Bournemouth University

A Strategy to Deploy Rapid Prototyping within SMEs

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A thesis submitted in partial fulfilment of the requirements of Bournemouth University for the degree of Doctor of Philosophy

July 2013

DEDICATION

To The Heart, Roots & Blooming Crowns of My Life

I dedicate this thesis to my unstintingly generous heart and roots…

The greatest parents anyone could ever have

My Father **MUSTAFA - ZUBAIDA** My Mother

For everything you have done, are still doing, and the sacrifices you made for me, I am sincerely grateful!

&

To the beautiful blooming crowns…

The cleverest children anyone could wish for

My Son **YOUSOUF - LUJAIN** My Daughter

&

My Wife

Rania

For supporting me through the journey

Your unconditional love has driven me forward

I Love You All!

Copyright Statement

Abstract

Ahmed **M**ustafa **R**omouzy **A**li

A Strategy to Deploy Rapid Prototyping within SMEs

The new century has provided extraordinary opportunities for new product development and manufacturing improvement through the creation of technologies in prototyping and manufacturing. These new technologies enable better allocation of financial resources, save time and create a culture of anticipation and innovation rather than one of design and development. Rapid Prototyping (RP) is at the forefront of this revolution in manufacturing. RP is based on completely new additive techniques that produce fully functional parts directly from a three-dimensional Computer Aided Design (CAD) model without the use of tooling. This offers the potential to change the concept of prototyping, manufacturing, service and distribution with opportunities for producing highly complex and customised products.

Small and Medium sized Enterprises (SMEs) are the foundation of the UK economy, generating value and making a significant and crucial contribution to its productivity and performance. The current trade and industry situation has boosted the importance of the SMEs in both developed and developing countries due to the increased reliance of the international partners, but the important point at this stage is that these SMEs should be ready to embrace this global technological challenge.

The context of this research, within industrial/manufacturing SMEs, has significance for stimulating new product development, productivity and competitiveness through the deployment of RP technologies within the SMEs. A broad literature review has been conducted, and a longitudinal mixed methodological approach was adopted for the data collection. This has involved a structured questionnaire survey followed by semi-structured interviews with the Executive Managers of SMEs from the industrial/manufacturing sector in the

South West of England. The analysis of the collected data, in tandem with the supporting literature, has revealed the factors that influence the deployment of RP technology in SMEs. These findings were formulated into a strategy to help SMEs in making the decision of whether or not to deploy RP technology. The strategy was validated through evaluation and feedback from the Executive Managers of a number of SMEs. This research has contributed new knowledge in the area of RP deployment in SMEs which could potentially have a role in assisting their business survival through increased growth and competitiveness.

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Acknowledgement

I would love to start with a very special quote about appreciation of the PROPHET MUHAMMAD 'May Allah Honour Him and Grant Him Peace', he said:

"WHOEVER DOES NOT THANK PEOPLE (FOR THEIR FAVOURS) HAS NOT THANKED ALLAH (PROPERLY), MIGHTY AND GLORIOUS IS HE!" (Musnad Ahmad, Sunan At-Tirmidhī)

Thus, I would like to express my deepest appreciation to all those who have made it possible for me to complete this thesis. Special gratitude is due to my supervisory team for their useful comments, remarks and engagement throughout the research journey. I could not have imagined having a better supervisory team for my PhD research.

My first supervisor, Professor Siamak Noroozi – for his continuous support, patience, motivation, enthusiasm, immense knowledge and for the long conversations about life expectancy, research, career, PhD and everything else. He has been invaluable on both an academic and a personal level, for which I am extremely grateful.

My second supervisor, Dr Philip Sewell – for his generous support, from which I have greatly benefited, as well as his understanding and for providing me with insightful discussions about the research. I really appreciate the extra time he spent working with me while he was so busy.

My third supervisor, Dr Tania Humphries-Smith – for her support, guidance and helpful suggestions, and for her skill in asking those challenging questions in a way that constantly directed me towards a much healthier research route, which I valued greatly.

My brother and loyal friend Dr Hossam Shaaban – for his constant and unconditional support during the most critical and crucial part of this research journey. Without his help, I would not have brought this research to a successful completion.

My wonderful English Friend Mr James Webb – for his tireless efforts to correct my ‘B’ and ‘P’ each time we meet, and for his help and support with the English language during my research journey.

The company participants – without your willingness to contribute your business information and thoughts, this would have been an unmanageable task.

Most of all, I owe everything to Almighty Allah for granting me the wisdom, health and strength to undertake this doctoral research and empowering me to achieve its completion.

Declaration

This work is entirely my own work. None of it has been taken from the work of others, expect where fully referenced and acknowledge. In particular, I have not copied or paraphrased an extract of any length form a document or source (including book, article, report, thesis, website, etc.) without identifying such document or source and using quotation marks as appropriate. I understand that I may be required to discuss with the thesis review committee the contents of this submission. I understand that plagiarism is a grave offence at Bournemouth University and that it carries the severest penalties.

Resulting Publications from this Research

Publications arising from this research are a clear indication of the significance of the outcomes of the study; parts of this thesis have already been published in the following peer reviewed journals *(see Appendix A)* and some other articles are being prepared for submission. It is worth mentioning that journal article no. 1 was invited for inclusion in the annual review version of the journal with the following message from the publisher:

> *"We are pleased to inform you that your article has been selected by our editorial board for inclusion in The International Journal of Knowledge, Culture and Change Management: Annual Review. Your article's inclusion in this journal is recognition of your scholarly achievement as well as your article's wide applicability in this field and its high editorial quality. We believe that you have much to contribute to the intellectual depth of this field and are delighted to offer you this opportunity. The annual review consists only of articles considered to be of wide interest across the field, which are selected by our editorial team in consultation with the Advisory Board. We do not accept direct submissions to the annual review. Candidates for inclusion in the survey journal include top-ranked articles, works by invited contributors, articles offered by plenary speakers at the conference, and articles selected from thematic journal submissions."*

<u>Journal Articles</u>

Published

1. Romouzy Ali, A. M, Noroozi, S., Sewell, P. and Humphries-Smith, T., 2012. The Barriers Hindering Rapid Prototyping Deployment within Small and Medium-Sized Enterprises: Which Should Come First? *The International Journal of Knowledge, Culture, and Change in Organizations: Annual Review,* Volume 12, pp. 15-28.
2. Romouzy Ali, A. M, Noroozi, S., Sewell, P. and Humphries-Smith, T., 2012. Adopting Rapid Prototyping Technology within Small and Medium-Sized Enterprises: The Differences between Reality an

Expectation. *International Journal of Innovation, Management and Technology*, vol. 3, no. 4, pp. 427-432.

In progress articles

3. Romouzy Ali, A. M, Noroozi, S., Sewell, P. and Humphries-Smith, T., 2013.Strategy to Deploy Rapid Prototyping within Small and Medium-Sized Enterprise.
4. Romouzy Ali, A. M, Noroozi, S., Sewell, P. and Humphries-Smith, T., 2013. The Internal factors influencing the deployment of RP technology within SMEs.
5. Romouzy Ali, A. M, Noroozi, S., Sewell, P. and Humphries-Smith, T., 2013. The External factors influencing the deployment of RP technology within SMEs.
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Conference Papers

1. Romouzy Ali, A. M, Noroozi, S., Sewell, P. and Humphries-Smith, T., "Adopting Rapid Prototyping Technology within Small and Medium-Sized Enterprises: The Differences between Reality and Expectation, *In: 2nd Conference on Innovation, Management and Technology, 23-24 July 2012, Singapore.*

2. Romouzy Ali, A. M, Noroozi, S., Sewell, P. and Humphries-Smith, T., 2012. The Barriers Hindering Rapid Prototyping Deployment within Small and Medium-Sized Enterprises: Which Should Come First? *In: Twelfth International Conference on Knowledge, Culture and Change Management, 6-8 July 2012, Chicago, USA.*

Conference Posters

1. Romouzy, A. M., 2013. *Strategy to Deploy Rapid Prototyping within SMEs,* School of Engineering, Design & Computing 6th poster Conference, Bournemouth University, UK

2. Romouzy, A. M., 2012. *Strategy to Deploy Rapid Prototyping within SMEs,* 4th Annual Postgraduate Conference, Bournemouth University, UK.
3. Romouzy, A. M., 2012. *Strategy to Deploy Rapid Prototyping within SMEs,* School of Engineering, Design & Computing 5th poster Conference, Bournemouth University, UK.
4. Romouzy, A. M., 2011. *Strategy to Deploy Rapid Prototyping within SMEs*, School of Engineering, Design & Computing 4th poster Conference, Bournemouth University, UK.
5. Romouzy, A. M., 2011. *Strategy to Deploy Rapid Prototyping within SMEs,* 3th Annual Postgraduate Conference, Bournemouth University, UK.
6. Romouzy, A. M., 2010. *Strategy to Deploy Rapid Prototyping within SMEs,* School of Engineering, Design & Computing 3rd poster Conference, Bournemouth University, UK.
7. Romouzy, A. M., 2009. *Strategy to prepare the Appropriate Model for the Product Design Program in the Industrial Design Field,* School of Engineering, Design & Computing 2nd poster Conference, Bournemouth University, UK.
8. Romouzy, A. M., 2009. *Strategy to prepare the Appropriate Model for the Product Design Program in the Industrial Design Field*, 2nd Annual Postgraduate Conference, Bournemouth University, UK.
9. Romouzy, A. M., 2009. *Strategy to prepare the Appropriate Model for the Product Design Program in the Industrial Design Field,* 1st Annual Conference for Egyptian Scholars in UK and Ireland, London, UK.

Chapter 1

Research Overview

1.1 Introduction

Globalisation trends, technological advancements and continuously increasing tough competition in the market place have always changed the rules of business (Bititci and Ates 2009). Conventional thinking prevailing in the international business community, and also in government planning, involves linking competitiveness with a favourable exchange rate or a positive balance of trade and industry that is supported even if the inflation rate is low. However competitiveness, in the modern sense, is linked to the will of the state to raise the productivity of available resources, whether human or technological.

The age of large factories is over. Today's markets are consumption limited, not production limited. In the new paradigm, mass-produced components are shipped to small, widely dispersed factories that assemble finished products locally to meet customer requirements at the point of sale. Products must be delivered exactly as local tastes demand (Pinto 2009).

Rapid Prototyping (RP) is a collection of technologies that are driven by Computer Aided Design (CAD) data to produce physical models and parts through an additive formation process (Borille et al. 2010), in contrast to Computer Numerical Control (CNC) machining that builds parts through a subtractive formation process. The growth of the RP field has been tremendous during the last decade. However, RP technology is still struggling to enter organisations for various reasons, including difficulties with management and implementation, and the high cost of machines, processes and materials (Vinodh et al. 2009).

"The term rapid prototyping really mischaracterises what we're doing with this technology" claims Ron Jones; president and CEO of Dynastrosi Laboratories Inc (LeGault 2008).

Small and Medium Enterprises (SMEs) are one of the pillars of industrial development and play an important role in the development of different products. SMEs are companies with between 1 and 249 employees and a turnover of 2 m to 50 m Euros, as defined in EU law (details of which follow in Chapter 2). Given the economic importance of industrial SMEs in the process of product development, these institutions enjoy comparative advantages in production and services that necessitate their presence next to large enterprises. These organisations enjoy the benefits of developing their organisational skills, which give them the ability to innovate and identify market conditions, thus potentially increasing their capacity to produce goods and services.

SMEs play a vital role in boosting market activity worldwide, with their high rates of employment and intrinsic features such as flexible production structure, innovation capabilities, and devotion to service and networking, each of which are valuable assets in today's economic environment (Selek 2009). In the manufacturing sector, SMEs act as specialist suppliers of components, parts, and sub-assemblies to larger companies because the items can be produced at a lower price than the large companies could achieve in-house. Lack of product quality supplied by SMEs could adversely affect the competitive ability of the larger organisations (Singh et al. 2008).

"SMEs need to be reached on a local basis, with active support and a practical demonstration of the benefits on offer" (Cox 2005, p.16).

Hence, it has become necessary to work to increase the effectiveness of these enterprises and to overcome all difficulties to increase their role in the process of product development. Since the concept of competitiveness is now so important in today's business world, it has become the primary indicator for boards, bodies and strategists globally. Therefore in contemporary product development the competitiveness of SMEs needs to be addressed, as they affect organisations, large and small companies, individuals wishing to sustain growth, productivity, and increase the living standards of their members.

"The decline in manufacturing does not have to be seen as unending and inevitable"(Cox 2005, p.17).

In this day and age, stiff competition, technology advancement and the globalisation of markets have meant that most companies have been forced to consider and implement a wide variety of innovative management philosophies, approaches, and techniques (Deros et al. 2009). The aim is to motivate the traditional manufacturing organisations to recognise RP technology and thereby achieve competitiveness (Vinodh et al. 2009). However, the applications which benefit most from RP begin with correct selection of the process that makes the selection procedure, as well as the right definition of prototype requirements; both very important steps (Borille et al. 2010).

However, the selection must be preceded by confidence and a feasibility study to bring these technologies to manufacturing processes already in use to support the adoption of this decision. Therefore, SMEs must have the knowledge and full awareness of the constructive contribution that this new technology brings, especially when the size of the SME is not comparable to the size of large companies that have independent departments for taking such decisions.

"UK manufacturing is also changing. Manufacturing is no longer the simple production of goods for one time sale but is now a complicated network involving much high value but sometimes less tangible activities spanning the whole product life-cycle, these include: design, R&D, marketing, logistics, lifetime services and disposal" says Iain Gary, Chief Executive (Technology Strategy Board 2008, p.3).

Technology will be utilised for the well-designed products that may offer global market opportunities for UK manufacturers where the value margin is such that the manufacture of the product is feasible in high cost economies. Products that exploit new global and environmental markets are likely to provide particular opportunities for UK wealth creation (Board 2008).

1.2 Contribution to Knowledge

There have been many optimistic attempts to find rational solutions to help SMEs, but these solutions are designed to solve the overall problem, which is the constraint to the adoption of new technologies. These solutions are good examples which explain the obstacles, but when trying to implement those solutions in certain SME sectors (manufacturing, engineering and industrial product design, which are the focus of this research) they immediately become inappropriate. Put simply, what has not been well investigated is the specificity of each sector and therefore its particular and customised barriers, as well as each technology's customised deployment criteria.

A review of the previous attempts to overcome the technology management barriers demonstrates encouraging results with regard to the adoption of new technologies. However, the review also reflects the fact that no work has been done to provide a specific strategy for SMEs to enable them to appropriately deploy RP technology. This shortcoming has been addressed in the present study.

"The obstacles may be clear, but that does not make them easy to address" (Cox 2005, P.17)

The next chapters review in depth the known facts, barriers and drivers that affect the deployment of new technologies within SMEs. In addition to SMEs' familiarity with the importance of technology, different forms of conventional approaches used by manufacturing sectors to meet the industrial demands have also been considered and put into context, building on the existing knowledge. The literature review has shown that much has been written about the barriers to and problems for general technology adoption in SMEs. Consequently, this research does not aim to further substantiate their existence. Rather, the research identifies and prioritises the RP genuine and specific barriers that directly prevent SMEs in the South West of England from deploying the RP technology within their industrial/manufacturing firms. This overall rationale was developed in response to the growing challenges SMEs are facing to cope with the innovative technologies in prototyping and manufacturing.

Striving for the highest level of development in industrial and manufacturing technologies is crucial. SMEs will be required to harness the huge improvements embodied in RP technology to ensure their survival and a high level of contemporary market share. Unfortunately, the existing technological deployment map alone will not be sufficient to keep SMEs competitive, a customised effort is needed to develop and tailor new deployment strategies that utilise practical technology deployment methodologies in addition to new styles of technology deployment approach. In many areas SMEs are too conservative in their exploitation of RP technology. When compared to RP and additive manufacturing technology installations in big firms, SMEs are several years behind. The literature review has also highlighted both the strengths and weaknesses of current SMEs' RP technology management, and revealed the need for a customised straight improvement in RP dissemination channels among SMEs.

This research has considered the various RP technology deployment approaches available to industrial/manufacturing SMEs in Europe and the significance of each of the approaches to their ability to innovate. This has revealed that there are three key approaches, which have developed simultaneously in the last 10 years, as ways to conquer the broad technology adoption problems in industrial/manufacturing SMEs. The three key approaches are:

SMEs' KTP-based approaches

Peças and Henriques (2006, p.54) "proposed model promotes the involvement of the young engineers with authentic industrial experiences, enables the build-up of their practical framework and encourages their entrepreneurial growth. It also promotes the innovation process in SME companies through the close collaboration with universities".

Ahmad et al. (2009, p.2) "this situation warrants a joint consortium of govt, academia and multinational corporations (MNCs) where the issues are addressed jointly as it requires knowledge and competencies in many areas and all the desired skills required to address the issue are not present in any one stakeholder".

Bititci and Ates (2009, p.8) “support the transformation of SMEs focusing on their business problems and challenges, and then on appropriate and contextualised tools, methods and technologies, support practical implementation of the modern approaches in SME day-to-day practice rather than focusing on providing knowledge”.

Cox (2005, p.17) “The challenge is to reach as many SMEs as possible, demonstrating the practical benefits of taking greater advantage of creative skills”.

Wormald and Evans (2009, p.343) “KTP programmes can work for SMEs, to bring in creativity to promote innovation in the companies”.

Azadivar et al. (2000,p.250) “success can be transferred from one successful implementation to another is by capturing this collective wisdom and making it available to the whole population”.

In academia, KTP’s are well known approaches that simplify the transfer of knowledge, with developments carried out by highly competent and qualified individuals. This is done under cooperative management by both an academic body and a business. “*Knowledge Transfer Partnerships (KTP) supports UK businesses wanting to improve their competitiveness, productivity and performance by accessing the knowledge and expertise available within UK Universities and Colleges”* (Knowledge Transfer Partnerships Website 2013)

Although KTP enriches the collaboration and awareness between academic bodies and businesses, it is not yet widespread within business culture. This is because not all businesses have the financial resources with which to pay their financial share in KTP. Also the nature of KTP as a form of external help falls under the heading of resistance to change, hindering the acceptance of any new culture within SMEs.

Computer-based tools for RP process selection approaches

Borille et al. (2010, p.60) "the selection process of RP technology has been studied for some time, and the focus of most works was to develop a new decision method. Some methods become quite complicated which could discourage the user to apply it".

Armillotta (2008, p.450) "a computer-based tool for the selection of techniques used in the manufacture of prototypes and limited production runs of industrial products. The underlying decision model, based on the AHP methodology, ranks available techniques by a score resulting from the composition of priorities at different levels, each considering homogeneous and independent evaluation criteria".

Rao and Padmanabhan (2007, p.83) "a methodology based on graph theory and matrix approach is suggested which helps in selection of a suitable RP process from among a large number of available alternatives for prototyping a given product or part. The proposed method considers RP process selection attributes, their interrelations, and the RP process selection index evaluates and ranks RP processes for a given RP process selection problem. The proposed method is a general method, can consider any number of quantitative and qualitative RP process selection attributes simultaneously, and offers a more objective and simple RP process selection approach. The proposed methodology can be extended to any type of selection problems".

Byun and Lee (2005, p.1338) "an effective methodology for selecting the RP system most appropriate for the end use of the part when multi attributes included both uncertain (or imprecise) and crisp data. The major factors used for RP process selection included accuracy, surface roughness, strength, elongation, the cost of the part and build time".

Kerbrat et al. (2010, p.64) "nowadays, layered manufacturing processes are coming to maturity, but there is still no way to compare these new processes with traditional ones (like machining) at the early design stage. In this paper, a new methodology is proposed to combine additive and subtractive processes, for tooling design and manufacturing. A manufacturability analysis is based on an octree decomposition, with calculation of manufacturing complexity indexes from the tool CAD model".

Munguia (2008, p.578) "soft-computing (SC) denotes the class of Artificial Intelligence technologies such as: fuzzy logic (FL), neural networks (NN), relational databases and rule-based decision making, which are used to deal with uncertainty and fuzziness on a wide variety of problems like decision making for process selection. This paper depicts a SC-based system for the selection of Rapid Manufacturing (RM) processes according to 2 main dimensions: general feasibility (FL-based) and cost estimation (NN-based). The aim is to asses RM feasibility according to a set of user-defined conditions".

Technology selection is a sequential part of the problem, and is not the main problem. Therefore, providing a selection system or model for a technology that is not yet considered strategically for deployment will only add more misunderstanding to the current situation. The barriers to technology need to be identified first, in order to work out the way to enable the drivers to make the right decision. These selection techniques can later be included and implemented at the stage where the technology is purposefully identified as needed.

Internet-based approaches

Tay et al. (2001, p.410) "In the global manufacturing and design arena, industrial competition through successful product development based on efficient prototyping can be further enhanced by the use of the distributed rapid prototyping system via the Internet for remote prototyping to considerably reduce the product development lead time".

Lan (2009, p.644) "Although Web-based technologies have been applied to collaborative product design and manufacturing for many years, real industrial applications have not been in place yet. As one of the most typical cases for Web-based collaborative product design and manufacturing system, Web-based RP&M

system has shown a promising prospect for networked manufacturing and service modes. However, there is still a long way for really commercial application of the Web-based RP&M systems".

Although these three key approaches could lead to a relative improvement in the technology adoption process, they are not bespoke to any specific given situation and so do not go beyond bringing a general understanding to a precise set of issues. As such, they do not fully solve the problem. Therefore, since the approaches are more generic in nature and less specific in customisation, they will generate post-adoption complications. The value of these three key approaches lies in the fact that they could be used as good points of reference when attempts are made to design a customised strategy for a specific sector, as is intended in this research. In other words, each of the three key approaches is valuable when the problem is identified exclusively by sector and the drivers and barrier sets are identified, prioritised and genuinely customised to that sector's needs.

There is a crucial need for SMEs to recognise RP technology as a potential development tool and decide through a state-of-the-art deployment strategy whether to link designing/prototyping systems and production systems with the RP technology systems. This then calls for a regular method of assessing the SME technology development processes to enable the firm to design and implement an innovative technology tool to strengthen their industrial/manufacturing capability.

The current situation is described by Gibson et al. (2009, p.320). "It is clear that only process planners who have a very detailed understanding of all the roles that Additive Manufacturing parts can play will be able to utilise the resources effectively and efficiently. Even then it may be difficult to perform this task reliably given the large number of variables involved. A software system to assist in this difficult task would be very valuable tool". The mature attempts in RP technology adoption operate mainly among the R&D sectors of the big industrial firms. Mellor et al. (2012) stated that the strategic orientation of business and manufacturing with R&D strategy must come first in order to implement additive technologies. However, this research also aims to reveal and explore alternative approaches to deploying RP technology within SMEs particularly through more prototyping/manufacturing advances.

