Accessed 14/06/06].

34. Rothwell, R. and Dodgson, M. (1991) "External Linkages and Innovation in Small and Medium-Sized Enterprises" R&D Management, Volume 21, Number 2, Pages 125-137.

35. Vossen, R.W. (1998) "Relative Strengths and Weaknesses of Small Firms in Innovation" International Small Business Journal, Volume 6, Number 3, Pages 88-94.

36. Windrum, P. and Berranger, P.D. (2002) "The Adoption of E-Business Technology by SMEs" [http://edocs.ub.unimaas.nl/loader/file.asp?id=643], [Accessed 14/06/06].

37. Koc, T. and Bozdag, E. (2007) "An Empirical Research for CNC Technology Implementation in Manufacturing SMEs" International Journal of Advanced Manufacturing Technology, Volume 34, Number 11, Pages 1144-1152.

38. Castrillón, I.D. and Cantorna, A.I.S. (2005) "The Effect of the Implementation of Advanced Manufacturing Technologies on Training in the Manufacturing Sector" Journal of European Industrial Training, Volume 24, Number 4, Pages 268-280.

39. Brychan, T. (2004) "A Model of the Diffusion of Technology into SMEs" [http://mbagroup1.tripod.com/sme.pdf], [Accessed 10/02/06].

40. Pursell, C. (1993) "The Rise and Fall of the Appropriate Technology Movement in the United States 1965-1985" Technology and Culture, Volume 34, Number 3, Pages 629-637.

41. Creswell, J.W. (2003) "Research Design: Qualitative, Quantitative, and Mixed Methods Approaches" 2nd Edition, London: Sage Publications.

42. Meredith, J., Raturi, A., Amoako-Gyampah, K. And Kaplan, B. (1989) "Alternative Research Paradigms in Operations" Journal of Operations Management, Volume 8, Number 4, Pages 297-326.

43. Hobbs, S. (2002) "A Pre-Transfer Assessment Framework for International Technology Transfer" Ph.D, University of Plymouth.

44. Barnes, J. (1995) "Cambridge Companion to Aristotle" Cambridge: Cambridge University Press.

45. Meredith, J. (1992) "Theory Building Through Conceptual Methods" International Journal of Production & Operations Management, Volume 13, Number 5, Pages 3-11.

46. Thong, J.Y.L. and Yap, C.S. (1997) "Effects of Resource Constraints on Small Business" Proceedings of the International Working Conference on Diffusion, Adoption and Implementation of Information Technology, Ambleside: Chapman & Hall, Pages 191-206.

47. Enzenhofer, W. and Chroust, G. (2001) "Best Practice Approaches in Know-How and Technology Transfer Methods for Manufacturing SMEs" Proceedings of the 27th EUROMICRO Conference, Warsaw: IEEE Computer Society, Pages 279-286.

48. Scientia Solutions (2005) "SME Business Needs and Requirements: Implications for Portal Strategies" [http://217.158.243.204/scientia2/whitepapers.nsf/LookupUNID/3C51080F57EEE382802570BA0059556B/$file/SME%20Business%20Needs%20and%20Requirements.pdf], [Accessed 10/02/06].

49. Barry, H. and Milner, B. (2002) "SMEs and Electronic Commerce: A Departure from the Traditional Prioritisation of Training?" Journal of European Industrial Training, Volume 26, Number 6, Pages 316-26.

50. Lewis, S. (2002) "Fear of the Unknown" Asian Business, February, Pages 41-52.

51. Darch, H. and Lucas, T. (2002) "Training as an E-Commerce Enabler" Journal of Workplace Learning, Volume 14, Number 4, Pages 148-155.

52. Jones-Evans, D. (1998) "SMEs and Technology Transfer Networks - Project Summary" Welsh Enterprise Institute, University of Glamorgan.

53. M-Institute (2007) "What Makes a Mid-Sized Company?" [http://www.m-institute.org/understanding_m/what_makes_a_mid-sized_company], [Accessed 27/02/07].