The common sense approach suggests that a specific sector-based approach should be developed in a tailored attempt to overcome RP technology deployment inadequacy by a customised strategy, to be designated based on the actual designing, industrial and manufacturing situation on the ground. Therefore this research has investigated and prioritised the customised barriers that hinder the deployment of RP technology within SMEs and suggested a new strategy to help these enterprises to appropriately make the decision on whether or not to deploy RP technology.

“*We can’t compete in the modern world simply by working harder or longer, we have to work smarter” s*ays Brendan Barber, General Secretary, Trades Union Congress (Cox 2005, p.16).

Accordingly, the contribution to knowledge lies in the competence offered by the suggested strategy to assist the SMEs in the South West of England to adequately deploy RP technology within their firms, and in the ability to use this technology in designing and manufacturing processes to compete in both local/global markets. Chua et al. (2010) present a diagram (Figure 1.1) that shows the results of integrating RP technology in the product life cycle, and that it reduces time and cost signficantly.

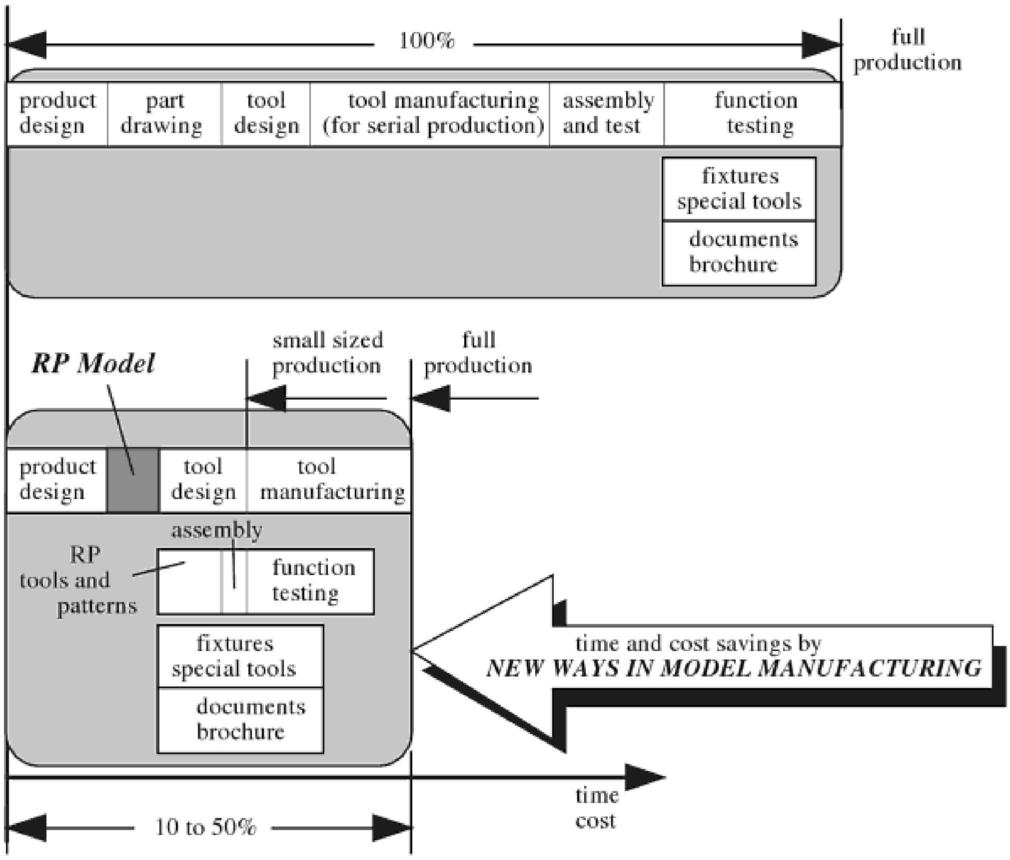

Figure 1.1 Results of integration of RP technology

(Source: Chua et al. 2010)

1.3 Research question, aim and objectives

The aim of the research was to answer the following question, which emerged and developed as a result of the synthesising process of the broad and extensive literature review in the field of new technology deployment within SMEs:

What are the main barriers that hinder the deployment of RP technology within industrial/manufacturing SMEs in the South West of England, and can a deployment strategy to assist SMEs be developed?

In order to answer the above, the following key questions were identified:

1. What is the level of awareness of SMEs of available new technologies?
2. To what extent is the RP technology recognisable within the SMEs?
3. To what extent are SMEs deploying RP technology, and how?

4. What are the common barriers that hinder the deployment of RP within SMEs, and which comes first?
5. What are the significant factors needed to develop a strategy for the deployment of RP technology within SMEs?

The main objectives of this research are:

1. To explore and prioritise the barriers that hinders the deployment of RP technology within SMEs.
2. To categorise the types of need for RP technology within industrial/manufacturing SMEs.
3. To investigate the impact of RP technology on the production performance level within SMEs.
4. To explore the factors potentially needed to develop a strategy to deploy RP technology within SMEs.

1.4 Overview of Methodology

The research question, aim and objectives have influenced the design of the research methods adopted by this study, since the research engaged a mixed methods study concerning barriers hindering the deployment of RP within SMEs in the South West of England. The methods were considered in view of the fact that research in industrial technology management which exclusively employs either a quantitative or a qualitative approach can present key challenges in the understanding of the results obtained. Currall et al. (1999, p.8) stated "we believe that a new methodological frontier lies, neither in the qualitative nor the quantitative domain exclusively, but rather in how the two techniques can be interwoven to maximise the knowledge yield of a research endeavour". The reason why these approaches will not work is that individuals engaged in the adoption process subjectively make their observations based on preceding practices and personal beliefs.

This challenge can be met through increased awareness and discussion between the researcher and SME individuals or other stakeholders about the environment for data collection related to industrial technology management and changes in that management. By synthesising quantitative and qualitative research methods in a mixed method research approach, the research was better able to comprehend this predicted prejudice with regard to the collected data. This research adopted an inductive approach and began by collecting data relevant to the barriers hindering the deployment of RP. When a considerable amount of data had been collected, the research looked for patterns in that data, aiming to develop a strategy - theory - that could explain those patterns. In contrast, the deductive approach begins with hypotheses that are developed from the standing theories, and then tests those hypotheses. Therefore, this research did not need a hypothesis. To prevent any bias of the data and results, the issues and barriers were identified from the literature and collected from the research participants without involving the researcher's personal views, as he worked in the same field.

Mixed Methods Research is defined by Erling et al. (2008) as an intellectual and practical synthesis based on the combination of qualitative and quantitative research methodologies and results. It recognises the importance of both quantitative and qualitative research methods but also offers a powerful third mixed research methodology that potentially will provide the most informative, complete, balanced, and useful research results. Mixed research actually has a long history in research practice because practicing researchers frequently ignore what is written by methodologists when they feel a mixed approach will best help them to answer their research questions (Johnson and Onwuegbuzie 2004). It is the third major research paradigm, adding an attractive alternative (when it is appropriate) to quantitative and qualitative research (Johnson and Christensen 2007).

Sydenstricker-Neto (1997) stated that "mixed method is a way to come up with creative alternatives to traditional or more monolithic ways to conceive and implement evaluation. It is likely that these alternatives will not be able to represent radical shifts in the short run. However, they are a genuine effort to be reflexive and more critical of the evaluation practice and, ideally, more useful and accountable to broader audiences". Johnson et al. (2007, p.112) indicated that, "mixed methods research is a systematic integration of quantitative and qualitative methods in a single study for purposes of obtaining a fuller picture and deeper understanding of a phenomenon. Mixed methods can be integrated in such a way that qualitative and quantitative methods retain their original structures and procedures (pure form mixed methods). Alternatively, these two methods can be adapted, altered, or synthesised to fit the research and cost situations of the study (modified form mixed methods)".

The study consists of two longitudinal phases. Phase One utilised a quantitative methods approach to identify and prioritise the barriers hindering the deployment of RP within the SMEs to gain a more comprehensive understanding of the situation on the ground. This approach involved conducting a postal questionnaire survey with a large number of SME executive managers. The results are presented in Chapter 5. Phase Two built on the conclusions of Phase One while conducting qualitative semi-structured interviews with the executive managers who gave consent to be contacted to participate in the next round of the data collection process. Those interviewees contributed to an understanding of the issues which create barriers to the deployment of RP. The outcomes of Phase Two are provided in Chapter 6. The overall combined approach provides inclusive insight into technology adoption in SMEs as a result of investigating RP deployment in particular.

1.5 Thesis Structure

This thesis starts by providing a background to the study of Rapid Prototyping technology and SMEs. The rationalisation for the research, based upon an extensive literature review in the areas of technology adoption within SMEs and the barriers hindering the deployment of technology, is provided in Chapter 2. As a part of this literature review, a list of the barriers which hold back any new technology adoption within SMEs was developed and presented in Chapter 3.

Based upon the literature review and subsequent list of barriers, a methodology for the research development is explained in Chapter 4, providing a rationale for the chosen mixed methods approach, the method used to select participants, the data collection process and analysis methods. The discussion of the findings arising from the analysed data is then presented in Chapters 5 and 6. The thesis concludes by outlining the distinctive contribution to knowledge offered by the suggested RP deployment strategy in Chapter 7 and draws attention to suggestions for further research. Figure 1.2 shows the inclusive thesis structure.

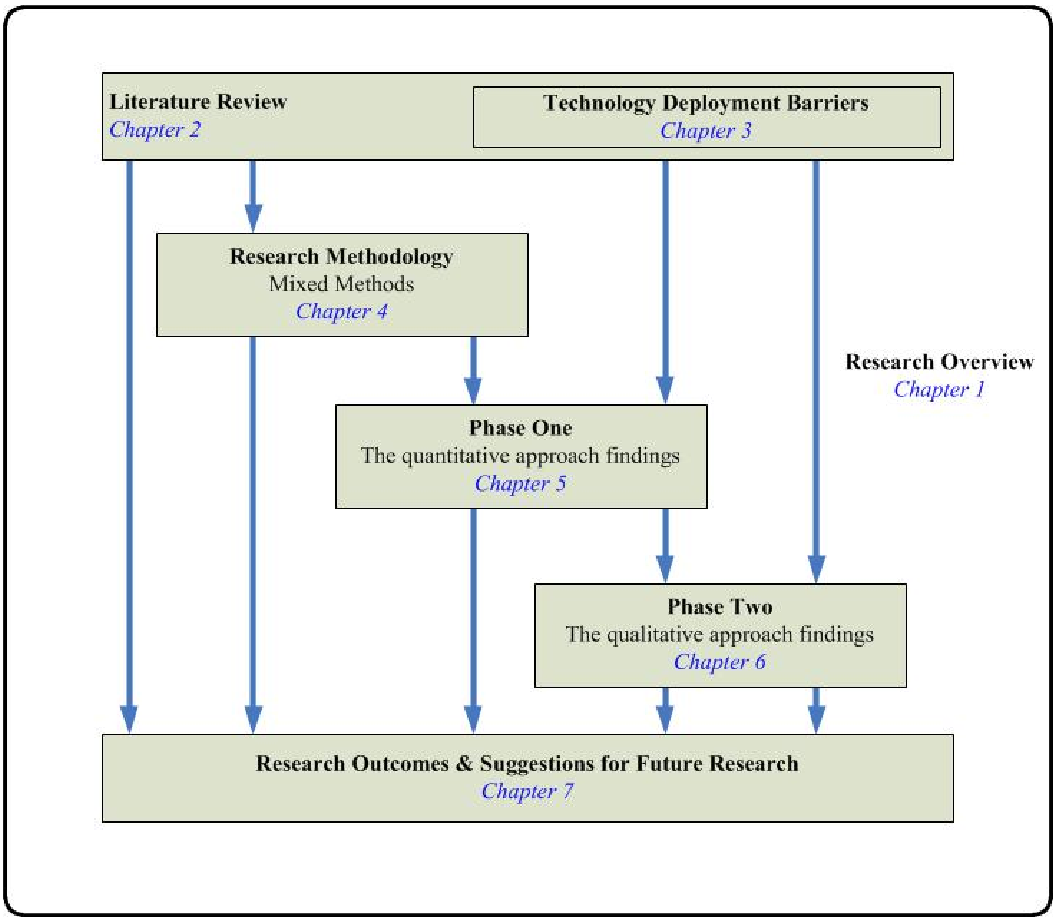

Figure 1.2 Inclusive thesis structure

1.6 Chapter Summary

This chapter has presented an overview of the research; the purpose, the distinctive contribution to knowledge, the research questions and a broad summary of the literature that are currently concerned with technology adoption by SMEs. In addition, Chapter 1 provided a concise outline of the methodology employed for this research. The subsequent two chapters begin with an overview of the background literature to this study, and are followed by a more detailed consideration of the barriers to technology deployment, taken from the SME literature, and the development of a list of barriers to be used in the course of this study.

Chapter 2

Literature Review

2.1 Chapter Overview

The previous chapter outlined the research, provided an overview of the research question, methodology, and contribution to knowledge and highlighted the thesis structure. This chapter brings together a review of the literature that addresses RP technology and SMEs providing details of the associated concepts in relation to the research context. Figure 2.1 shows the chapter structure.

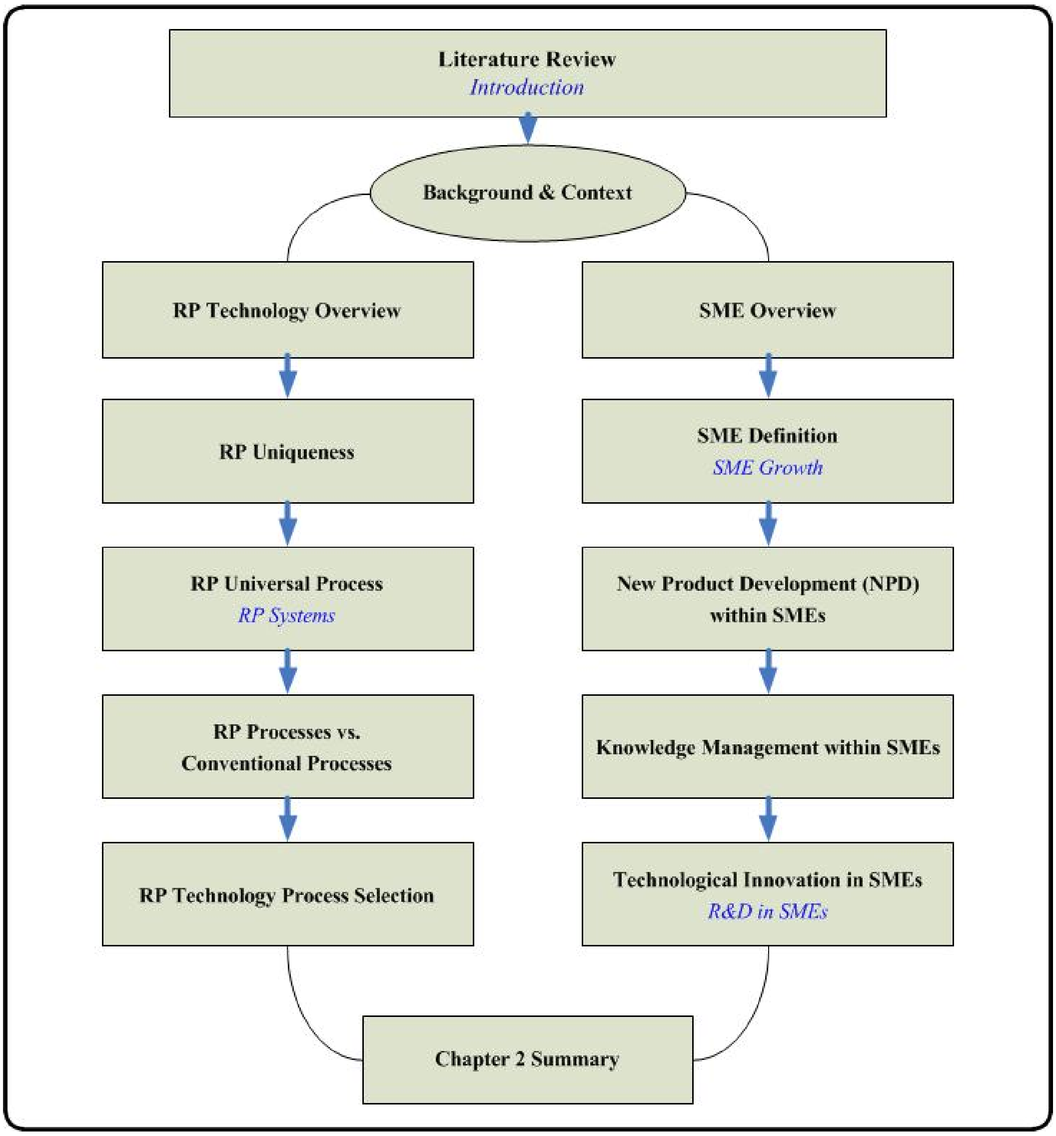

Figure 2.1 Chapter 2 structure

2.2 Background and Context

Human evolution was founded on forming/shaping knowledge, and the narration of civilisation has been boosted by the advancement of forming/shaping expertise (Yan et al. 2009). To develop a new product, it is necessary to fabricate a prototype of a designed product or mechanism before providing enormous investment for new machinery (Rao and Padmanabhan 2007). Before the 1990s, industrialised societies had to waste significant time building prototype products and mechanisms to test their performance (Vinodh et al. 2009). The chase for lower operational costs and enhanced manufacturing competence has pushed a great number of industrialised firms to adopt Advanced Manufacturing Technologies (AMT) for a variety of processes (Dangayach and Deshmukh 2005; Romouzy-Ali et al. 2012). Manufacturing has been developing over the years as different needs and technologies arise. Customers of the twenty-first century demand products and services that are fast, right, cheap and easy (Dangayach and Deshmukh, 2001).

It is recognised that products launched before their competitors are commonly more profitable and enjoy a larger share of the market (Rao and Padmanabhan 2007). The reliance on old technology and production processes is one of the main causes behind limited, standardised markets which are restricted by their inherent capabilities (Ahmad et al. 2009). AMTs have been recognised as a new way for industrialised corporations to gain competitive improvement. The spectacular advances in AMTs at a diversity of organisational levels can be credited to abundant benefits that improve the competitive situation of the adopting firms. AMTs influence not just manufacturing, but entire industries, providing new challenges to a business's ability to manage both technologies and manufacturing (Dangayach and Deshmukh 2005). To improve competitiveness in modern mass production industry, products should be designed and manufactured with two key goals which are often in conflict, firstly decreasing time and cost; and secondly improving quality and flexibility (Kerbrat et al. 2010). With the increased complexity of the products, the product life cycles and time to market are shortening and to ensure long term success, the manufacturers are required to concentrate on both markets and technology (Ahmad et al. 2009). Given this situation, Rapid Prototyping (RP) technology has emerged worldwide to support industrialised communities (Vinodh et al. 2009). Upcoming products will take advantage of leading edge modern technologies through RP and its derivative techniques (Yan et al. 2009).

RP technology occupies the top of the new cutting-edge AMTs list. RP technology, as defined by Borille et al. (2010, p.51), "is a collection of technologies that are driven by Computer-Aided Design (CAD) data to produce physical models and parts through an additive process". As a new technology that fabricates three-dimensional physical prototypes, RP technology has been developed to reduce product development time and cost (Byun and Lee 2005), as well as enhancing quality and flexibility which integrate into customised products. This range of customisation is to create a fully integrated system for the production and supply of high added value products that are personalised and customised to fit both geometrically and functionally the requirements of the user, and are provided not in weeks but hours (Direction 2005). "We're on the verge of a revolution in how things are made", said Greg Morris, Morris Technologies, as reported by Ogando (2007).

Cavalieri et al. (2004) stated that, despite the fact that RP technology is remarkably on the rise, and potential RP applications have become open-ended, it is still not recognised adequately within the majority of industrial/manufacturing/engineering/design companies. As reported by Legault (2008), Ron Jones, president and CEO of Dynastrosi Laboratories Inc, stated that "The term Rapid Prototyping really mischaracterises what we're doing with this technology", as the new AM concept was materialised from RP technology and its unlimited possibilities. Mostly those companies all fall in the category of SMEs.

Singh et al. (2008, p.530) stated that, "in manufacturing sector, SMEs act as specialist suppliers of components, parts, and sub-assemblies to larger companies because the items can be produced at a cheaper price than the large companies could achieve in-house. Lack of product quality supplied by them could adversely affect the competitive ability of the larger organisations". For that reason, it has become necessary to work to increase the effectiveness of these enterprises and to overcome all difficulties to increase their role in the process of product development. Cox (2005, p.16) indicated that “SMEs need to be reached on a local basis, with active support and a practical demonstration of the benefits on offer”.

Since the introduction of the concept of competitiveness and its importance in today's business world, contemporary product development and the competitiveness of SMEs have not necessarily progressed, even though it could potentially improve the productivity and growth of companies, large and small, and increase the living standards of its members. In view of that, and as stated by Cox (2005, p.17), “the decline in manufacturing does not have to be seen as unending and inevitable”, but as an opportunity to learn more willingly and to search out how to end this decline.

Deros et al. (2009, p.387) said, “in this day and age, stiff competition, technology advancement and the globalisation of markets, most of the companies have been forced to consider and implement a wide variety of innovative management philosophies, approaches, and techniques”. This gives rise to another question: should companies, in particular SMEs, wait to become compelled to consider new technologies such as RP? The answer to that question might be what Brendan Barber, General Secretary, Trades Union Congress, said in the treasury report, as concluded by Cox (2005, p.16) “we can’t compete in the modern world simply by working harder or longer, we have to work smarter”.

Developed technologies are for well designed, high value products that may offer global market opportunities for UK manufacturers where the value margin is such that the manufacture of the product is feasible in high cost economies. Products that exploit new global and environmental markets are likely to provide particular opportunities for wealth creation for the UK (Board 2008). Livesey (2006, p.1) commented: “manufacturing has a strong future in the UK. That future is based on generating high value – to the company, to shareholders and to the country. High value manufacturers have strong financial performance, are strategically important, and have positive social impact”. The globe is changing. Globalisation, digital infrastructures and the expansion of emerging economies present the current challenges to UK manufacturing sectors.

Yet where there are challenges there are also opportunities (Board 2008). Knowledge has long been known as a vital means of organisational survival and competition (Chan and Chao 2008). This revolution will affect every field in our modern industrialised communities, as the research opportunities (Figure 2.2) and the massive efforts currently on-going will reform and shape the globe and the life style we used to know. Future changing scenario, where more production is required, demand the awareness and adoption of latest technology and processes and only this can ensure an effective role in global value chains (Ahmad et al. 2009).

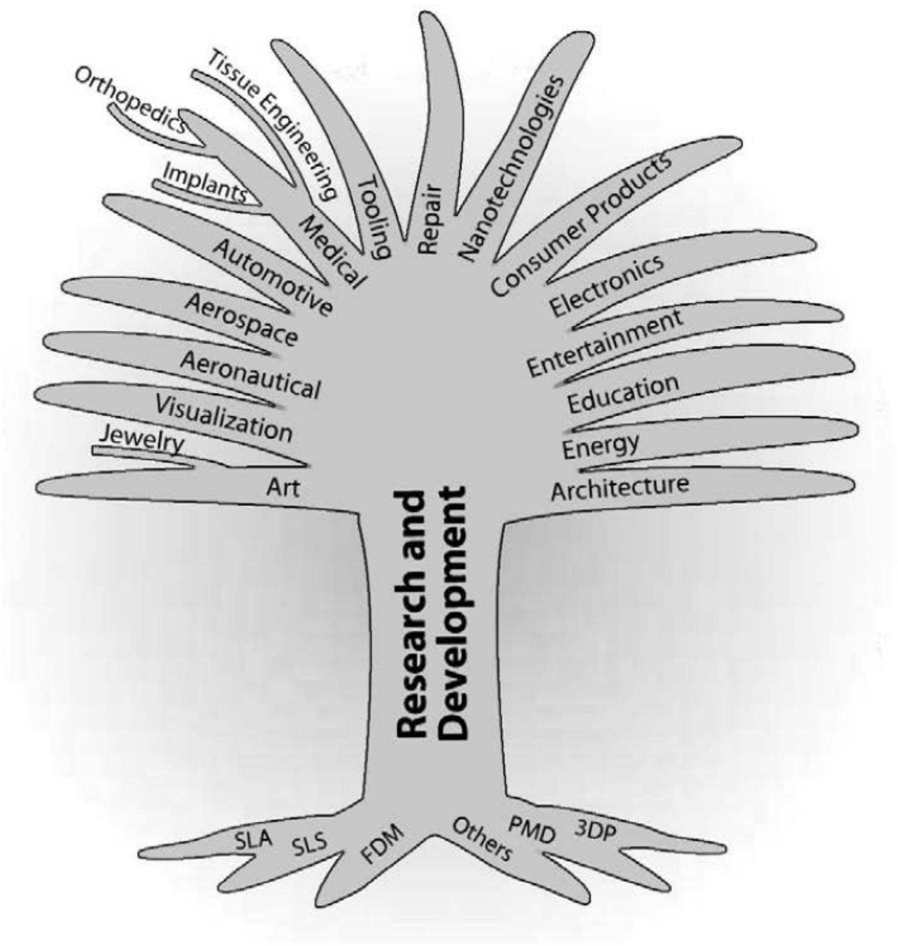

Figure 2.2 Schematic visualisation of the RP field research opportunities

(Source: Bourell et al. 2009)

2.3 Rapid Prototyping Technology Overview

As mentioned earlier, RP technology refers to the construction of a 3-D physical part/product from CAD data by means of layer fabrication devoid of the need for tooling (Figure 2.3). RP is a moderately new technology that was first commercialised by the company 3D Systems in 1987 (Byun and Lee 2005). 3D Systems (USA) was founded in 1986 and originally developed Stereolithography (SLA), which is generally considered to be the earliest RP technique introduced. A wide range of RP techniques have since been developed. RP actually offers great benefits in terms of time and cost reduction as well as improved quality of the final product when used during a product development process (Lan et al. 2005).

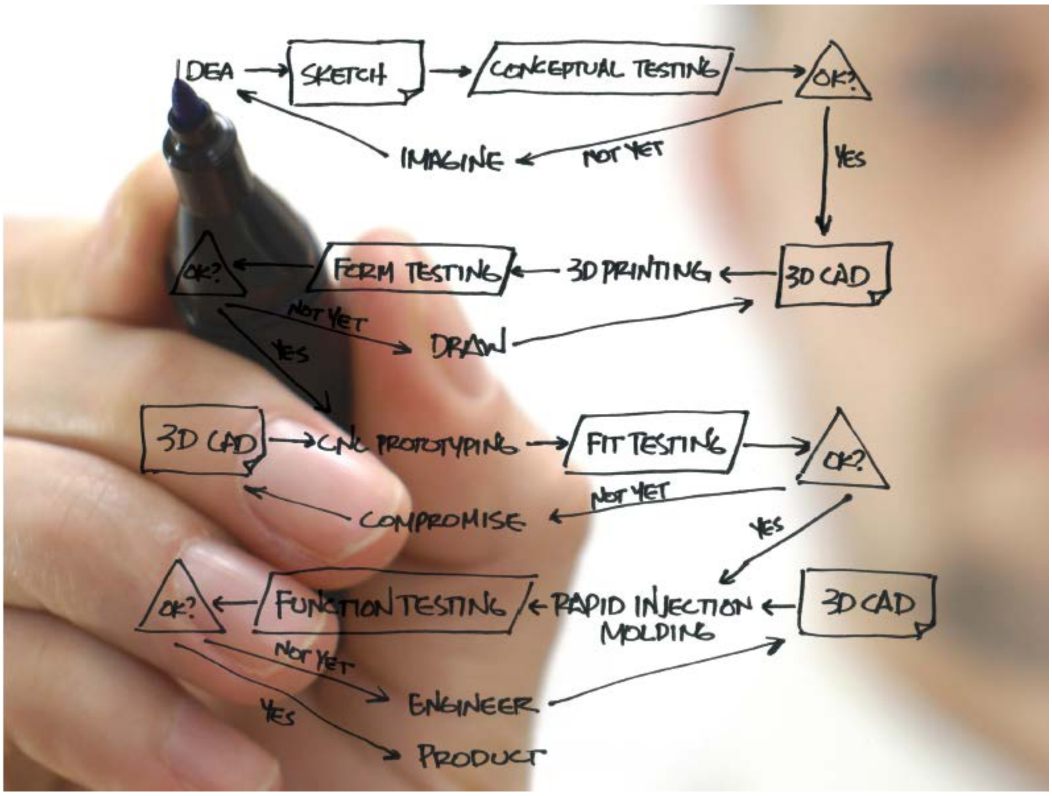

Figure 2.3 Prototyping Process

(Source: Labs 2009)

RP technology was a startling and revolutionary development of the advances made by Computer Aided Design in tandem with Computer Aided Manufacturing. The chronological development from the year of inception is presented in Table 2.1. This historical development illustrates the time when the first computer was introduced to the time when CAD systems were introduced, a period of less than two decades. Similarly, there are two decades between the introduction of the first commercial RP system and the advancements of AM processes and their unlimited applications. Time wise, a pattern of two decades separates each new industrial/manufacturing technological revolution. Therefore, and based on the state-of-the-art AM revolution which is the natural development of the RP technological revolution, there is astonishing potential for new developments in the current decade due to RP technology, which has already been existence for more than 20 years .

Table 2.1 Rapid Prototyping Technology chronological development and related technologies

Year of Inception	Technology
1770	Mechanisation
1946	First computer
1952	First Numerical Control (NC) machine tool
1960	First commercial laser
1961	First commercial Robot
1963	First interactive graphics system (early version of Computer Aided Design)
1988	First commercial Rapid Prototyping system

(Source: Chua et al. 2010)

RP has a clear use as a means for conceptualisation. Moreover, RP technology can be used for testing, such as when an air foil shape is put into a wind tunnel. Likewise for silicone rubber moulds and investment casts, RP prototypes can be utilised to make male models for tooling. At present, final parts can be produced via RP technology; typically the RP materials used not to be sufficiently durable or accurate but this has become a thing of the past for most of these techniques and associated materials.

With regard to the most recently developed RP materials, RP is appropriate and it does offer great possibilities for producing complex shapes such as parts which are nested and contained by other parts. Furthermore, RP technology can also produce complex nested parts using multiple materials with multi colours in the same product. This has led to the emergence of the new terms, Layered manufacturing (LM), Rapid Manufacturing (RM), Solid Free-Form Fabrication (SFF), Rapid Tooling (RT), and most recently Additive Manufacturing (AM) and 3D printing (Bourell et al. 2009; Wohlers 2008; Wohlers 2009, 2010).

2.4 Layered Manufacturing (LM)

During the last 15 years of its life, Layer Manufacturing (LM) technology has developed massively. In the beginning LM was seen as typically appropriate for RP processes to produce prototypes for evaluation, testing and validating new products. LM processes are not exclusively utilised for that purpose only to any further extent, as with the introduction of new developed materials together with new advanced processes, LM technology has applications within all different manufacturing fields (Dimitrov et al. 2006). At the present time, although LM processes are approaching maturity, it is difficult to compare these new developments with traditional ones, such as CNC which is wholly established in the industrial/manufacturing environments (Kerbrat et al. 2010).

2.5 Rapid Manufacturing (RM)

Rapid Manufacturing (RM) is the practice of making use of a computer aided design accompanied by automated additive manufacturing processes to create parts that are used directly as finished components or products (Hopkinson et al. 2006). RM processes are capable of providing any geometry without restriction and any structures with a broad range of material compositions (Direction 2005). RM is being developed from the established RP technologies (Hague et al. 2003).

RP technology is having a reflective influence on the way enterprises create and produce their prototypes, models, parts, products and even tooling components. This influence has been recognised in production, to the extent that some companies now produce final end-user manufactured parts directly through RM processes. Regardless of the absence of fixed standards, RM productiveness promotes development reinforced by users, agents and creators. This practice, termed rapid or additive manufacturing, is emerging and creating stimulating market opportunities. Therefore, the most momentous area of development in this era may turn out to be RM (Freitag et al. 2003; Munguia et al. 2008).

2.6 Additive Manufacturing (AM)

Additive manufacturing (AM) is the process of piecing together materials to create parts from 3D characteristic data, typically layer-by-layer, contrasted with subtractive conventional practices. AM is utilised to construct prototypes, physical models, patterns, tooling mechanisms, and production parts in metal, plastic, and multiple materials. AM systems create objects which can be challenging or problematic to create using any other technique, by means of using thin, horizontal cross-sections from computer-aided design models, medical scanning systems, 3D scanners and video games platforms (Wohlers 2012).

2.7 Rapid Tooling (RT)

More than 20 techniques of Rapid Tooling (RT) have been technologically advanced on a global scale, as a direct response to the increasing demand for more rapid and less costly tooling approaches. RT's market potential has made many enterprises track the improvement and commercialisation of their methods, processes, and systems development (Freitag et al. 2003). Since the inception of RP technology, the manufacturing has been infused with the potential for not only rapidly creating prototypes of new products, but also the development of tooling for manufacturing (Beer et al. 2005). The term RT is normally used to outline a practice which either, makes use of RP technology processes directly to create a tool for a limited volume of products, or uses an RP technology prototype as a pattern from which to fabricate a mould rapidly (Efunda 2010). RT has not been clearly defined or commonly debated as an evolving technology. From the viewpoint of the conventional tool-making industry, the accuracy of RT is still below that which can be achieved through CNC milling. Thus the savings in cost and time at least have to be such that it may compensate for other aspects of the mould/moulded product. If, however, cost, quality and time-wise, the process does not compete with conventional methods of tooling, there will be little motivation for a new paradigm (Beer et al. 2005).

Although conventional methods of tooling are quite well recognised within the industrial and manufacturing environments, Efunda (2010) stated that RT is different from conventional in that “tooling time is much shorter than for a conventional tool. Typically, time to first articles is below one-fifth that of conventional tooling. Tooling cost is much less than for a conventional tool. Cost can be below five per cent of conventional tooling cost. Tool life is considerably less than for a conventional tool. Tolerances are wider than for a conventional tool”.

According to Beer et al. (2005), RT’s aim is to offer the same level of durability and precision or higher when compared to CNC methods. Significant savings in labour and time are being claimed these days by RP technology professionals and service providers, which reflect the enormous improvements that have been accomplished in this field. On the other hand, when comparing RT methods to CNC methods, the technology is not quiet fully formed. This indicates that the tangible benefits cannot be generalised and cases should be assessed on an individual basis. RT methods’ common limitations when compared to CNC at that time were included the following: tools fabricated through RT methods were less precise and less durable; limited part sizes and geometry complexity; parts produced were not identical; and modification and correction was not always easy for tools produced through RT methods.

Brooke (2013) reported that “it seems that although the industry prefers additive manufacturing as the main umbrella term for the technique, 3-D printing has already stirred up so much media interest that it cannot be disassociated with developments at either the maker or the industrial end of the spectrum. And it seems this is not the final time the debate will be revisited regardless of this fact”. Therefore, and based on what has previously been said, it is important to mention that the terms Layer Manufacturing (LM), Rapid Manufacturing (RM), Additive

Manufacturing (AM), and Rapid Tooling (RT) are used interchangeably in this literature to indicate the same cluster of processes, as they all emerged from the same additive formation technology concept of Rapid Prototyping (RP). This is owing to the fact that references are using different terms while referring to RP technology.

2.8 RP Uniqueness

The unique benefit of deploying RP technology in various tangible applications (Figure 2.4) is the reduction of lead time in manufacturing as well as the obvious saving in time-to-market (Vinodh et al. 2009). The distinct value of RP technology can be perceived in the associated advantages (Rao and Padmanabhan 2007), which include: extraordinary design flexibility with operational communication to enable instant object alterations; processing time decrease with saving up to 75%, allowing short-term development time; prototypes created from CAD data files can be produced within hours enabling quick assessment of manufacturability and evaluation of design efficiency; while RP techniques reduce cost by up to 50%, costly mistakes are also reduced; prototypes created through RP technology can be used in consequent manufacturing processes to obtain the end-user parts; rapid tooling fabrication for manufacturing processes; and incorporating required features while reducing redundant features in the early design stages to prolong the product lifetime (Efunda 2010).

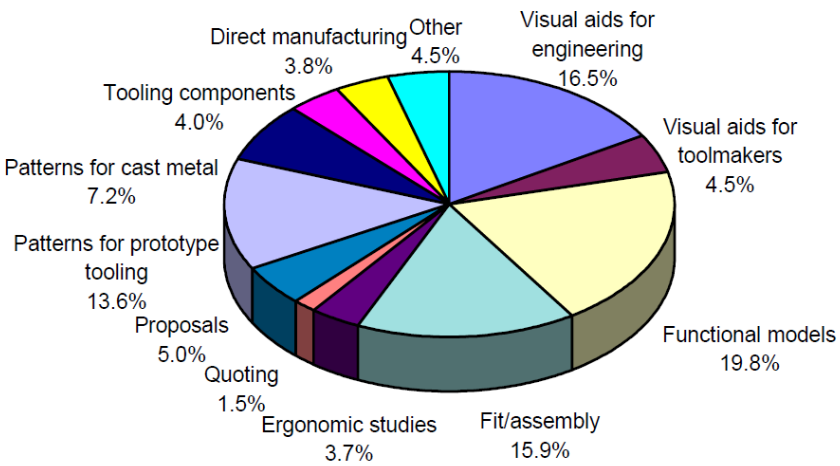

Figure 2.4 Various tangible applications of RP technology
(Source: Wohlers 2002)

As the prices of the RP machinery fall, the use of RP technology goes up and the RP techniques progressively become more popular. As a result, industries now have greater opportunity to deploy RP processes to improve the phases of their product development (Borille et al. 2010). Figure 2.5 shows the industrial usages of RP technology. This is where parts or products are quickly manufactured for use in: motor vehicles; consumer products; business machines; medical applications; academic experiments and presentations; aerospace; government and military, and for many other uses.

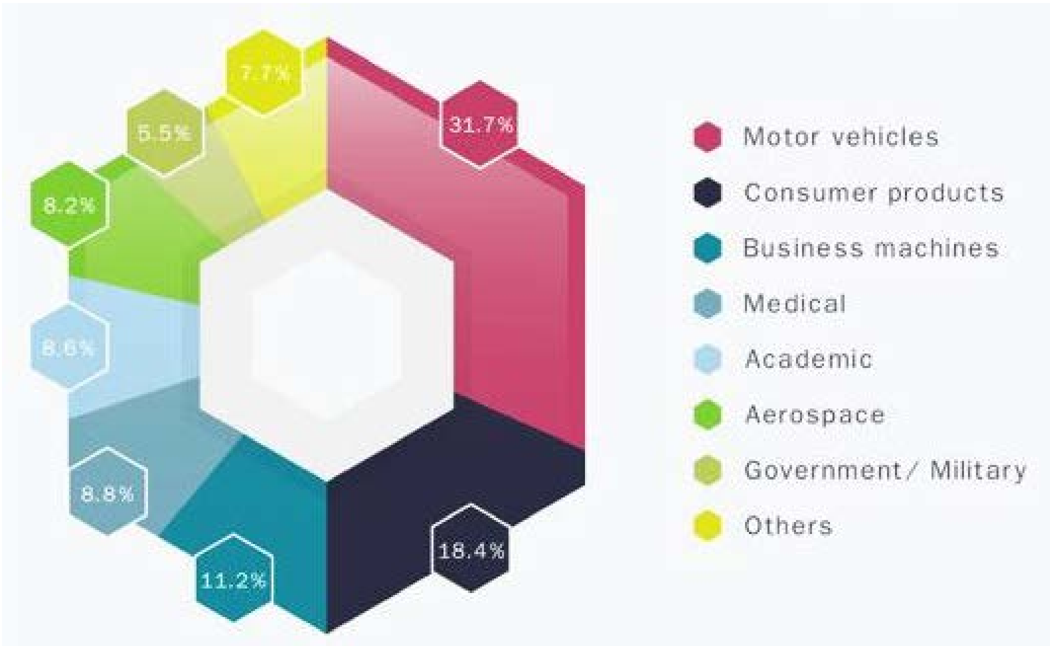

Figure 2.5 Breakdown of world RP usage
(Source: Disrupt3d 2013)

Obviously, ‘rapid’ is a comparative term. RP technology refers mostly to the ‘optimum’ manufacturing existing processes for complex products and small production lots. Depending on the size and complexity of the product geometry, RP prototypes can be built within three to seventy-two hours. This may sound like a long time, but then again it is much quicker than the weeks or months needed to produce the same prototypes by means of conventional manufacturing processes such as CNC machining. These significant time savings enable manufacturers to take their products to market faster and more competitively quality/price-wise (Goda 2008).

RP technology provides unique competences that traditional manufacturing processes cannot compete with, owing to the enormous revolution that it has triggered in product development cycles. Now it is impacting upon the concrete manufacturing of all products, as well as prototyping and modelling applications. Customisation, advances in product quality, multi-functionality, and much lower overall development budgets are all clear examples of how significant the impact of RP technology can be. Businesses of all sizes are investigating how RP technology may be used to strengthen their companies and open up new opportunities (Wohlers 2009). Figure 2.6 displays the percentage of parts production within businesses worldwide using AM technology.

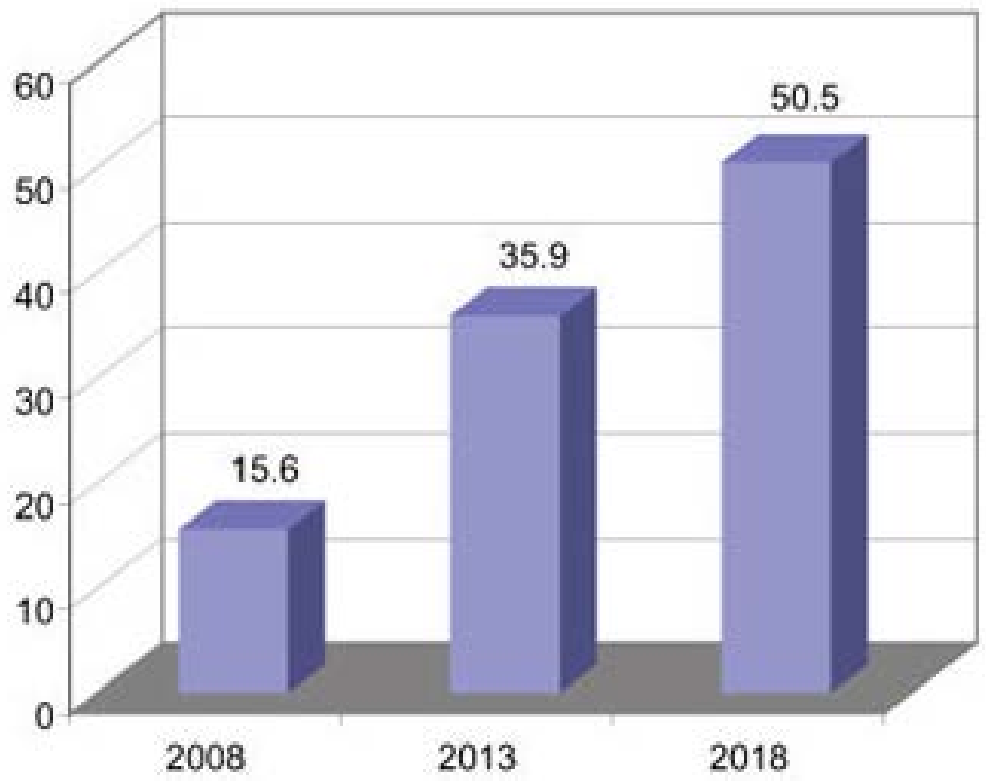

Figure 2.6 Percentage of parts production within businesses worldwide using AM technology

(Source: Wohlers 2010)

One more unique feature of RP technology is the integration of both technology and management for quickly responding to the vigorous demands of customers (Vinodh et al. 2009). According to Bourell et al. (2009) AM unique competences mainly include:

- Complex Form: AM technology has the potential to create almost any form. This includes hierarchical structures and complex cellular constructions, in addition to customised parts, enhanced material composites, 1-off products, and integration and assembly of objects.

- Tailored material properties: AM technology enabled the production of products with composite material configurations and proposed properties that can be created layer-by-layer.

- Multipart functionality: AM technology made embedding components such as sensors, hardware, and actuators possible while creating functioning kinematic joints, and depositing conductive materials, that have enabled the creation of functional devices in one process.

RP technology continues to grow owing to more than two decades of research and development motivated by the emerging new machineries, techniques, and applications. Moreover, there has been a rapid increase in the countries embracing RP technology. Figure 2.7 shows the countries deploying AM technologies worldwide. In the years to come, the impact of additive processes will assume greater consequence in the up-to-date remarkable influence on design and manufacturing (Wohlers 2010). AM has constructed a strategic link between the completed design and manufacturing tooling so that products can be delivered to end-users more quickly and efficiently. Even for relatively large production batches, some corporations will find that AM technology will shortly become the manufacturing process of choice (Bourell et al. 2009).