54. Hagmann, C. and McCahon, C. (1993) "Strategic Information Systems and Competitiveness" Information and Management, Volume 25, Pages 183-192.

55. McKiernan, P. and Morris, C. (1994) "Strategic Planning and Financial Performance in UK SMEs: Does Formality Matter?" British Journal of Management, Volume 5 (Special Edition), Pages 31-41.

56. Haksever, C. (1996) "Total Quality Management in the Small Business Environment" Business Horizons, Volume 39, Number 2, Pages 33-40.

57. Lefebvre, L.A., Mason, R. and Lefebvre, E. (1997) "The Influence Prism in SMEs: The Power of CEOs' Perceptions on Technology Policy and Its Organizational Impacts" Management Science, Volume 43, Number 6, Pages 856-878.

58. Smallbone, D. (1997) "Growth and Survival of Small Rural Manufacturing Firms" Rural Research Report 32, Rural Development Commission.

59. Krumwiede, D. and Sheu, C. (1996) "Implementing SPC in a Small Organisation: a TQM Approach" Integrated Manufacturing Systems, Volume 7, Number 1, Pages 45-51.

60. Sun, H. and Cheng, T.K. (2002) "Comparing Reasons, Practices and Effects of ISO9000 Certification and TQM Implementation in Norwegian SMEs and Large Firms" International Small Business Journal, Volume 20, Number 4, Pages 421-442.

61. Lee, C.Y. (1997) "JIT Adoption in Small Manufacturers in Korea" Journal of Small Business Management, Volume 35, Number 3, Pages 98-107.

62. Manoochehri, G.H. (1988) "JIT for Small Manufacturers" Journal of Small Business Management, Volume 26, Number 4, Pages 22-30.

63. Human Resource and Organisational Development Consultancy (2006) "Organisational Flexibility" [http://www.hrodc.com/Organisational_Flexibility.htm], [Accessed 15/05/07].

64. Gupta, M. and Cawthorn, G. (1996) "Managerial Implications of Flexible Manufacturing for SMEs" Elsevier Advanced Technology, Volume 16, Number 20, Pages 77-83.

65. Blili, S. and Raymond, L. (1993) "Information Technology: Threats and Opportunities for Small and Medium-Sized Enterprises" International Journal of Information Management Science, Volume 13, Number 1, Pages 439-448.

66. Carrie, A.S., Macintosh, R., Scott, A. and Peoples, G.A. (1994) "Linking Strategy to Production Management Structures and Systems" International Journal of Production Economics, Volume 34, Pages 293-304.

67. Evans, J.S. (1991) "Strategic Flexibility for High Technology Manoeuvres: A Conceptual Framework" Journal of Management Studies, Volume 28, Number 1, Pages 69-89.

68. Parsons, G.L. (1985) "Strategic Information Technology: Towards Strategic Information Systems" Cambridge MA: Abacus Press.

69. Martin, C. (2002) "Technology Diffusion within Small and Medium Enterprises in Australia: Report on the Effectiveness of Dissemination Methods" [http://www.smartlink.net.au/library/techdiff.pdf], [Accessed 21/05/07].

70. Robert, J., Buhman, C., Garcia, S. and Allender, D. (2003) "Bringing COTS Information Technology into Small Manufacturing Enterprises" [http://www.iccbss.org/2003/presentations/Robert_121300W.pdf], [Accessed 21/05/07].

71. Medland, A. and Mullineux, G. (1988) "Principles of CAD - A Coursebook" London: Kogan Page.

72. Boden, B. (1999) "Initiative for Small and Medium Enterprises" [http://www.nwlean.net/sme.htm], [Accessed 01/05/07].

73. Stamm, C.L. and Golhar, D.Y. (1991) "Customer and Supplier Linkages for Small JIT Manufacturing Firms" Journal of Small Business Management, Volume 29, Number 3, Pages 43-49.