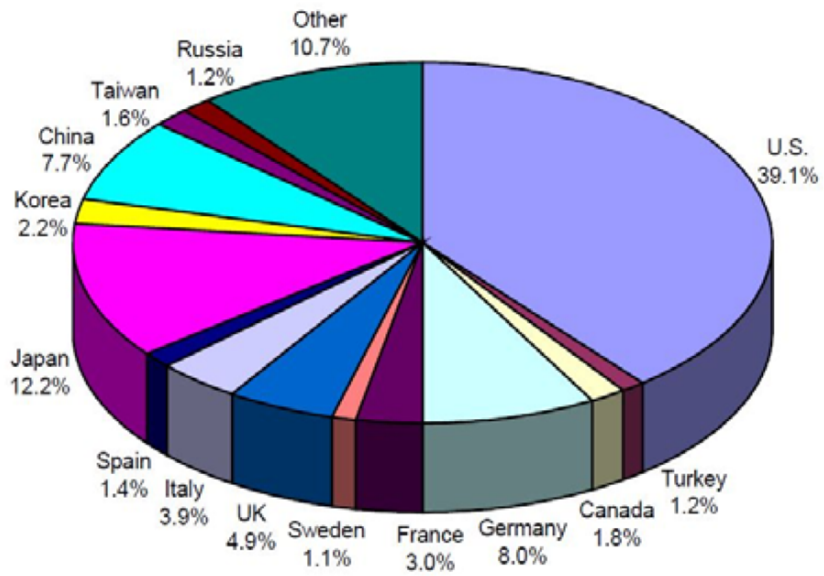

Figure 2.7 Countries that have deployed AM technologies
(Source: Wohlers 2010)

What makes RP technology potentially so compelling is that it cuts across a large number of industries and applications. Consumer products, automotive, aerospace, and medical are employing AM technology for future advances. Huge amounts of research, development and investment within those main industries are boosting AM technology to new heights. Figure 2.8 illustrates AM products and service revenues for 2009 and 2010. Further contributions to AM technology future advances will be through industries including dentistry, the military, ornaments, construction, electronic games and toys, souvenirs, furniture and building fixtures. The products created by AM technology are the early versions of customised-products, new trends and/or one of its kind items. AM applications will include, marine equipment, defence assemblies, means of transportation, and fittings, amongst many others. In addition, there will be those which were previously thought impossible due to cost issues, safety difficulties, or even lack of manufacturability (Bourell et al. 2009).

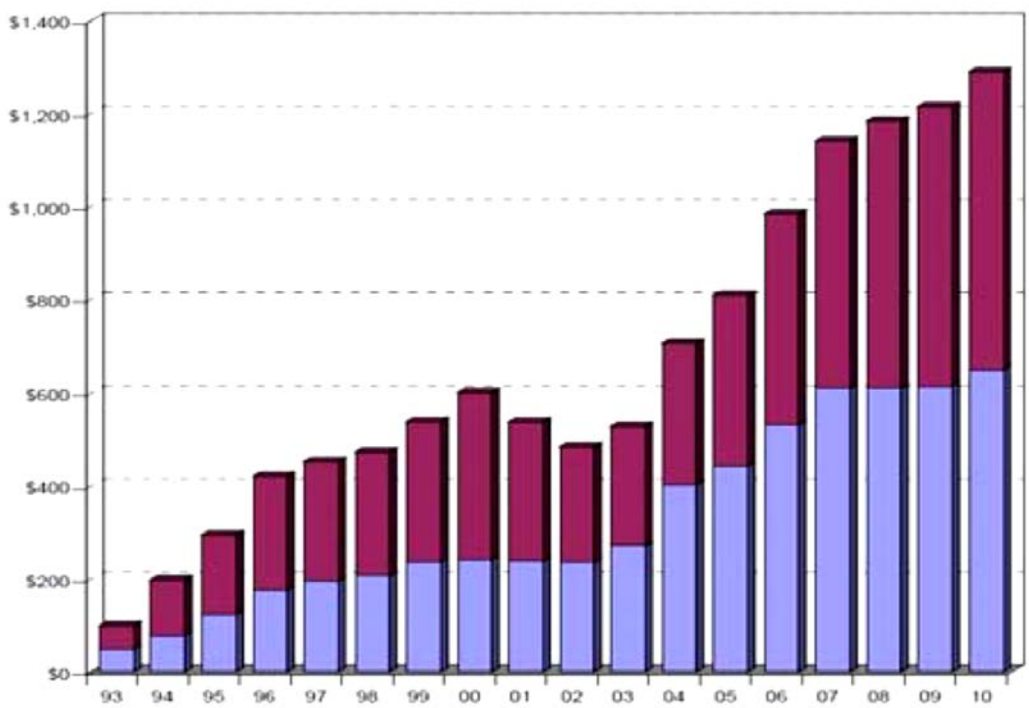

Figure 2.8 Revenues (in millions of dollars) for AM products and services worldwide; the bars for 2009 and 2010
(Source: Wohlers 2009)

Bourell et al. (2009) reported that the next-generation of AM technology processes must fully demonstrate their incorporation of sustainability principles; that they must include a reduction in manufacturing and materials costs, energy use, industrial waste, toxic and hazardous materials and adverse environmental effects. In addition to these improvements is a requirement to safeguard the health of the workforce, and also that products made by AM technology must adhere to established reusability, recyclability, recoverability, and disposability standards.

2.9 RP Universal Process

Figure 2.9 shows the universal process model adopted by RP techniques, as all RP systems are of a similar nature. Overall, five stages are involved in the process model; these stages in order are 3-D modelling followed by data file conversion and transmission, where a CAD model is created and to avoid the stair stepping with minimising the resolution, it is converted to STL format. At that time the checking and preparing stage starts, where the RP software checks and processes the STL file to create sliced-layers of the object being prepared for fabrication.

Finally creating and post processing the fabricated objects or parts where the fabrication process starts with creating the first layer of the physical object, and then the object is lowered by the thickness of the next layer while repeating the same process up until the object is completed. Then the fabricated object/part is removed with any support material, for cleaning and finishing processes. The processes in steps 3 and 5 may be repeated iteratively, until an acceptable part or object is produced, and depending on the number of parts required (Chua et al. 2003).

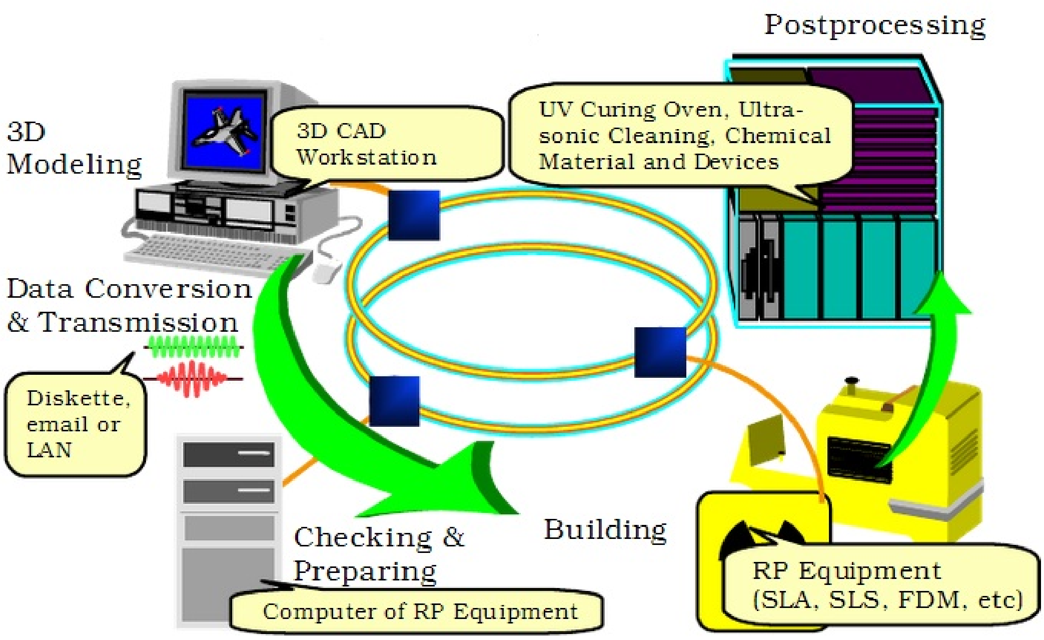

Figure 2.9 General RP process model
(Source: Chua et al. 2010)

2.10 RP Systems

RP technology includes a group of different techniques, although all of these techniques are additive fabrication methods. Figure 2.10 shows the most widespread systems, which are described in the following section of this chapter.

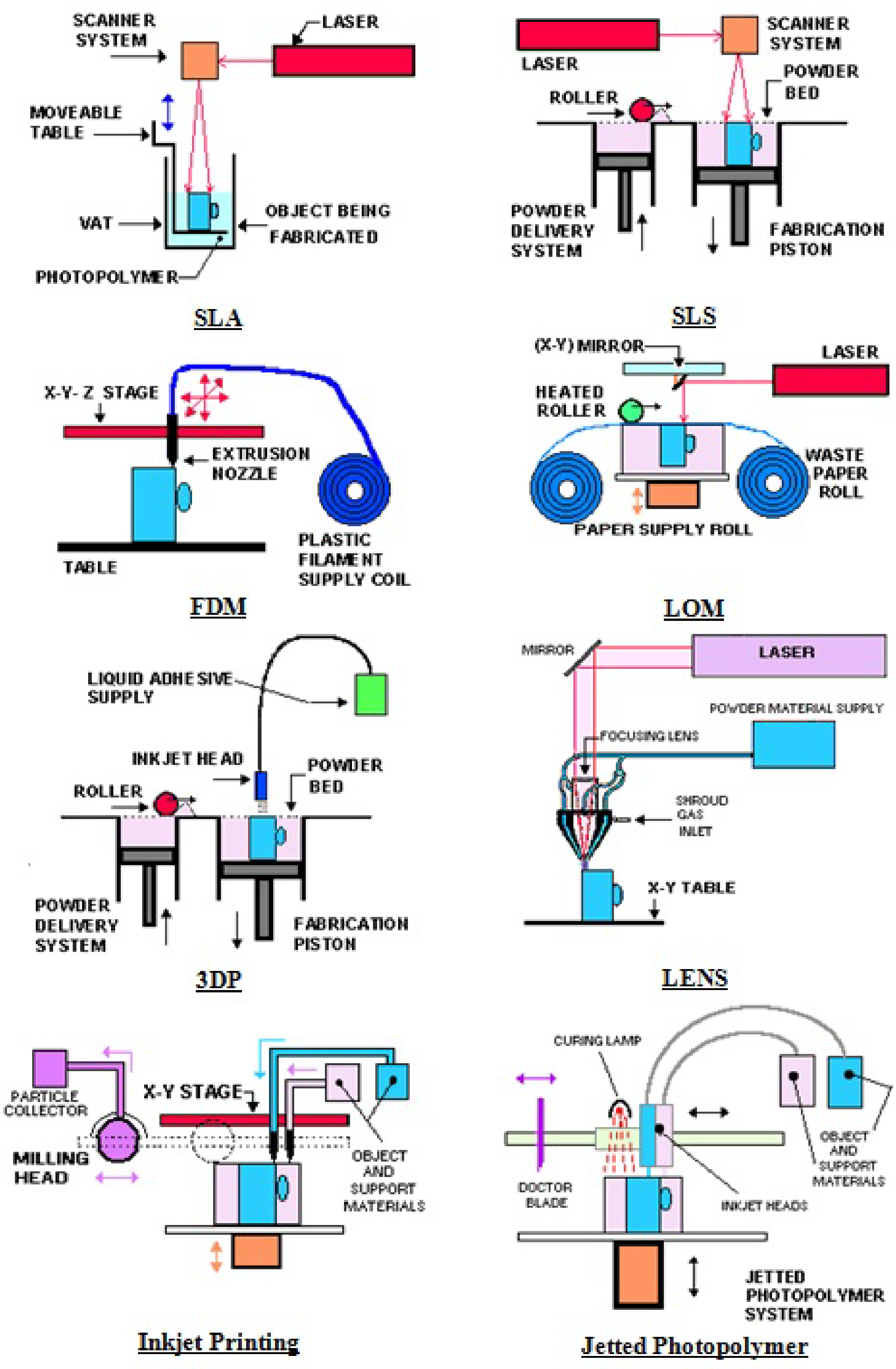

Figure 2.10 RP widespread systems

2.10.1 Stereolithography (SLA)

Since it can create very precise and detailed polymer objects, Stereolithography (SLA) is the most extensively utilised RP technology system. SLA was the earliest RP system, invented by Charles Hull and announced by 3D Systems, Inc. in 1988 (Custompartnet 2008).

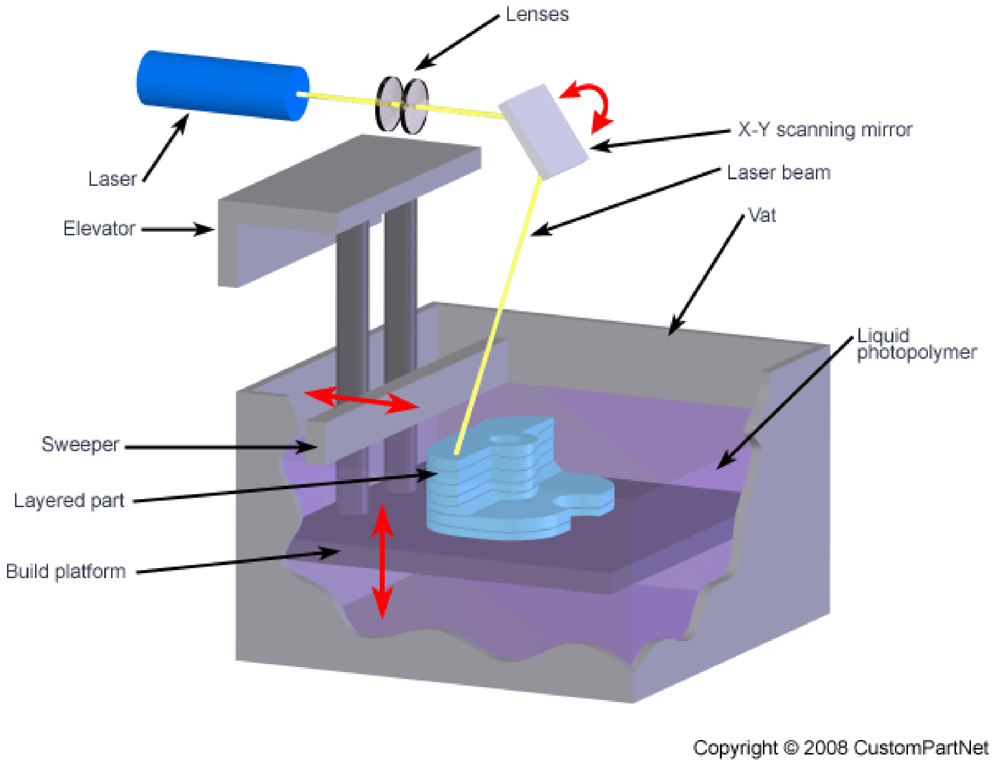

Figure 2.11 SLA process systems
(Source: Custompartnet 2008)

Chua et al. (2003, p.42) described the SLA process as follows: "the process begins with the vat filled with the photo-curable liquid resin and the elevator table set just below the surface of the liquid resin (Figure 2.11). The operator loads a three-dimensional CAD solid model file into the system. Supports are designed to stabilise the part during building. The translator converts the CAD data into a STL file. The control unit slices the model and support into a series of cross sections from 0.025 to 0.5 mm (0.001 to 0.020 in) thick. The computer-controlled optical scanning system then directs and focuses the laser beam so that it solidifies a two-dimensional cross-section corresponding to the slice on the surface of the photo-curable liquid resin to a depth greater than one layer thickness. The elevator table then drops enough to cover the solid polymer with another layer of the liquid resin. A levelling wiper or vacuum blade moves across the surfaces to recoat the next layer of resin on the surface. The laser then draws the next layer. This process continues building the part from bottom up, until the system completes the part. The part is then raised out of the vat and cleaned of excess polymer". Based on the final fabricated part, in some cases a final cure may be needed, where the part will be placed in a UV oven. Subsequently, supports are removed and surfaces are finished.

2.10.2 Fused Deposition Modelling (FDM)

The Fused Deposition Modelling (FDM) process was developed by S. Scott Crump in Eden Prairie, Minnesota. It was first technologically advanced in the late 1980s and was commercialised and introduced in 1990 by Stratasys. FDM is the second most commonly used RP technology after SLA, and is broadly used for prototyping, modelling, and manufacture applications (Custompartnet 2008).

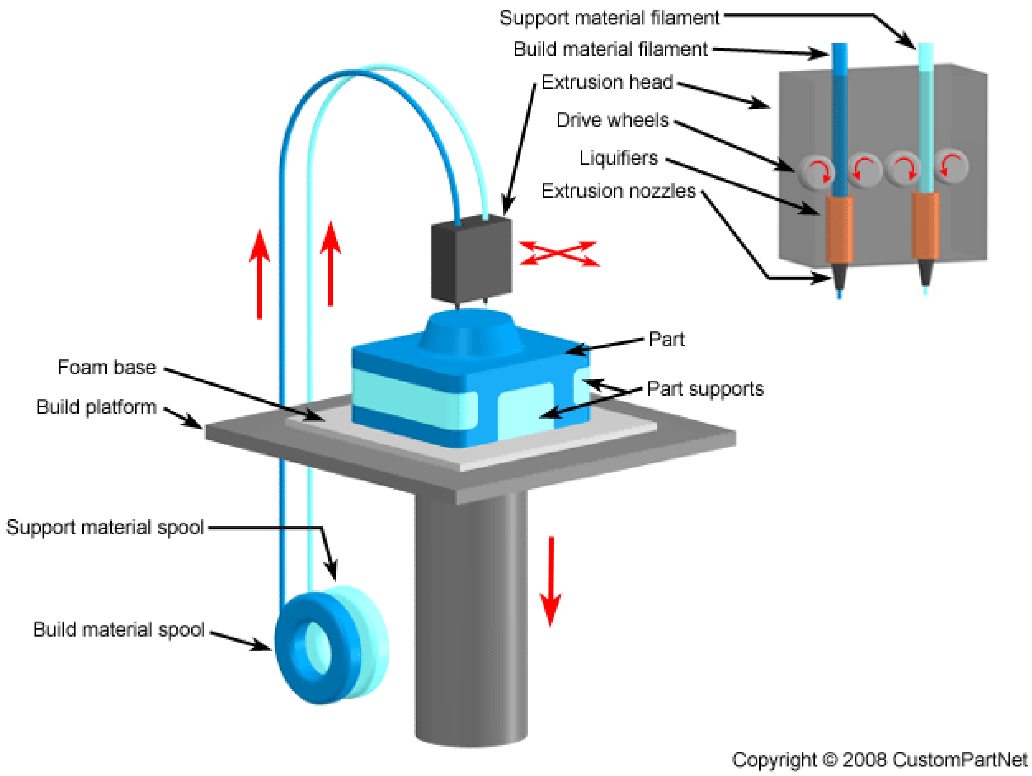

Figure 2.12 FDM process systems
(Source: Custompartnet 2008)

Chua et al. (2003, p.114) described the FDM system as follows: “the CAD file is sliced into horizontal layers after the part is oriented for the optimum build position, and any necessary support structures are automatically detected and generated. The slice thickness can be set manually to anywhere between 0.172 to 0.356 mm (0.005 to 0.014 in) depending on the needs of the models. Tool paths of the build process are then generated which are downloaded to the FDM machine. The modelling material is in spoolsvery much like a fishing line. The filament on the spools is fed into an extrusion head and heated to a semi-liquid state. The semi-liquid material is extruded through the head and then deposited in ultra-thin layers from the FDM head, one layer at a time. Since the air surrounding the head is maintained at a temperature below the materials’melting point, the exiting material quickly solidifies. Moving on theX–Y plane, the head follows the tool path generated by Quick Slice®or Insight generating the desired layer. When the layer is completed, the head moves on to create the next layer. The horizontal width of the extruded material can vary between 0.250 to 0.965 mm depending on model. This feature, called‘road width’, can vary from slice to slice. Two modeller materials are dispensed through a dual tip mechanism in the FDM machine. A primary modeller material is used to produce the model geometry and a secondary material, or release material, is used to produce the support structures (Figure 2.12). The release material forms a bond with the primary modeller material and can be washed away upon completion of the 3-D models”.

2.10.3 Selective Laser Sintering (SLS®)

At the University of Texas in Austin, USA, Carl Deckard and colleagues technologically advanced the Selective Laser Sintering (SLS®) system. The SLS® technology process was patented in 1989 and was eventually sold by DTM Corporation. However, in 2001, 3D Systems purchased DTM Corporation (Custompartnet 2008).

Chua et al. (2003, p.175) described the SLS® process as follows: “the STL file format are first transferred to the Vanguard™ system where they are sliced. From this point, the SLS® process (Figure 2.13) starts and operates as follows: (1) a thin layer of heat-fusible powder is deposited onto the part-building chamber;

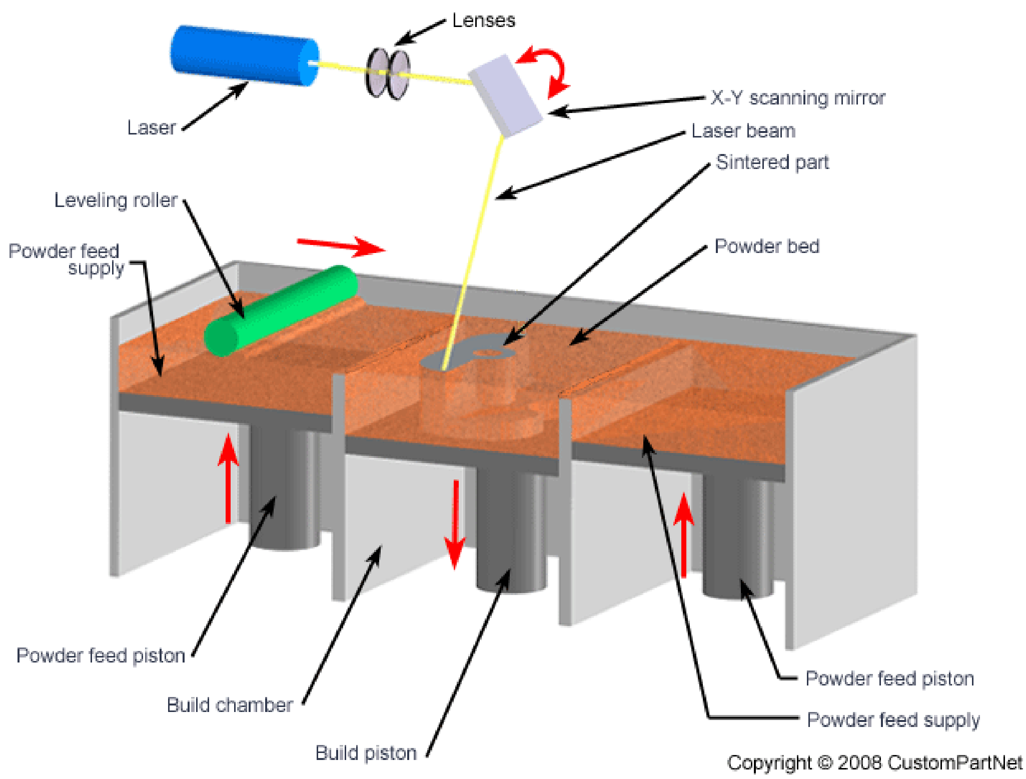

Figure 2.13 SLS® process systems

(Source: Custompartnet 2008)

(2) The bottom-most cross-sectional slice of the CAD part under fabrication is selectively “drawn” (or scanned) on the layer of powder by a heat-generating CO2 laser. The interaction of the laser beam with the powder elevates the temperature to the point of melting, fusing the powder particles to form a solid mass. The intensity of the laser beam is modulated to melt the powder only in areas defined by the part’s geometry. Surrounding powder remains a loose compact and serves as supports; (3) when the cross-section is completely drawn; an additional layer of powder is deposited via a roller mechanism on top of the previously scanned layer. This prepares the next layer for scanning; (4) Steps 2 and 3 are repeated, with each layer fusing to the layer below it. Successive layers of powder are deposited and the process is repeated until the part is completed. As SLS® materials are in powdered form, the powder not melted or fused during processing serves as a customized, built-in support”.

2.10.4 Laminated Object Manufacturing (LOM)

The Laminated Object Manufacturing (LOM) system was invented by Michael Feygin in 1985, and was developed by Helisys of Torrance, CA. LOM was originally commercialised in 1991 (Custompartnet 2008).

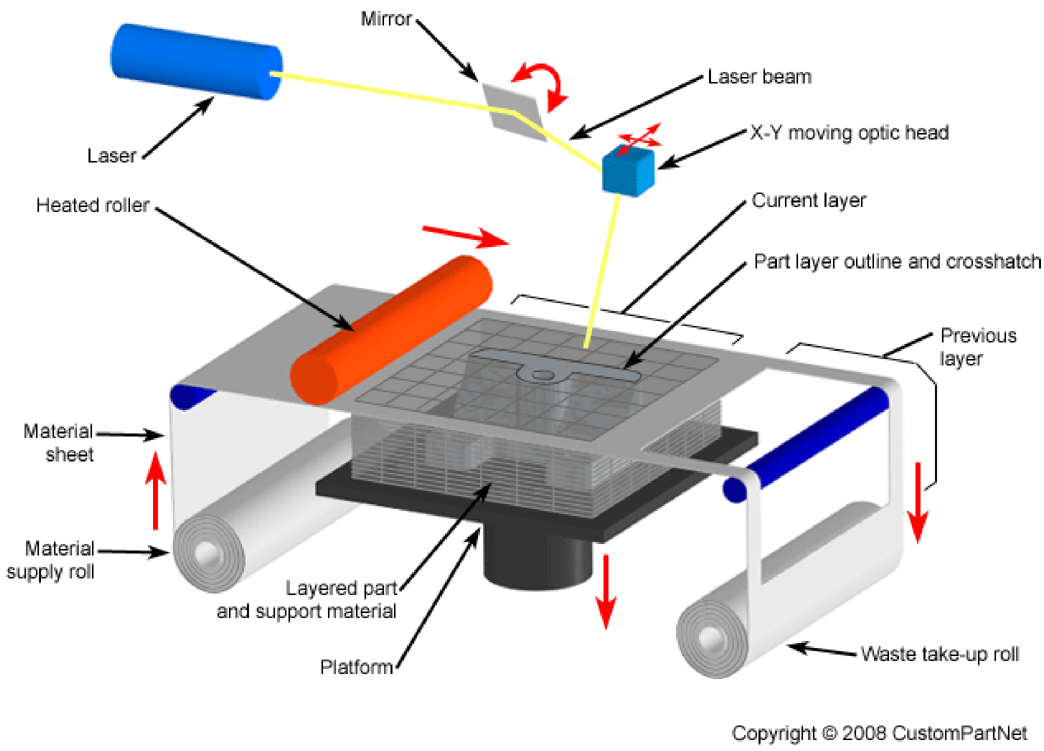

Figure 2.14 LOM process systems

(Source: Custompartnet 2008)

Chua et al. (2003, p.138) described the LOM process as follows: "in the building phase, thin layers of adhesive-coated material are sequentially bonded to each other and individually cut by a CO2 laser beam (Figure 2.14). The build cycle has the following steps: (1) LOMSlice™ creates a cross-section of the 3-D model measuring the exact height of the model and slices the horizontal plane accordingly. The software then images crosshatches which define the outer perimeter and convert these excess materials into a support structure. (2) The computer generates precise calculations, which guide the focused laser beam to cut the cross-sectional outline, the cross-hatches, and the model's perimeter. The laser beam power is designed to cut exactly the thickness of one layer of material at a time. After the perimeter is burned, everything within the model's boundary is "freed" from the remaining sheet. (3) The platform with the stack of previously formed layers descends and a new section of material advances. The platform ascends and the heated roller laminates the material to the stack with a single reciprocal motion, thereby bonding it to the previous layer. (4) The vertical encoder measures the height of the stack and relays the new height to LOMSlice™, which calculates the cross section for the next layer as the laser cuts the model's current layer. This sequence continues until all the layers are built. The product emerges from the LOM™ machine as a completely enclosed rectangular block containing the part".

2.10.5 Three Dimensional Printing (3DP)

In the late 1980s, at the Massachusetts Institute of Technology (MIT), Three Dimensional Printing technology was developed, normally referred to by the abbreviation 3DP, and licensed to a number of corporations such as Soligen Corporation and Extrude Hone (Custompartnet 2008).

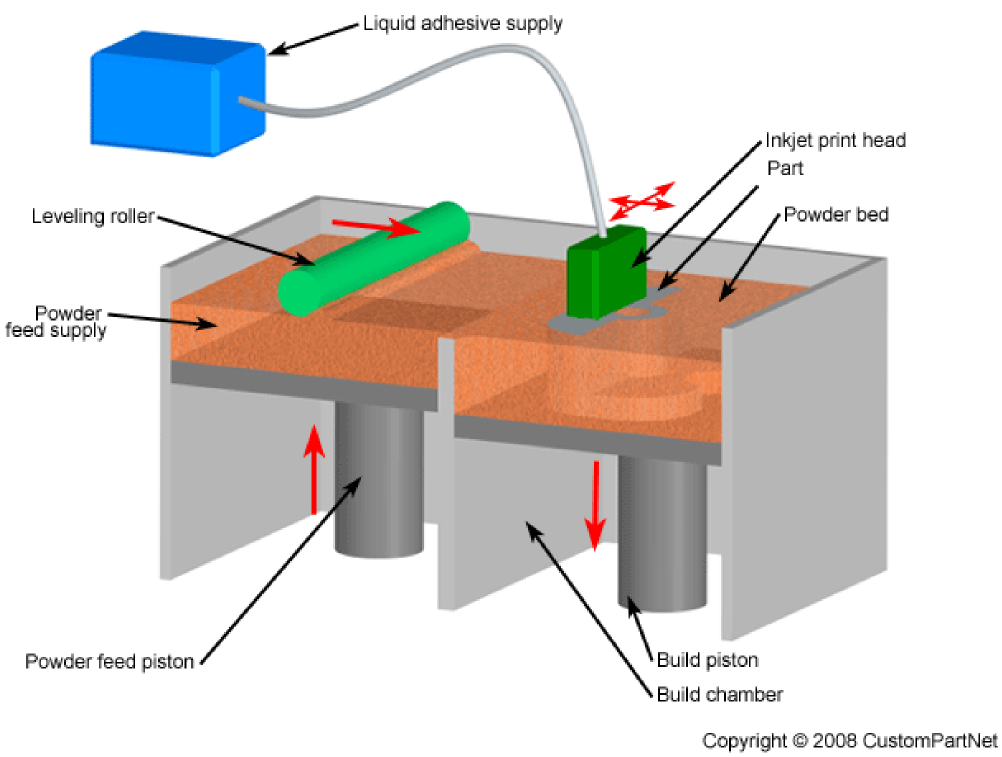

Figure 2.15 3DP process systems

(Source: Custompartnet 2008)

3DP is similar to the SLS® system, but an ink-jet printing head deposits a liquid adhesive that binds the material as a replacement for using a laser to sinter the material (Custompartnet 2008).

Chua et al. (2003, p.197) described the 3DP process as follows: “(1) the machine spreads a layer of powder from the feed box to cover the surface of the build piston. The printer then prints binder solution onto the loose powder, forming the first cross-section. For monochrome parts, Z406 colour printer uses all four print heads to print a single-coloured binder. For multi-coloured parts, each of the four print heads deposits a different colour binder, mixing the four colour binders to produce a spectrum of colours that can be applied to different regions of a part. (2) The powder is glued together at where the binder is printed. The remaining powder remains loose and supports the layers that will be printed above. (3) When the cross-section is completed, the build piston is lowered, anew layer of powder is spread over its surface, and the process is repeated. The part grows layer by layer in the build piston until the part is completed, completely surrounded and covered by loose powder. Finally the build piston is raised and the loose powder is vacuumed, revealing the complete part. (4) Once a build is completed, the excess powder is vacuumed and the parts are lifted from the bed. Once removed, parts can be finished in a variety of ways to suit your needs. For a quick design review, parts can be left raw or “green”. To quickly produce a more robust model, parts can be dipped in wax. For a robust model that can be sanded, finished and painted, the part can be infiltrated with a resin or urethane”.

2.10.6 Inkjet Printing

Inkjet printing is a technique of additive fabrication systems; it is grounded on the 2-D printing method of using a jet to deposit small drops of ink on paper. In the inkjet printing process, thermoplastic and wax materials are used in a melted state as a replacement for the ink. The inkjet process is usually referred to as ‘thermal phase change inkjet printing’, as while printing, the material melted drops instantaneously cool and harden to create a layer of the object (Figure 2.16). This basic technique was used by some systems developers resulting in different inkjet printing devices. For instance, the Model Maker (MM) developed by Solid scape

Inc., and Multi Jet Modelling (MJM) technology in the Thermo Jet Modeller machines developed by 3D Systems (Custompartnet 2008). Singh et al. (2010, p.673) described the 3DP process as follows: “The process essentially involves the ejection of a fixed quantity of ink in a chamber, from a nozzle through a sudden, quasi-adiabatic reduction of the chamber volume via piezoelectric action. A chamber filled with liquid is contracted in response to application of an external voltage. This sudden reduction sets up a shockwave in the liquid, which causes a liquid drop to eject from the nozzle. The ejected drop falls under action of gravity and air resistance until it impinges on the substrate, spreads under momentum acquired in the motion, and surface tension aided flow along the surface. The drop then dries through solvent evaporation. Recent studies show that drop spreading and the final printed shape strongly depend on the viscosity, which in turn is a function of the molar mass of the polymer. More interestingly, the aforementioned group also found a printing height dependence of the final dried-drop diameter, which was a function of the polymer concentration”.

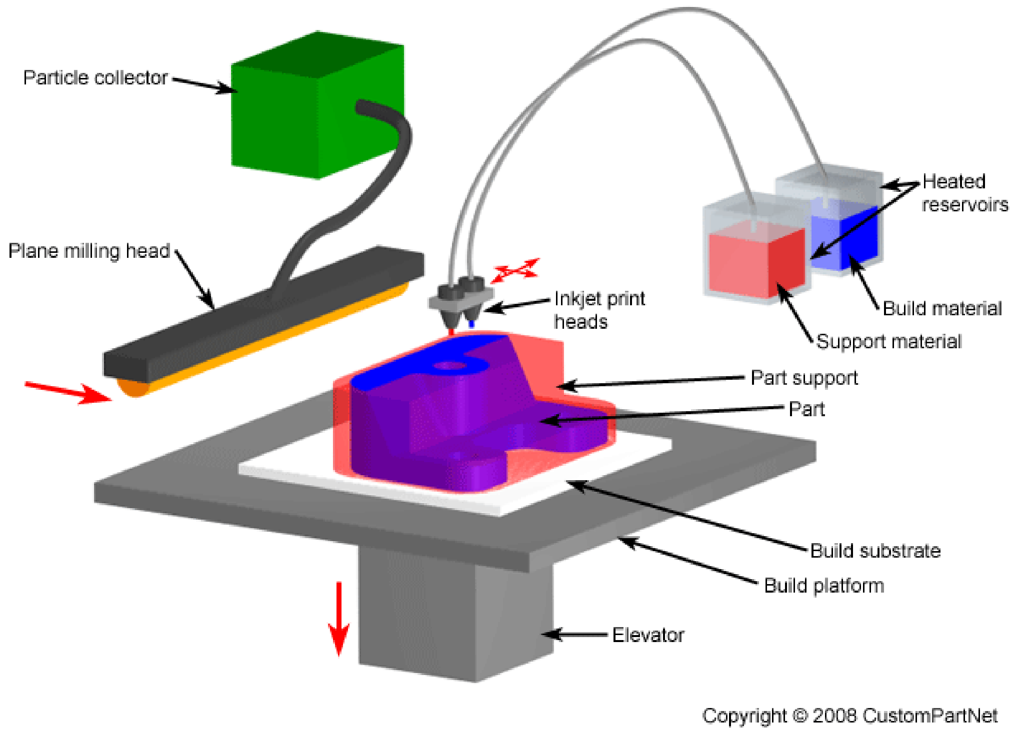

Figure 2.16 Inkjet Printing process systems
(Source: Custompartnet 2008)

2.10.7 Jetted Photopolymer

By means of combining the techniques used in Inkjet Printing and SLA methods, Jetted photopolymer is an additive system that benefits equally from both techniques. The way of fabricating, respectively, is analogous to Inkjet Printing, as it uses an array of inkjet print-heads to deposit small droplets of both build and support materials to create every single layer of an object. On the other hand, a liquid acrylate-based photopolymer is used in SLA as the build material that is cured by a UV source once a layer is placed (Figure 2.17). Therefore, the term 'Photopolymer Inkjet Printing' is frequently used to refer to Jetted Photopolymer (Custompartnet 2008).

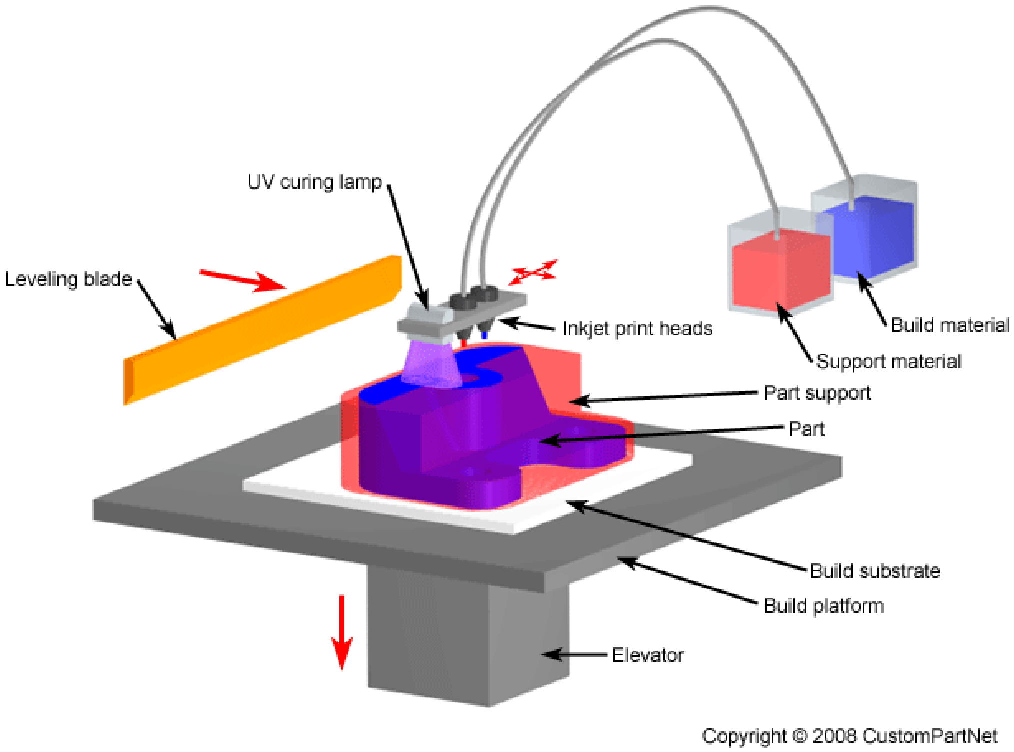

Figure 2.17 Jetted Photopolymer process systems
(Source: Custompartnet 2008)

Barclift and Williams (2012, p.876) described the 3DP process as follows: "During printing, the print-block moves along the X-axis and deposits material in two back-and-forth translations (which constitutes a full "pass"). Jetting occurs only in the first forward translation; the remaining translations are solely to complete polymer curing. After completing a full pass, printing continues in the next printing "path" along the Y-axis of the build tray. The extents of each printing path are defined by the width of the print-heads. As translation between printing paths is a process bottleneck, the process's CAM interface automatically places parts in the build tray such that the longest dimensions are aligned along the X-axis, near the print origin".

2.10.8 Laser Engineered Net Shaping (LENS®)

Engineered Net Shaping (LENS®) is a technology in which a metal powder is injected into a molten pool created by a focused, high-powered laser beam. The LENS® method is similar to SLS®, the main variance being the technique of powder supply. LENS® was developed by Sandia National Laboratories and can create metal objects directly from a 3-D CAD model (Palčič et al. 2009).

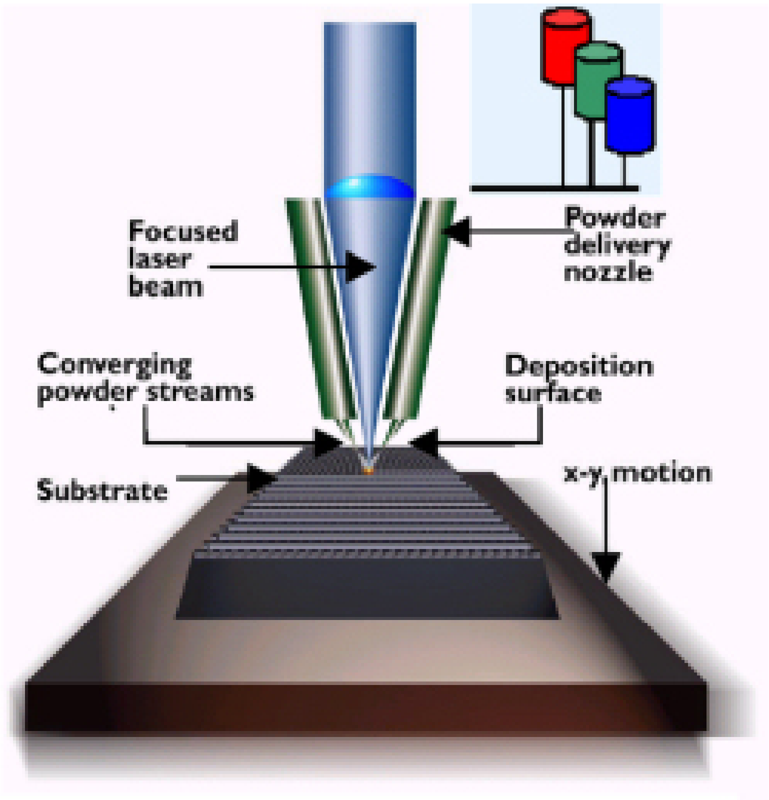

Figure 2.18 LENS® process systems
(Source: Mudge and Wald 2007)

Chua et al. (2003, p.204) described the LENS® process as follows: “The LENS™ process builds components in an additive manner from powdered metals using a Nd:YAG laser to fuse powder to a solid (Figure 2.18). It is a freeform metal fabrication process in which a fully dense metal component is formed. The LENS™ process comprises of the following steps: (1) A deposition head supplies metal powder to the focus of a high powered Nd:YAG laser beam to be melted. This laser is typically directed by fibre optics or precision angled mirrors. (2) The laser is focused on a particular spot by a series of lenses, and a motion system underneath the platform moves horizontally and laterally as the laser beam traces the cross-section of the part being produced. The fabrication process takes place in a low-pressure argon chamber for oxygen-free operation in the melting zone, ensuring that good adhesion is accomplished. (3) When a layer is completed, the deposition head moves up and continues with the next layer. The process is repeated layer by layer until the part is completed. The entire process is usually enclosed to isolate the process from the atmosphere. Generally the prototypes need additional finishing, but are fully dense products with good grain formation”.

2.11 RP Processes vs. Conventional Processes

Since the late twentieth century, the conventional manufacturing processes of casting/moulding, removal and formation methods (Figure 2.19) have been insufficiently flexible to meet all demands in the increasingly competitive manufacturing market. This globalised economy, has required custom-made and flexible fabrication methods. Simultaneously, CAD, laser, numerical control, and material technologies have been rapidly developing (Yan et al. 2009). During this fast state of development, RP technology emerged to introduce processes that produce models, prototypes, and tooling components from 3-D CAD data, Computer Tomography (CT), Magnetic Resonance Imaging (MRI) scan data, and data created from 3-D software programmes.