74. Groover, M.P. and Zimmers, E.W. (1984) "CAD/CAM Computer-Aided Design and Manufacturing" Englewood Cliffs: Prentice-Hall.

75. Gott, B. (2003) "Evolution from 2D to 3D - A Product Development Manager's Perspective" [http://www.ingenea.com/Downloads/whitepapers/Evolveto3D_wp_06_ProductDevelopmentManager.pdf], [Accessed 03/03/07].

76. Alibre (2006) "3D CAD Buyers Guide" [http://www.alibre.com/AlibreLibraries/ftp/inforequest/3D-CAD-Buyers-Guide.pdf], [Accessed 20/09/06].

77. Begg, V. (1984) "Developing Expert CAD Systems" London: Kogan Page.

78. MacKrell, J. and Herzog, B. (2003) "Computer-Aided Engineering" [http://media.wiley.com/assets/152/07/applications.pdf], [Accessed 04/03/06].

79. Hodgkiss, B. J. (1983) "The Application of CAD – a Case Study" in "Efficiency in the Design Office" Wembley: Mechanical Engineering Publications.

80. Jones, P.F. (1992) "CADCAM Features, Applications & Management" London: Macmillan.

81. Chama, B.N. (2007) "Impact of the A380 Project on the Financial Performance of EADS" [http://www.bth.se/fou/cuppsats.nsf/all/465e52e638b57294c1257354006311eb/$file/Final_Thesis_George_and_Brian.doc], [Accessed 14/09/08].

82. Halton, R. (1993) "Making CADCAM Work" UK: Prentice Hall International.

83. Diaz, M.S., Machuca, J.A.D. and Alvarez-Gil, M.J. (2003) "A View Developing Patterns of Investment in AMT Through Empirical Taxonomies: New Evidence" Operations Management, Volume 21, Pages 577-606.

84. Boyer, K., Leong, G., Ward, P. and Krajewski, L. (1997) "Unlocking the Potential of Advanced Manufacturing Technologies" Operations Management, Volume 15, Number 1, Pages 331-347.

85. Chung, C. (1996) "Human Issues Influencing the Successful Implementation of Advanced Manufacturing Technologies" Engineering and Technology Management, Volume 13, Number 3, Pages 283-299.

86. Buxton, W., Kasik, D. and Ferguson, D.R. (2005) "Ten CAD Challenges" IEEE Computer Graphics and Applications, Volume 25, Number 2, Pages 81-92.

87. McMahon, C.A. and Browne, J. (1993) "CADCAM from Principles to Practise" London: Addison-Wesley.

88. Lundvall, B.Å. (2006) "DRUID Working Paper No.06-6 - Knowledge Management in the Learning Economy" [http://www.druid.dk/wp/pdf_files/06-06.pdf], [Accessed 12/02/07].

89. Bessant, J., Phelps, B. and Adams, R. (2005) "A Review of the Literature Addressing the Role of External Knowledge and Expertise at Key Stages of Business Growth and Development" [https://dspace.lib.cranfield.ac.uk/bitstream/1826/1036/1/Bessant-Phelps-Adams-Rev%20of%20Lit%20Business%20Growth%20and%20Development-Final%20Report.pdf], [Accessed 14/02/07].

90. British Standards Institution [http://www.bsi-global.com], [Accessed 28/11/06].

91. Health & Safety Executive [http://www.hse.gov.uk], [Accessed 28/11/06].

92. National Composites Network [http://www.ncn-uk.co.uk], [Accessed 28/11/06].

93. Marine South West [http://www.marine-south-west.org.uk], [Accessed 28/11/06].

94. Cornwall Marine Network [http://www.cornwallmarine.net], [Accessed 28/11/06].

95. British Marine Federation [http://www.britishmarine.co.uk], [Accessed 28/11/06].

96. European Commission (2005) "European Union Support Programmes for SMEs" [http://ec.europa.eu/enterprise/entrepreneurship/sme_envoy/pdf/support_programmes_2005_en.pdf], [Accessed 09/09/06].