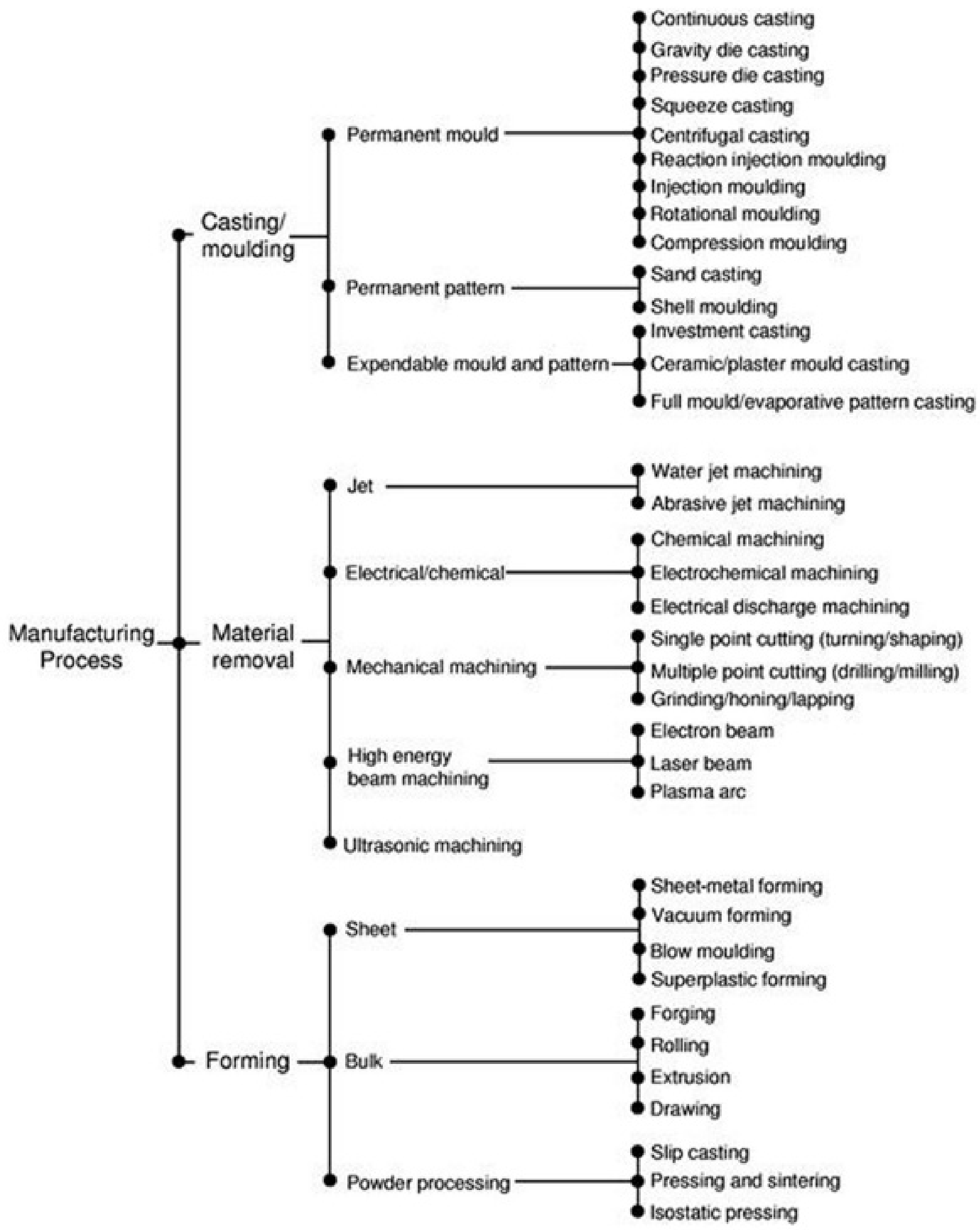

Figure 2.19 General classification of conventional manufacturing processes

(Source: Swift and Booker 2013)

With this additive methodology for fabricating objects, RP processes create parts from liquid, powder and solid form materials (Figure 2.20) or even composite liquid, powder and solid materials to form physical objects. RP systems build from plastic, wood, ceramic, metal, and composite materials (Freitag et al. 2003).

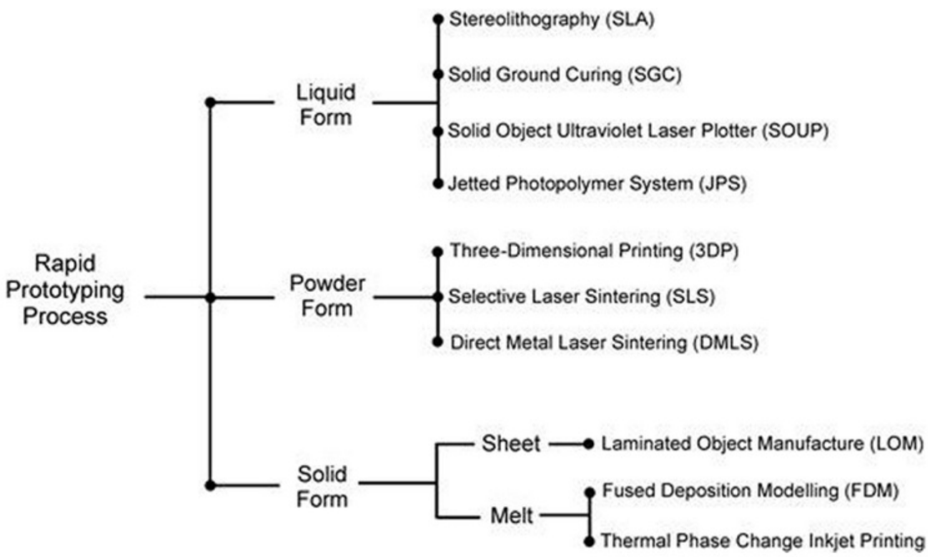

Figure 2.20 General classification of RP processes

(Source: Swift and Booker 2013)

Hence, it is sometimes advantageous to compare RP to conventional manufacturing processes to make inroads in introducing RP technology. RP technology allows designs to be modified with a minimum of production line changes when compared to conventional production methods. RP technologies will help in developing the high-speed formation and moulding of manufacturing and production components for generations to come (Bourell et al. 2009). Table 2.21 shows the benefits of using RP technology in comparison with CNC and conventional manufacturing processes.

Table 2.2 Conventional, CNC, and RP construction methods comparison (Source: Patilet al. 2012)

Variables	Conventional	CNC Machining	Rapid Prototyping
Forming process	Subtractive manufacturing process which requires skills, various tools, jigs & fixtures	Subtractive manufacturing process which may also require programming skills	Additive manufacturing process without much human intervention or tooling
Operations	Single operation only can be performed at a time	Simultaneous operations on the parts are restricted	Multiple operations are integrated in the part building process
Post-Operations	Secondary or tertiary machining operations are required depending on the complexity of the product	Secondary machining operations are required complete a part fabrication.	Secondary operations are not required as fine shaped product is obtained.
Tools	Different types of cutting and finishing tools are required to form specific features and profiles on the part	Different types of cutting and finishing tools are required to form specific features and profiles on the part	No special tools are required
CAD data	CAD model is not required	CNC tool path generation based o on CAD data requires more time to generate a program	Time required to process a CAD data (STL format) for part building is very nominal
Risk factor/error	very high risk factor since there can be manual errors	high risk factor while prototype machining for initial product	Risk factor while prototype building is very less
Integral Features	Integral features within the part cannot be built	Forming integral features within the part are limited	Integral features within the part can be easily built
End product	Single product at a time	Single product at a time	Multiple product/total assembly/multiple assemblies at a time
Operator	Compulsory until the completion of job	Required for programming & feeding the parts to CNC machine	May not be required, best suitable for web based manufacturing
Nature of the product	Only solid product can be obtained	solid & hollow (depending on wall thickness) products can be obtained	solid, hollow (depending on wall thickness) and coarse/sparse product can be obtained

2.12 RP Technology Process Selection

RP technology process selection is a particularly challenging task (Lan et al. 2005). Selection of the appropriate process has become ever more significant, owing to the fast development of RP as well as the enriched product development requirements to satisfy end-users (Rao and Padmanabhan 2007). Early attempts to compare RP systems through benchmarking trials have met with limited success due to the inability of the RP technology sellers to reach a decision on a mutual standard part (Masood and Soo 2002). Other attempts were made to develop and modify decision making approaches, adapting them to handle general RP technology selection cases (Borille et al. 2010). This is just as difficult as for those hiring a service provider to assist them in making the right choice of the most appropriate process; even those individuals with related RP technology knowledge find it challenging as there are numerous RP processes, and the right decision is influenced by many selection criteria (Byun and Lee 2005). Although RP machines are becoming cheaper, to the extent that RP technology is more reachable, the snowballing variety of RP systems and RP service providers creates a problem for users who need to make an appropriate selection (Borille et al. 2010). Every year a number of new RP technology systems are introduced (Lan et al. 2005). Additionally, a great number of factors or selection criteria (for example time, cost, accuracy, building envelop, material type, and surface roughness) which can be either qualitative or quantitative, must be synthetically considered when evaluating and selecting a proper RP system (Lan et al. 2005). Table 2.3 presents a value comparison summary for using FDM versus CNC versus hybrid, through criteria that relate to design and manufacturing to highlight the strengths and weakness of both methods. Every single RP technology system has its own strengths, weaknesses, applications, advantages and limits. It is problematic issue that cannot be resolved simply with statistical methods. Deciding on the suitable RP technology process entails a comprehensive awareness of the relationships between the product quality, material properties, cost, fabrication time and other issues (Byun and Lee 2005).

Furthermore, the explanations and decisions with regard to these criteria are usually verbal and ambiguous (Lan et al. 2005). On the other hand, the most effective approach to profiting from RP technology starts with the appropriate choice of the process, along with the accurate description of user requirements (Borille et al. 2010). This can be made more complex by several secondary processes which are frequently used in tandem with RP technology, and by the common lack of benchmark standards and industrial experience.

Similarly, the deployment of RP technology generally requires extensive alterations to product development practice. The potential improvements which could result of using RP technology, should be thoroughly embedded with the relevant modifications in the development process chain.

Despite this, the RP technology selection process has now been researched for quite some time, and the attention of most researchers has been on developing a new decision making method. A number of these methods are quite complex, often to the extent that users are discouraged from using them (Borille et al. 2010).

Table 2.3 Value comparison summary for FDM, CNC and hybrids
(Source: Townsend and Urbanic 2012)

Criteria that relate to design and manufacturing	Grow product value	Lower resource cost	Alignment with purpose (teleology)				Process comparison		
			Delivery time	Affordability	Quality	Adaptability	AM (FDM)	Hybrid	CNC
Geometric design freedom (9 – most freedom)	√				√	√	9	9	1
Attainable accuracy (9 – most accurate)	√				√		1	9	9
Flexibility (machine availability) (9 –most options)		√	√			√	1	9	1
Raw material cost (9 – least expensive)		√		√			1	5	9
Fabrication time (9 – fastest)		√	√			√	1	5	9
PP time (9 – simplest)		√	√	√		√	9	5	1
Less training required to operate machine (more flexibility in operator work, less specialized knowledge, etc.) (9 – least training)		√		√	√	√	9	5	1
Consistent results (9 – most consistent)	√						5	5	9
Etc	Totals =						36	52	40

2.13 SME Overview

The business world is swiftly moving. Small and Medium sized Enterprises (SMEs) have been pushed into new trends of globalisation to cope with the varying needs of their clients (Marri et al. 2007). Big companies see SMEs as satellites that orbit them seeking profits and possible revenue (Raghunath, 2001). The current age of globalisation should help SMEs retain the capacity to modernise rapidly, to create adequate products and satisfactory services to capture future business opportunities (Dangayach and Deshmukh 2005). Within only five years, 2002-2007, in Europe, the total number of SMEs rose by over 2 million, whilst the total number of large companies increased by only 2000 (Lopriore 2009). SMEs are recognised in manufacturing, industrial and engineering businesses, as well as by academia, as outstanding and leading foundations for the development of services and products (Fossum 2010). A broad range of businesses is covered by SMEs, in which they have a significant mutual role in developed and developing markets (Dangayach and Deshmukh 2005). There are more than 26 million companies in the European Union alone, around 2.5 million of which (approximately 10%) are manufacturing companies, and 99% of this 2.5 million are SMEs (Bititci and Ates 2009). The British are ‘a nation of shopkeepers’, said Napoleon and it is true; Britain is the homeland of SMEs and they are a pillar of its economy (Rowe 2008). The position of manufacturing is optimistic throughout the UK which has encouraged family run business careers in this sector, this promising image reinforcing the important role of SMEs (Fossum 2010).

2.14 SME Definition

SMEs mainly and most commonly are defined globally by their total number of employees or their capital investment or both together (Dangayach and Deshmukh 2005). According to Verheugen (2005), an enterprise is any establishment involved in an economic practice, regardless of its legitimate arrangement. When certified as an enterprise, the information of the enterprise can be recognised in line with the staff headcount, annual turnover, or annual balance sheet (Figure 2.21).

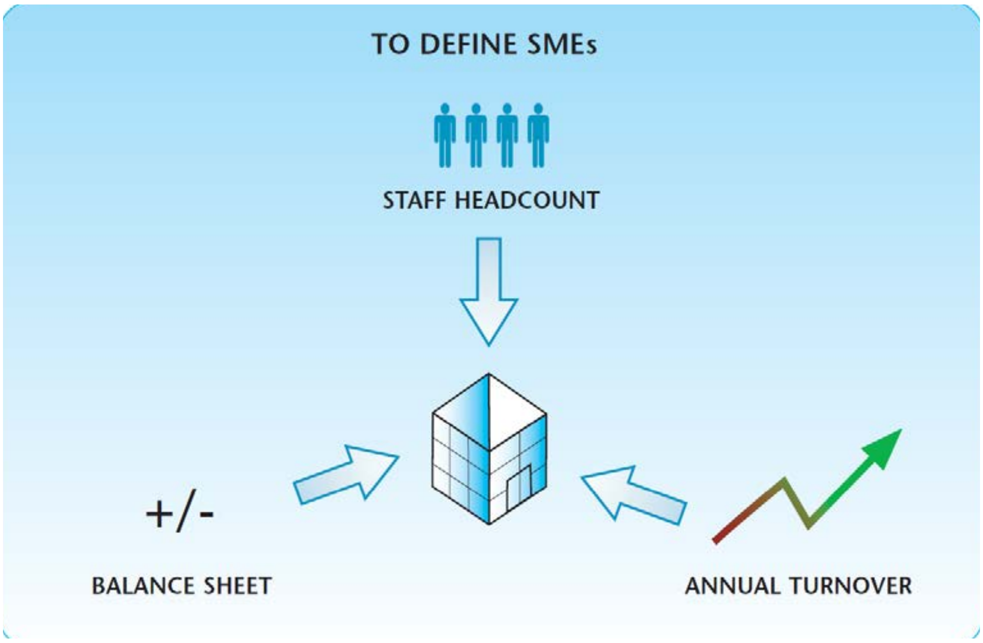

Figure 2.21 SME Definition Criteria

Source: (Verheugen 2005)

The European Union defines such enterprises as those with fewer than 250 employees, less than 25 per cent owned by another company, and which have either an annual gross revenue not greater than 50 million euros, or an annual balance sheet total not greater than 43 million euros (Verheugen 2005). This is the standard classification (Figure 2.22) adopted by the UK government (Cox 2005).

Enterprise category	Headcount: Annual Work Unit (AWU)	Annual turnover	or	Annual balance sheet total
Medium-sized	< 250	≤ €50 million (in 1996 € 40 million)	or	≤ €43 million (in 1996 € 27 million)
Small	< 50	≤ €10 million (in 1996 € 7 million)	or	≤ €10 million (in 1996 €5 million)
Micro	< 10	≤ €2 million (previously not defined)	or	≤ €2 million (previously not defined)

Figure 2.22 SME thresholds

(Source: Verheugen 2005)

2.15 SME Growth

Cox (2005, p.18) stated that "what an 'enterprise economy' requires is not so much more SMEs, but more SMEs that don't want to remain SMEs". Upon start-up, new businesses have a tendency to grow rapidly, but this has a tendency to stop the minute the business has grasped a satisfactory balance. Growth does not take place as a linear regression, but is rather tense with variation and periods of unproductivity (Dobbs and Hamilton 2007). Having simple structures and processes has endowed SMEs with flexibility, direct feedback mechanisms, short decision-making processes, improved consideration and the ability to provide more rapid responses to client desires than larger businesses. Despite these benefits, they are under notable pressure to maintain their position in both national and international marketplaces (Singh et al. 2008).

Mainstream UK SMEs have limited drivers and do not wish to grow. Many are satisfied to continue within their original marketplaces, every so often supplying only one or two key clients in their local region. The Telegraph newspaper (2013) recently published an article entitled ‘British SMEs reluctant to grow’ declaring that “Small and medium-sized businesses, often dubbed the engine room of the British economy, are fearful of expansion and growth”. The article also stated that, “Despite Chancellor George Osborne’s challenge to UK businesses to double exports to £1 trillion by 2020, research from the mid-tier accountancy firm Baker Tilly showed 96pc of SMEs are “content” with their current levels of success”. This was a direct result of the practice of SMEs owner/managers desiring steady revenue. Irrespective of the ups and downs in the market or environmental locations, they have adopted a strategy that carries on their business with existing products and customers. They have deliberately sought out a low-risk strategy, but clearly in a quickly shifting market this could turn out to be a high-risk choice, and many were seen to persist in their habits regardless of market moves or governmental alterations. On the other hand, the key approach of SMEs that were motivated, with confident growth plans, was to broaden their customer base (Mosey et al. 2002).

According to Dangayach and Deshmukh (2005), SME growth happens in four key phases: the pre start up, the start-up, the pre-maturity and the maturity. These phases are based on the time that the company has been in existence along with its level of growth. In pre start-up, the business hunts for materials and ways to start the company. This includes products and services required in the market that the company intends to target, and similarly, the resources required to run the company effectively, and how to get hold of these resources. The second phase involves all the information gathered by the company that is essential to start the business. Within the pre-maturity phase the company develops an understanding of the business, for example, efficient resource management, staff management, and finance management, but mostly how to manage the company. In the fourth phase the business executive has a very good understanding of the company’s market, the customers and the many other parts of the business that are important to taking positive action.

2.16 New Product Development (NPD) within SMEs

Manufacturing has transformed fundamentally over the last two decades. Furthermore, the only thing certain in the years to come is the revolutionary speeding up in the manufacturing fields (Peças and Henriques 2006). Awareness of potential manufacturing growth rates is significant in shaping the whole enactment of the NPD progression. The sooner this is understood, the sooner the compromise concerning rates and product development will be managed (Cavalieri et al. 2004). New developments and manufactured goods will be promoted and motivated by powerful competition through the advent of new manufacturing technologies (Peças and Henriques 2006). Nowadays, businesses are required to develop products rapidly enough to satisfy customers swiftly, whilst playing catch-up with cost-effectiveness, quality and innovation (Vinodh et al. 2009).

NPD is a dilemma facing SMEs. Despite the fact that they recognise the necessity for NPD, their ability to pursue it is often quelled by other more urgent demands. Where NPD practices are carried out, they have to be completed with limited resources. Preferably, this must stimulate the usage of resourceful and operational systems in order to exploit the gained profits. Disappointingly, this does not seem to be the case in SME practice (Woodcock et al. 2000). On the other hand, this desperately negative assessment hides the fact that, in the SME sector, an insignificant number of companies are moving onward and flourishing through the release of new innovative products (Mosey et al. 2002).

2.17 Knowledge Management within SMEs

Knowledge is the key to the competitiveness of an organisation and its continued existence and collaboration. Despite devoted efforts to keep an eye on recommended Knowledge Management (KM) directives on their achievements, SMEs regularly have problems and face the risk of potential failure or disappointing KM outcomes (Chan and Chao 2008). SMEs have difficulties in incorporating the gained knowledge into their everyday practice (Bititci and Ates 2009).

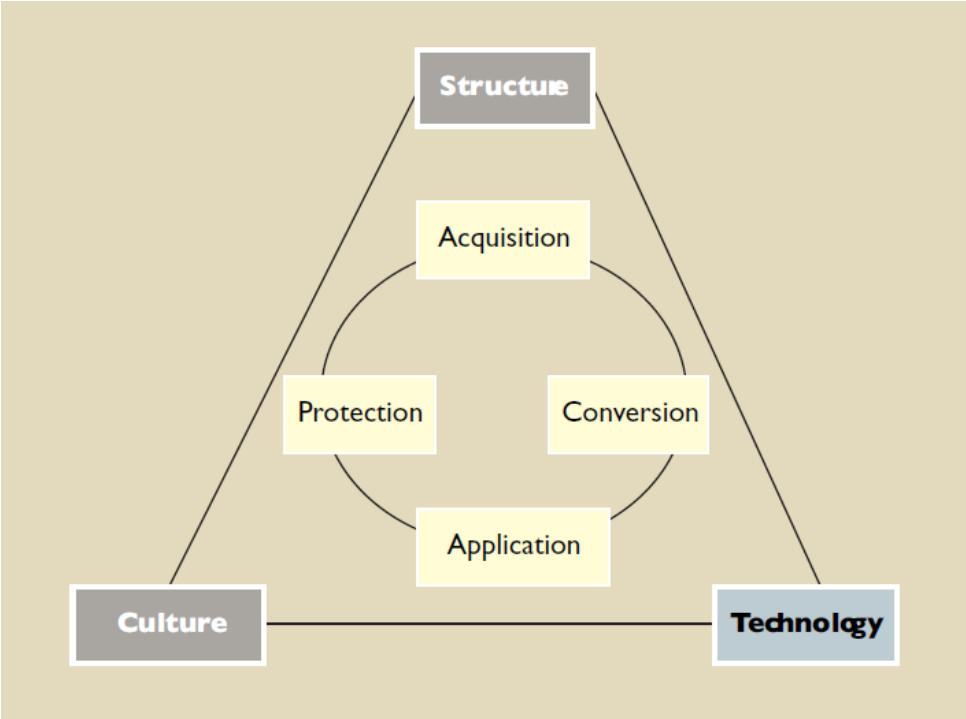

Figure 2.23 Knowledge Management Potential

(Source: Chan and Chao 2008)

Bititci and Ates (2009. p.3) reported that "SME managers do not use web portals because of the overwhelming quantity of information". According to Chan and Chao (2008), the KM set-up, along competence to use it, needs to be further reinforced with technology (Figure 2.23). It was found that most SMEs are not investing adequately in KM-related technologies due to financial limitations. Further cooperative strategies, infrastructures, and constant evaluation could address common considerations and promote recognition of the new technologies.

2.18 Technological Innovation in SMEs

"Innovate or fail. Markets are being transformed, brands are being built, products and services are being re-designed, replaced or developed through innovation", said Penny Egan, Executive Director, Royal Society for the Encouragement of Arts, Manufactures and Commerce (Cox 2005, p.17). To remain present in today's competitive world, SMEs have a duty to deploy state-of-the-art Advanced Manufacturing Technologies (AMT) on a constant basis (Azadivar et al. 2000). AMTs are the most important element in the value and quality developments in

SMEs. Many earlier studies have specified that investment in AMT can reinforce competitive advantage (Dangayach and Deshmukh 2005). Darbanhosseiniamirkhiz and Wan Ismail (2012) stated that: "Recent studies reveal that successful manufacturing companies which were successful in AMT implementation had opted for a more flexibility-oriented organisational culture that might have comforted the AMT implementation through creating an atmosphere of encouragement and trust".

The introduction of modern technologies in SMEs is often either misplaced, is carried out by a single stimulus that does not encompass the overall driving force of the company, or is the responsibility of a proprietor, who does not have enough time to implement them properly (Azadivar et al. 2000). Peças and Henriques (2006, p.55) stated that "SMEs have specific needs, usually more technological and/or organizational based". Success in technological improvement is mostly subject to the awareness and understanding of the decision maker. Azadivar et al. (2000) found that the main features of technological improvement in SMEs are:

- The decision maker in these businesses is repeatedly one person, almost certainly the owner, who has his/her individual importance arrangement that may/may not establish a proper development.
- Planning for new technological improvements is normally customer driven instead of built on ideas and observations of requirements in the near future.
- It is not problematic to generate novel concepts for developments. The key difficulty lies in the technique for selecting the developments and in allocating resources to them.

Bititci and Ates (2009, p.2) reported that, "companies, in particular SMEs, need to significantly enhance their capability to pull through innovative technologies to assist in their move to high-value added innovative product market strategies".

2.19 Research and Development (R&D) in SMEs

Manufacturing businesses undertake continual and profound operational modifications to take account not only of manufacturing requirements, but of the results of activities such as Research and Development (R&D). Additionally, other specialised services and managements all over the world are progressively dedicating attention to the funding of domestic industrial actions (López-Gómez and Gregory 2009). The majority of large companies have R&D sections that are responsible for bringing improvements to the company's products, as well as highlighting these improvements to top management and simplifying their implementation. SMEs, on the other hand, frequently do not have a suitable equivalent mechanism (Azadivar et al. 2000). Figure 2.24 shows the levels of investment in R&D within companies, and that SMEs are less likely to invest in R&D.

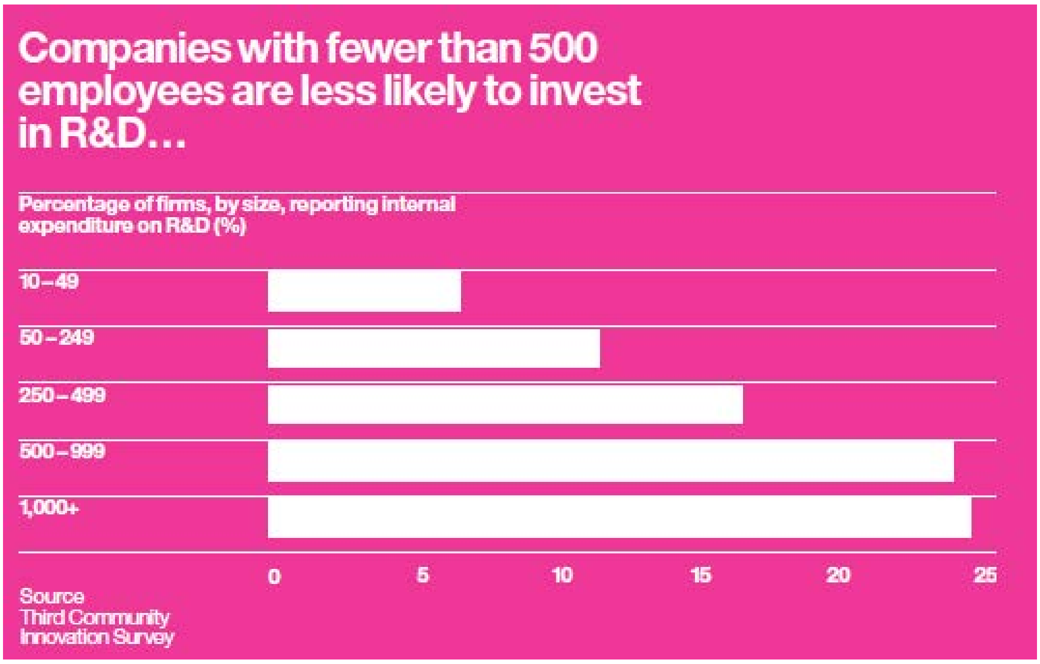

Figure 2.24 Percentage of companies, by size, reporting internal spending on R&D (Source: Cox 2005)

2.20 Chapter Summary

This chapter provided a detailed overview and background to RP technology, which is the focus of this research, in tandem with an in-depth description of SMEs, which are the type of company examined by the study. This has shown that RP technology has the great potential and relevance to enable SMEs to survive global challenges and to grow through them technologically. However, the deployment of RP technology within SMEs has not yet been satisfactorily acknowledged. Therefore, the barriers to RP technology implementation are set out and discussed in the following chapter.

Chapter 3

Technology Deployment Barriers

3.1 Introduction

The previous chapter provided an overview of the background literature concerning RP technology and SMEs, and highlighted the importance of the impact of both RP technology and SMEs on the industrial economy. Although, RP technology has a recognised potential in developing the SMEs, it is not well recognised by the SMEs themselves. This situation is the result of a group of barriers that hinder the deployment of technology in general within SMEs. This chapter presents a list of these barriers. Figure 3.1 shows the chapter structure.

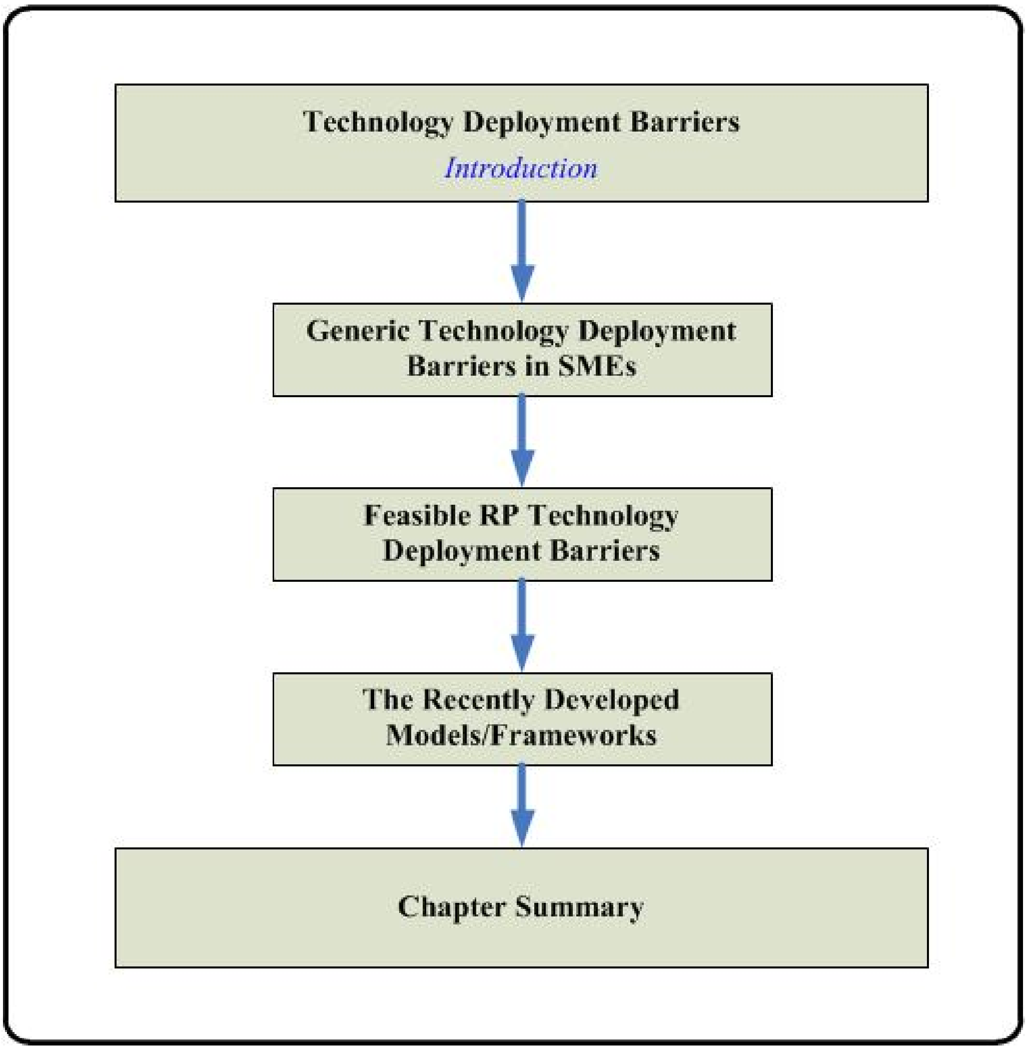

Figure 3.1 Chapter 3 structure

3.2 Generic Technology Deployment Barriers in SMEs

Tactical arrangements need to be made in order for SMEs to adequately develop their ranking from local to global. This can be achieved by distinguishing and developing new market chances, which involve the usage of cutting-edge technologies, to build new dissemination networks, merchandise, facilities and shopper sectors (Singh et al. 2008). Bititci and Ates (2009, p.09) emphasised the significance of having a generation with a strategic attitude, as they stated that “better technology, better tools may help SMEs but we should not miss the real opportunity of creating a new generation of SMEs with a strategic mindset”. The managing principles and operating capitals in SMEs are not the same as those in big businesses, hence it is important to assess product improvement concerns from an SME perspective (Millward and Lewis 2005).

SMEs are perceived internationally as the main source for economic development, however many SMEs have not even considered modern technologies for developing their operational strategies. SMEs’ key difficulties are linked to lack of knowledge, product design, growth competence, training set-up and networking. Additionally, SMEs are not keeping an eye on any broad framework so as to develop their policies as well as effectiveness (Singh et al. 2008). SME manufacturing businesses in the UK operate in an ever-increasingly tough financial environment due to cheaper products being made overseas. Government plans promote the view that manufacturing businesses need to shift up the value-added chain with the aim of generating a strong economic benefit (Millward and Lewis 2005). The key barriers that hinder the technological modernisation within SMEs are as follows:

Absence of an appropriate practice for promoting and developing new improvements, as there is no proper research and development role, no financial plan assigned to the advance of innovative concepts, products and practices, and no explicit accountability for any person, so modernisation never assumes primary importance on the daily list of things-to-do (Azadivar et al. 2000). The research and development principles within SMEs are vague owing to economic limitations (Ahmad et al. 2009). Cultural routine concerns. This is a category of issues that result from the individualities of, predominantly, the owners, who are the main decision makers (Millward and Lewis 2005).

The absence of adequate resources is another major issue, as there is no commitment to innovation since in-house product design and industrial and improvement expertise do not exist. In addition, there is no available time over and above that which is essential for daily engagements (Azadivar et al. 2000). In addition to the unavailability of appropriate tools for considering the threats and the ambiguities associated with any new development or machinery, the risk related to any modernisation is looked at by SME senior managers as a barrier that can be overcome simply through satisfactory debate. However, even when the doubts involved are recognised, it is difficult to initiate these debates (Azadivar et al. 2000). Ahmad et al. (2009, p.4) stated that "most managerial positions at SMEs are acquired based on experience and lack professional qualifications".

Prioritisation structure is one more significant concern, as within SMEs there is no scheme for highlighting, ranking and ordering the large numbers of projects that have been under consideration at many stages. Therefore, imminent difficulties take priority over state-of-the-art developments that are put to one side until their next opportunity for consideration (Azadivar et al. 2000). Decision making within the SME is a huge issue which renders RP providers powerless to sell their innovative ideas, and this acts as a barrier to the launch and continuation of advanced developments.

In summary, opposition to proposed transformations within SMEs, due either to personality or decision making customs, is perceived as a strategic barrier to technology deployment (Azadivar et al. 2000; Ahmad et al. 2009). Regardless of the clear call for development, SMEs are busy dealing with their day-to-day business and do not seem to notice the demand for novel concepts and approaches. Subsequently, when challenged by excess volumes and tough competition, they have no resources with which to meet those demands (Azadivar et al. 2000).

3.3 Feasible RP Technology Deployment Barriers

An AMT could be an advantageous chance for a company but could similarly be a risk, as an incorrect choice as well as excessive assets in an inappropriate area could decrease the economic benefit of a business (Ahmad et al. 2011). The decision to capitalise in AMT should be associated with the market-customer-needs and the product's physical characteristics (Mellor et al. 2012). Ahmad (2012) stated that even with these boundless benefits, the degree of acceptance of RP technology within SMEs is noticeably small. He also reported that the results of a survey of 262 UK businesses revealed that 85% do not use RP technology. He referred to lack of awareness of the RP capabilities and pointed out that this is a crucial element hindering these businesses from taking advantage of modern technology. In addition to that he stated that the mainstream clusters who point to RP as not applicable were unaware of the influence it could have on their companies. Goyal and Grover (2012) reported that unsuccessful implementations of AMT run at between 50% and 75% despite its numerous advantages. For example, AMT is understood to enable businesses to combine low volume batches and customised sets with the low cost competence of standardised bulky production (Saberia and Yusuffb 2011).

Figure 3.2 Feasible RP technology deployment barriers

RP technology is at the top of the AMT list, and despite the established awareness of RP and unlimited potential in innovative practices that loom in the near future, there are a number of key barriers that delay its progression at a faster rate (Drizo and Pegna 2006). These can be categorised into three main groups (Figure 3.2), management barriers, technical barriers, and non-technical barriers.

3.3.1 Management Barriers

The organisational complications in SMEs are mainly because many of their executives lack acceptable levels of learning and qualified training and they fulfil inadequately many of the capacities of manufacture and quality mechanisation (Ahmad et al. 2009). Management anticipation is an essential concern, as initial promises have to be met by reality and management's understanding of the potential of today's RP technology can be coloured by their past experiences (Bourell et al. 2009). Representative difficulties mainly include the adoption of AMT in a way that does not protect flexibility, and management associates who are resistant to cultural change (Goyal and Grover 2012).

Size-wise, Mellor et al. (2012) stated that one of the significant issues for the effective adoption of manufacturing technology is the management of an organisation, and that enterprises that implement a manufacturing technology before re-structuring their organisational management and procedures run into great technical hitches as small and medium companies cannot be treated as scaled down versions of bigger ones; the concepts substantiated in big companies are not appropriate for small and medium ones. Decision-making is a significant process for small businesses when deciding upon and implementing an AMT approach (Ahmad 2012). Thus, to make a sensible adoption decision, company executives have a duty to appropriately measure to what extent the management structural philosophy must change. Moreover the managers must consider the time and the cost of positioning the alterations in the managerial structure (Goyal and Grover 2012).

This is significant for SMEs because, as explained earlier, they are unlike the big corporations due to: the low educational level of their management; the fact that the majority of executive positions are held by people who lack professional qualifications and have knowledge which was attained only on the basis of experience; and that there is no R&D owing to lack of financial resources (Ahmad et al. 2011). Therefore, and as suggested by Goyal and Grover (2012), strong organisational management together with a good financial position constitute the critical prerequisites for the adoption of AMT. Additionally, for positive adoption of AMT, the need for planning improvement, staff training, service-provider development, customer feed-back processing, and integration of organisational departments should be assessed. Millward and Lewis (2005, p.380) argue that, “the culture within small companies may mean that dominant managers are a necessary element; operational change in this context shouldn't seek to change management's personality, but should rather seek to promote a more systematic approach to design”.

Mellor et al. (2012) place emphasis on the term Design For Manufacture (DFM) and they identified it as every characteristic of the design practice wherein the elements involved in producing the planned product are reflected clearly with a view to manufacturing the design. For this reason in-house design and development practices make available an attractive environment for SMEs to develop their affordability and revenue progression, once linked to the conventional manufacturing method. In addition, SME manufacturing businesses are, over and over again, in a leading position to recognise new production chances as a consequence of their close operational contacts with businesses and customers (Millward and Lewis 2005). It is anticipated that the designer’s acceptance of the innovative design for ‘additive’ manufacturing controls will be a persuasive dynamic in AM adoption attitude (Mellor et al. 2012).

Goyal and Grover (2012) argue that ‘early adopters’ focus on educating themselves from technology-vendors and specialists who shed light on worries in the fabrication procedure. The direct objective of developers is to choose techniques that advance manufacturing practices and support the accomplishment of wanted ideas. Feasibly for early adopters, the proper practice for progressing manufacturing processes is to gain as much information and knowledge as possible and to develop an awareness of the innovative technology. Goyal and

Grover (2012) also argue that with 'late adopters' the development ambiguity is comparatively far less for the reason that the technology process has been experiential by developers who largely assisted technology-vendors in eliminating most procedure ambiguity for the following adopting peers.

Mellor et al. (2012) put forward the view that additional processes, which are expected to be considerably transformed by the implementation of AM, include quality control and manufacturing planning. The cost of machines, materials, and maintenance is seen as a stumbling block (Figure 3.3) to widespread implementation of RP/AM technologies. According to Greg Stein of Northrop Grumman, aerospace businesses repeatedly have need of a 3:1 return on their investment, meaning that for every single dollar spent on AM, they need to obtain $3 in return to cover adoption and maintenance expenses.

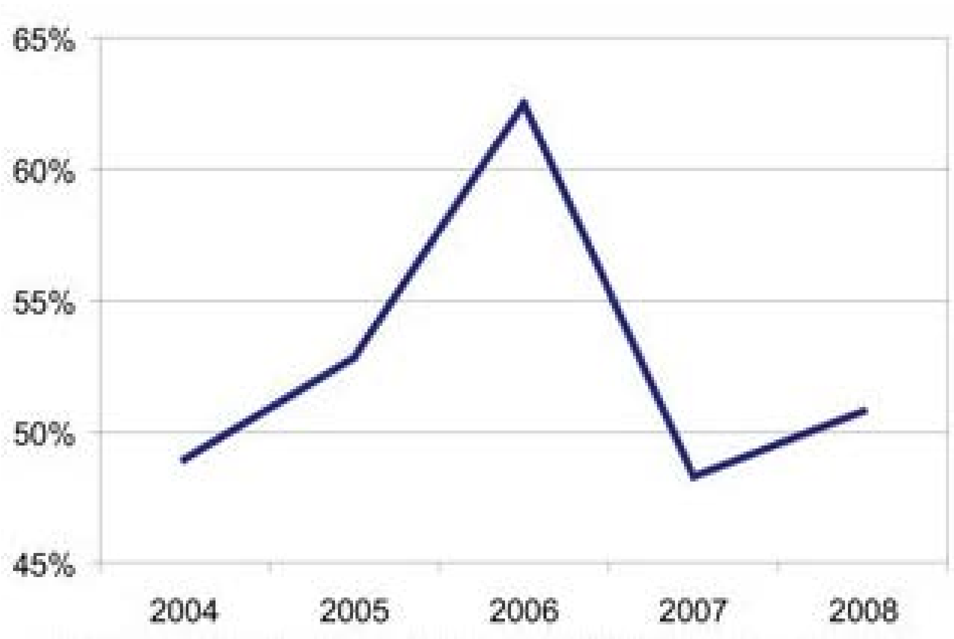

Figure 3.3 Purchases of RP/AM systems by service providers

(Source: Wohlers 2010)

For businesses that are comparing existing manufacturing processes to AM, it is believed that many must realise a gain of at least 30-40% when changing the old conventional processes for the new ones. Any gain which is less than 30-40% is generally not of value when weighted against the anticipated risk and disturbance of exchanging an established technique for a new one The apparent risk and anticipated revenues differ extensively from business to business. Cost is only one of many other elements that affect the implementation of a completely new technology or the initiation of a new development building on a new method. Time-to-market is one more essential element; a number of businesses are eager to spend more if the time improvements are momentous (Bourell et al. 2009). Goyal and Grover (2012) stated that standard implementation strategies which are based on 'net present value', 'return on investment', 'payback period', and 'internal rate of return', through which business financial assessment is conducted, have been found to be insufficient for AMT investments. Equally insubstantial paybacks growing from the implementation of AMT are hard to enumerate in financial language and the executive procedure necessitates a lasting vision. Businesses choose not to adequately capitalise in AMT, therefore, strategic methods are recommended over financial methods in AMT rationalisation.

3.3.2 Technical Barriers

Rao and Padmanabhan (2007, p.81) reported that "each system has its own strengths, defects, applications, utilities and limitations". The absence of technical standards similarly characterises a key barrier to implementation. A number of these features of AM technology are probably owing to their comparative immaturity and executives must be attentive to this when making-decisions to implement (Mellor et al. 2012). However, to guarantee continuing achievement, it is required that companies focus on both technology and marketplaces as the dependency on the conventional manufacturing techniques and failure of the SMEs to be familiar with the profits accessible by the RP technology (Figure 3.4) is hindering this sector from playing its substantial role in global markets, as quite a few companies are concerned about losing their businesses to international corporations (Ahmad 2012).

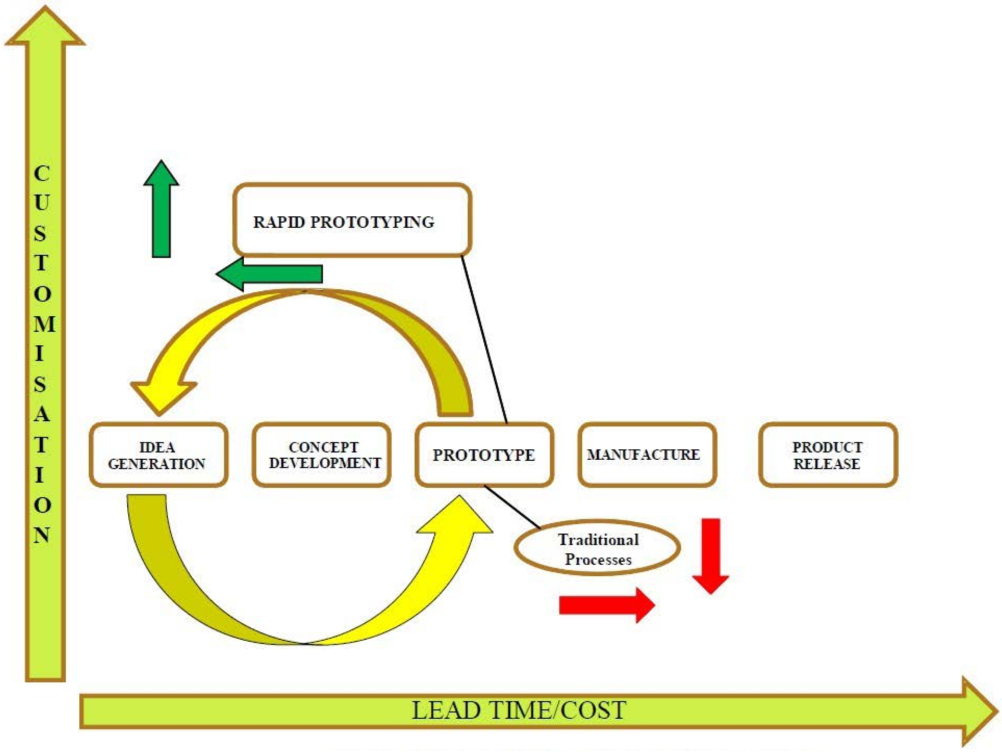

Figure 3.4 Role of RP technology in product development cycle
(Source: Ahmad et al. 2011)

Even though there is a multiplicity of RP/AM technologies, a number of limitations are still present across many additive processes. According to Bourell et al. (2009, p.16), mutual limitations include the following: “part fabrication times which are significantly slower than mass production processes such as injection moulding; most machines are designed in such a way that they have inherent trade-offs between part size, accuracy and speed, with part accuracy often being sacrificed in light of speed or size; there are significant geometric and property variations between ‘identical’ parts built on different machines; many processes require highly skilled operators or need careful periodic tuning to operate well; many machines lack hardware reliability; most machine vendors have a closed architecture, which precludes researchers from making meaningful changes to processing conditions; even the lowest-cost platforms costs around than £2000, which limits adoption by educational institutions and individuals; and although many processes are inherently capable of multi-material deposition, few have hardware and software implementations which enable simple, effective use of these capabilities”.