97. Department for Trade & Industry [http://www.dti.gov.uk/about/index.html], [Accessed 28/11/06].

98. Department for Trade & Industry (2004) "Strategic Plan for KTP" [http://www.ktponline.org.uk/admin/documents/ktp_strategy_revised.doc], [Accessed 24/11/06].

99. Department for Trade & Industry (2003) "Competing in the Global Economy: the Innovation Challenge" [http://www.dti.gov.uk/files/file12093.pdf], [Accessed 25/11/06].

100. Business Link [http://www.businesslink.gov.uk], [Accessed 28/11/06].

101. Google Scholar [http://scholar.google.co.uk], [Accessed 15/11/06].

102. Microsoft Live Academic [http://search.live.com/academic], [Accessed 15/11/06].

103. British Library [http://www.bl.uk], [Accessed 16/11/06].

104. Materials Knowledge Transfer Network [http://www.materialsktn.net], [Accessed 28/10/08].

105. Anonymous (2001) "The Converge Project - Mould-Making in Ireland" TSER Programme of DGXII.

106. Papaconstantinou, G., Sakurai, N. and Wyckoff, A. (1996) "Embodied Technology Diffusion: An Empirical Analysis for 10 OECD Countries" [Online http://www.sourceoecd.org/10.1787/686654085563], [Accessed 02/02/07].

107. Harper, D. (2001) Online Etymology Dictionary [http://www.etymonline.com/index.php?term=technology], [Accessed 03/04/07].

108. Elmuti, D. and Kathawala, Y. (2001) "An Overview of Strategic Alliances" Management Decision, Volume 39, Number 3, Pages 205-217.

109. Unlocking Cornish Potential [http://www.cornwall.ac.uk/ucp/index.php?page=_Home], [Accessed 12/08/08].

110. Knowledge Transfer Partnerships [http://www.ktponline.org.uk], [Accessed 15/05/06].

111. Power Faraday (2003) "HPRF Newsletter: The Teaching Company Scheme" [http://www.powerfaraday.org.uk/objects/downloads/HPRFNewsletter10.pdf], [Accessed 27/10/06].

112. Department for Trade & Industry (2004) "Knowledge Transfer Partnerships Annual Report 2004/5" [http://www.ktponline.org.uk/shared/KTP_AR04_05%20v8%20Final.pdf], [Accessed 28/11/06].

113. Gable, G.G. (1991) "Consultant Engagement for Computer System Selection: a Pro-Active Client Role in Small Businesses" Information and Management, Volume 20, Pages 83-93.

114. Browne, N. (2006) "Leading Change - Guidelines for Managers" Aberdeen: Robert Gordon University.

115. Kotter, J. (1996) "Leading Change" Boston: Harvard Business School Press.

116. Deming, W.E. (1986) "Out of the Crisis" Cambridge MA: Cambridge University Press.

117. Crosby, P. (1979) "Quality is Free" New York: McGraw-Hill.

118. Ishikawa, K. (1985) "What is Total Quality Control?" Englewood Cliffs NJ: Prentice-Hall.

119. Juran, J.M. and Godfrey, A.B. (1999) "Juran's Quality Handbook" 5th Edition, New York: McGraw-Hill.

120. Robinson, A. (1990) "Modern Approaches to Manufacturing Improvement: The Shingo System" Portland: Productivity Press.

121. Kondo, Y. (2002) "Keeping the "dream" in mind is indispensable for successful leadership" Managing Service Quality, Volume 12, Number 3, Pages 146 - 150.

122. Kok, J.D., Uhlaner, L. and Thurik, R. (2001) "Human Resource Management with Small and Medium Sized Enterprises: Facts and Explanations" [http://www.entrepreneurship-sme.eu/pdf-ez/B200103.pdf], [Accessed 03/02/06].

123. Sunseeker International [http://www.sunseeker.com], [Accessed 10/06/07].

124. Tribon [http://www.tribon.com], [Accessed 10/06/07].

125. Vacanti Systems (ProLines) [http://www.vacanti.com], [Accessed 10/06/07].

126. Dassault Systemes (CATIA) [http://www.3ds.com], [Accessed 10/06/07].

127. Solidworks [http://www.solidworks.com], [Accessed 10/06/07].

128. Ashlar Vellum (Cobalt) [http://www.ashlar.com], [Accessed 10/06/07].

129. Formation Systems (Maxsurf) [http://www.formsys.com], [Accessed 10/06/07].

130. Autodesk (AutoCAD) [http://www.autodesk.com], [Accessed 10/06/07].

131. Dell [http://www.dell.com], [Accessed 10/12/06].

132. McNeel, Rhino Wiki [http://en.wiki.mcneel.com], [Accessed 05/05/07].

133. Proteus Engineering, Rhino Marine [http://www.rhinomarine3d.com], [Accessed 10/06/07].

134. Lorraine, R. (2006) "CNC Sheetcutting Nightmare!" Rhino Newsgroup Post [http://news2.mcneel.com/scripts/dnewsweb.exe?cmd=article&group=rhino&item=236621&utag], [Accessed 22/08/06].

135. Lorraine, R. (2007) "Linking Universities with Industry" [http://www.swmas.co.uk/info/index.php/KTP], [Accessed 20/08/07].

136. Mathaisel, D., Cathcart, T. and Comm, C. (2003) "A Framework for Benchmarking, Classifying, and Implementing Best Sustainment Practices" [http://web.mit.edu/dfxm/www/Pubs/Framework%20for%20Best%20Sustainment%20Practices%20Nov%202003.pdf], [Accessed 07/11/06].

137. Chesbrough, H. and Rosenbloom, R.S. (2001) "The Role of the Business Model in capturing value from Innovation: Evidence from XEROX Corporation's Technology Spinoff Companies" [http://www.hbs.edu/research/facpubs/workingpapers/papers2/0001/01-002.pdf], [Accessed 08/11/06].

138. Kaplan, R.S. and Norton, D.P (2000) "Having Trouble with Your Strategy? Then Map It" Harvard Business Review, Volume 78, Number 5, Pages 167-276.

139. Linder, J.C. and Cantrell, S. (2001) "Five Business Model Myths that Hold Companies Back" Strategy & Leadership, November-December, Pages 13-18.

140. Tucci, C. and Afuah, A. (2000) "Internet Business Models and Strategies" Irwin: McGraw-Hill.

141. Nepal, C., Karki, B.R. and Niraula, K.P. (2002) "Technology Transfer in SMEs: Problems and Issues in the Context of Nepal" [http://www.unescap.org/tid/publication/indpub2306_chap3.pdf], [Accessed 07/08/06].

142. Dosi, G. (1990) "The Nature of Innovative Processes" Technical Change and Theory, London: Pinter.

143. Handy, C. (1999) "Understanding Organisations" London: Penguin Group.

144. Kolb, D., Rubin, I. and McIntyre, J. (1979) "Organisational Psychology: An Experimental Approach" New Jersey: Prentice-Hall.

145. Emory, W.C. (1985) "Business Research Methods" 3rd Edition, Illinois: Irwin.

146. Joppe, M. (2000) "The Research Process" [http://www.ryerson.ca/mjoppe/rp.htm], [Accessed 20/05/06].

147. Seliger, H. and Shohamy, E. (1989) "Second Language Research Methods" Oxford: Oxford University Press.

148. Hamblin, M.J. (1983) "CAD for the Small User" in "Efficiency in the Design Office" London: Mechanical Engineering Publications.

149. Elliot, T. (2004) "Re: CAD System for Kingfisher Boats" [Email from tim.elliot@ihug.co.nz], [Sent on 17/11/04].