These limitations differ based on the purpose of each RP technology method and from case to case (Beer et al. 2005).

3.3.3 Non-Technical Barriers

Bourell et al. (2009) reported that, in spite of the fact that technical barriers exist, in most technological ranges the main barriers are non-technical, human-based concerns. In the case of RP technology this includes lack of education as a key hindrance. Ahmad et al. (2009) indicated that within SMEs the education levels are below accepted levels. Cultural differences are another key barrier. Cox (2005) indicated that SMEs should benefit from accessible, knowledgeable individuals, research competence, and access to services such as RP technology. Vested interests that stifle innovation are another hindrance. Cox (2005, p.16) stated that “lack of awareness of the role that greater creativity might play in the business was identified as one of the key barriers to SMEs making greater use of creative skills”. Finally, lack of imagination can be a problem. Cox (2005, p.20) reported that “creativity cannot be viewed as a skill possessed by the gifted few. It needs to pervade the thinking of the whole business”.

Based on the above discussion, it has been found that common barriers that hinder the deployment of RP technology within SMEs are as follows: lack of proper practice; cultural and performance issues; lack of resources; lack of professional qualifications; prioritisation systems; decision making; resistance to change; lack of education; RP process limitations; lack of imagination; and vested interests that stifle innovation. This list of barriers will be prioritised, in terms of their influence, for further study.

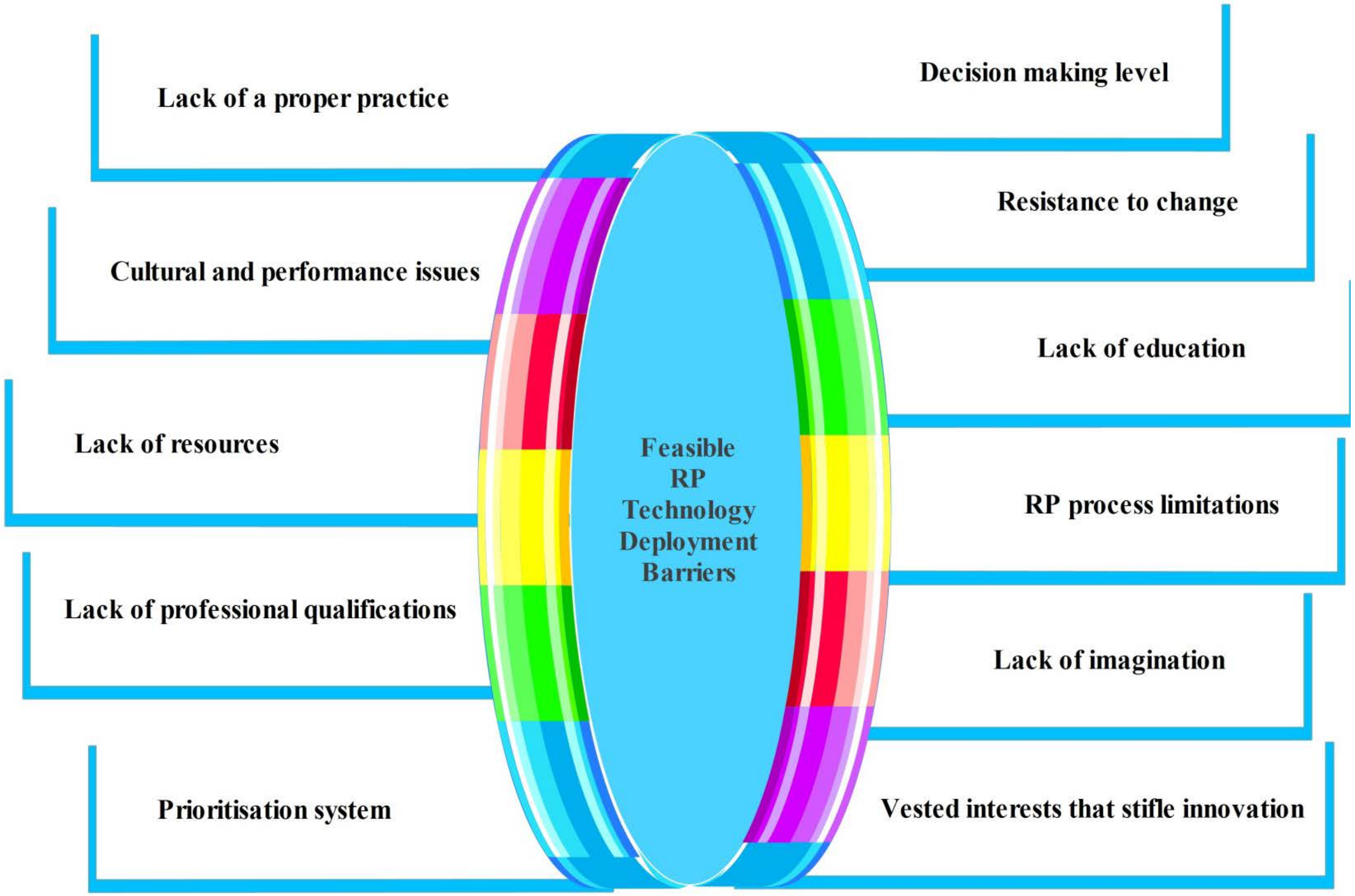

Figure 3.5 Feasible RP technology deployment barriers

Many researchers have developed frameworks and models for the adoption and selection of technologies. However, and as explained in Chapter 1, all these trials were generic, for any technology, and mainly focused on the selection and the financial analysis. Additionally, none of these frameworks has investigated the common barriers in depth to identify and prioritise them for each type of new technology. A recent paper by Ahmad (2012) summarised the research literature on AMT adoption (Figure 3.6) as follows:

Year	Author	Technology Focus	Description
2008	Ruder *et,al*	Telecom	Focus on technology selection based on organizational competencies and business objectives.
2007	Farooq *et,al*	Manufacturing Technology	Focus on technology selection decisions based on the supply chain and risk perspective
2006	Shehabuddeen *et,al*	Packaged Technology	Based on Scanning, Selection , Acquisition and adoption cycle for the technology selection
2002	Trokkeli *et, al*	Generic Technology Selection Guide	Framework developed for the acquisition of any technology based on the core competencies of the organization
2001	Kengpol *et,al*	Advanced Manufacturing Technology (AMT)	Technology acquisition decision based on technical, manufacturing and financial parameters

Figure 3.6 Summary of the literature on technology studies
(Source: Ahmad 2012)

- Kengpol and O'Brien (2001) suggested an information system and a decision making model (Figure 3.7) that combines equally the quantitative and qualitative factors. The model offers an instrument to select AMT by accessing technical, manufacturing and financial factors. The system delivers a number of models to put a figure on the profit loss owing to early as well as late promotion of the product, plus more additional motivation on the economic advantages through incorporating the cost benefit analysis with the decision making model (Ahmad 2012).

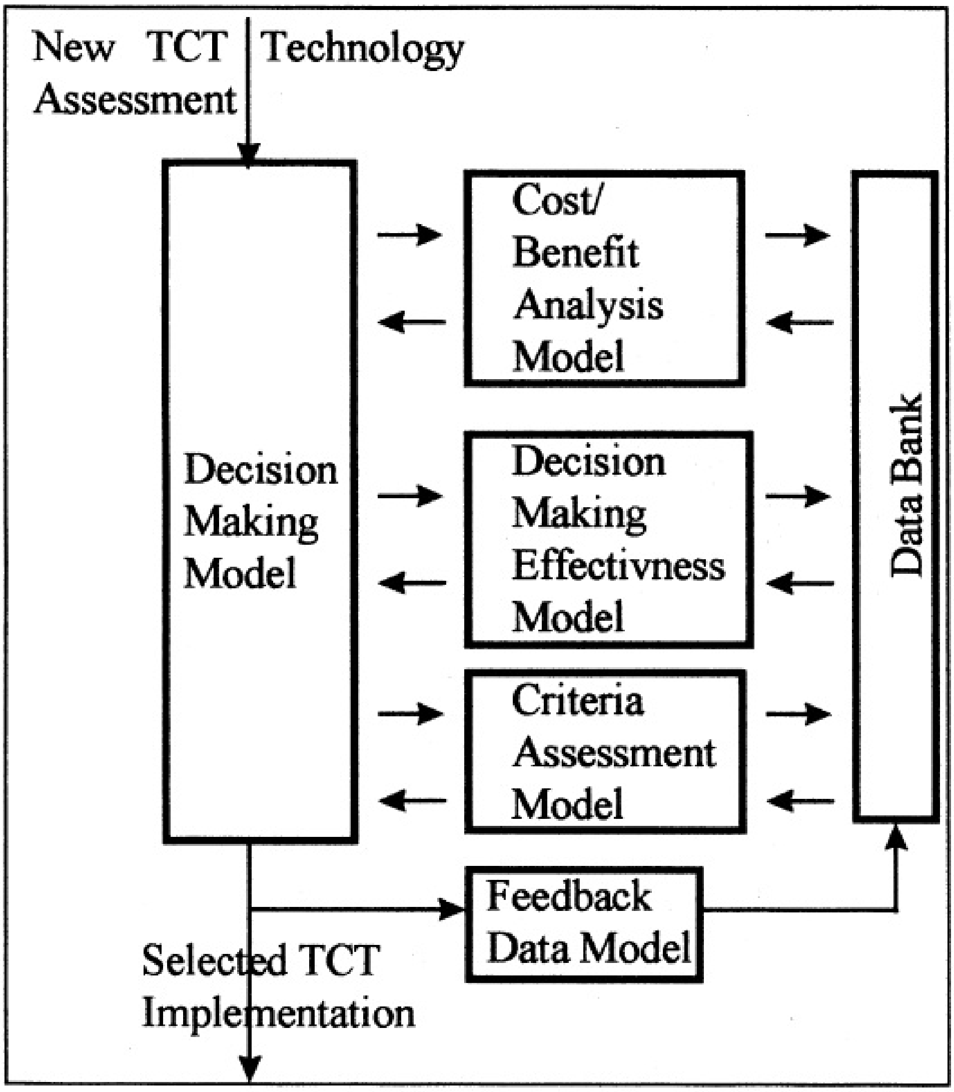

Figure 3.7 Kengpol and O'Brien decision support tool
(Source: Kengpol and O'Brien 2001)

- Torkkeli and Tuominen (2002) have suggested a method for selection of technologies based on core-competence. Their established method was intended for big engineering businesses, manufacturing and technology driven corporations, but they stated that it can be adapted for the needs of dissimilar categories of firm without difficulty. Their method involved seven consecutive stages (Figure 3.8) and the explanation of required factors in each stage. All the determined stages were claimed to be essential in methodical technology selection combined with managing core-competence, as they stated that the method was developed to prove how technology selection is a challenging and multifaceted task.

INPUT ➔	THE PHASES OF THE PROCESS	➔ OUTPUT
• Purpose and tasks of the technology to be selected • Determination of relevant participants (people representing the key functions, all business units, important cross functional or cross-SBU teams and important projects) • Business goals of the company • Business strategy of the company	1. IDENTIFICATION OF EXISTING CORE COMPETENCIES (See questions 1 to 8 described in chapter 3.2)	• List of existing core competencies and technologies • Components of company's core competencies • Linkages between core competencies and competitive advantages of company • Duration of competitive advantages • Trends in the industry • Redefined business strategy
• Existing core competencies and technologies • Competence-product matrix	2. ESTABLISMENT OF THE CORE COMPETENCE AGENDA	• Existing and new competencies and products matrix • Requirements for technologies
• Knowledge of experts • Planned application areas and tasks for technology • Requirements of different SBUs for technology	3. IDENTIFICATION OF ALTERNATIVE TECHNOLOGIES	• List of possible technologies to be developed or acquired • Characteristics of technology alternatives
• Business goals of the company • Experts' knowledge and opinions about importance of different requirements and competencies	4. MAPPING OF SELECTION CRITERIA AND DETERMINATION OF THEIR IMPORTANCE	• List of criteria • Classified criteria in the evaluation categories • Distribution of experts' evaluations on importance of criteria
• Information and knowledge from different SBUs • Experts' knowledge and opinions about capabilities of alternatives to fulfill criteria	5. ASSESSMENT OF ALTERNATIVE TECHNOLOGIES	• Distribution of experts' evaluations on capabilities of alternatives to fulfill criteria • Fulfillment of criteria • Total weighted points • The best assessed technology
• Assessment results of alternatives • The most important criteria • Additional arguments and opinions of participants • Technology portfolio • Requirements and opinions of participants for the selected technology	6. ANALYSIS OF RESULTS AND SELECTION OF TECHNOLOGY Select best possible technology, which strengthens competencies (bundle of technologies, portfolio)	• Impact of the selected technology on different operations and departments of the company • Means to avoid the negative impacts of the failed criteria
• Market-competence matrix • Leverage areas of technology • Technology vulnerability • Potential partners and alliances	7. DEPLOYMENT, PROTECTION AND DEFENDING OF CORE COMPETENCIES	• Needed future development • Regular "competence review" • Possible opportunities for achieving new markets or making new products • Sustainable competitive advantage

Figure 3.8 Torkkeli and Tuominen generic technology selection guide
(Source: Torkkeli and Tuominen 2002)

- Shehabuddeen et al. (2006) suggested a framework that involves four key factors. These factors are elements associated with the: selection of technology and decision making; filtration-concept; practice outlook of selection of technology and applicable techniques; and the structured view of internal and external firm agents. Their framework initial filter is associated with selection of technology requirements. This is enabled via a screening process of technologies that are not adequate for the required need and also enables the identification of technologies that demonstrate looked-for characteristics through financial, external pressures, and technical sub filters.

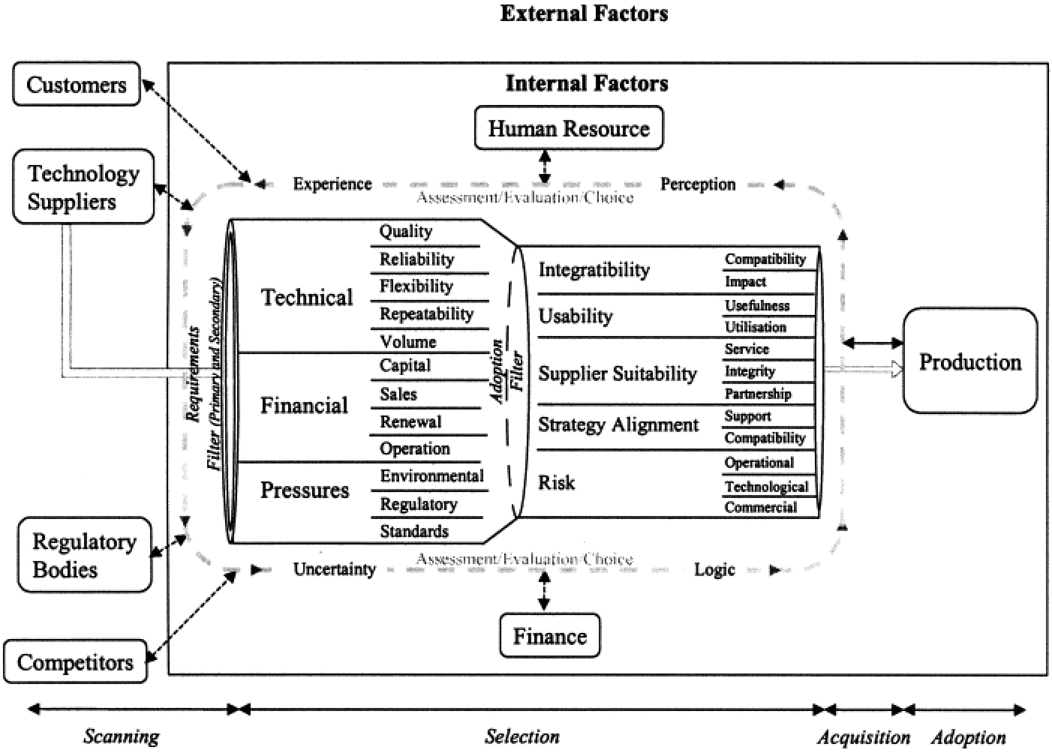

Figure 3.9 Shehabuddeen et al. technology selection framework
(Source: Shehabuddeen et al. 2006)

- Farooq (2007) proposed a technology selection framework that involves six methodically connected phases, which integrates manufacturing and supply chain aims in a decision making framework (Figure 3.10). It was claimed that his proposed framework was inspired by the technology selection frameworks that were available at the time of conducting his search of the literature. It was reported that the goal was to develop an efficient decision making framework that is easy to comprehend, deals with all elements concerning selection of technology and can be considered valid in every category of manufacturing. Farooq also stated that his framework involves the manufacturing and supply chain together to achieve the company's aims.

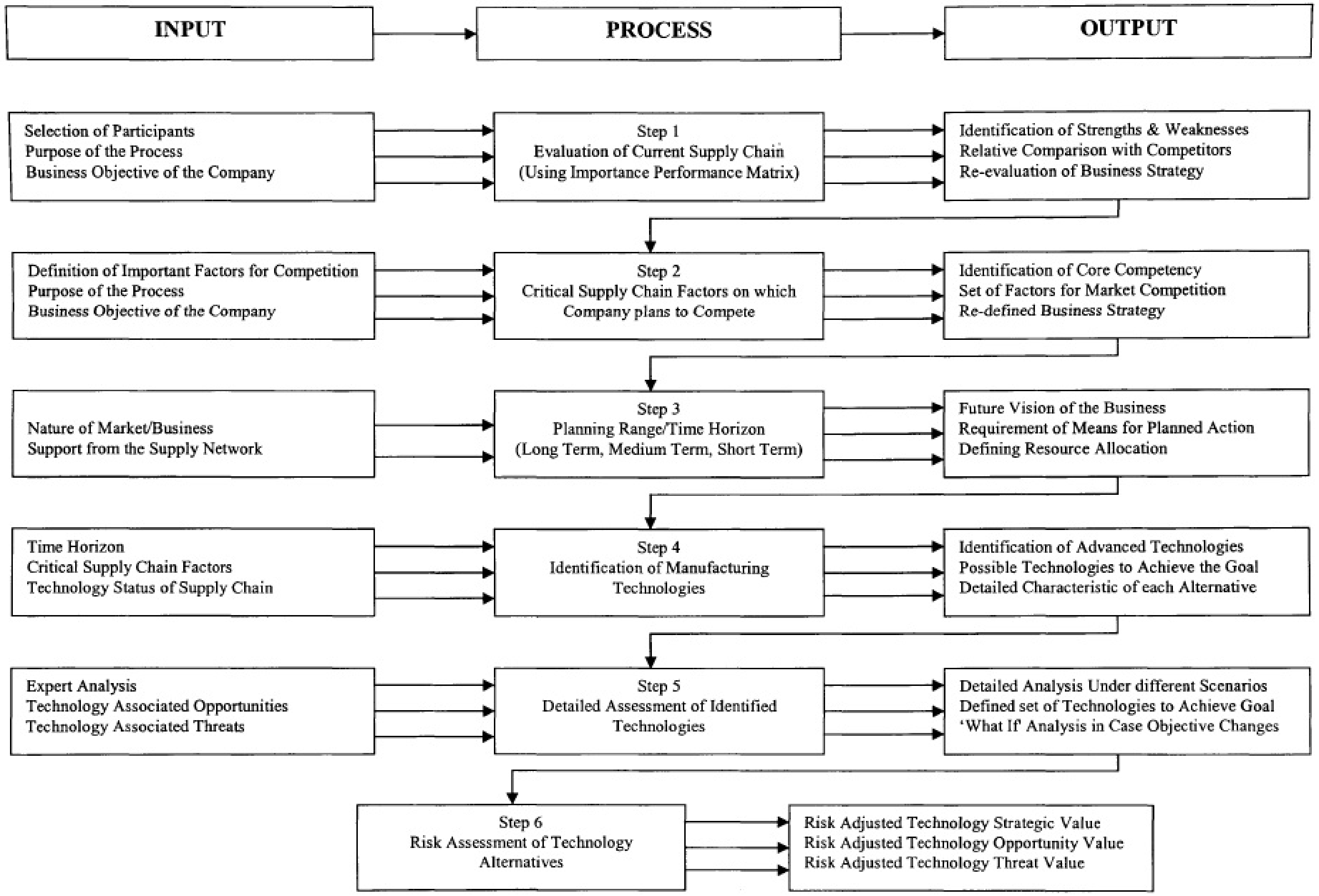

Figure 3.10 Farooq technology selection framework
(Source: Farooq 2007)

- Ruder et al. (2008) suggested a technology selection framework (Figure 3.11) that associates main capabilities with the technology selection. They stated that the framework recognises first the main capabilities and then builds associations through the technology selection procedure.

Inputs	Phases of the process	Outputs
• list of relevant and affected participants	1. Identification of decision makers and stakeholders	• A list of the participants for the group that will make the decision • A list of participants that will be affected by the decision • A list of any other participants
• The purpose and task of the new technology • The business goals and strategy of the organization	2. Identification of existing core competencies	• A list of existing core competencies and technologies • Linkages between core competencies and the competitive advantage of the organization • Trends in the industry
• List of existing core competencies and technologies • Trends in the industry	3. Establishment of agenda and strategy	• Redefined business strategy • Requirements of the new technology
• The knowledge of experts • Planned application areas and tasks for the technology • Requirements of the organization	4. Identification of alternative technologies	• A list of possible technologies to be acquired • The characteristics of all the technology alternatives
• Business goals of the organization • Expert's knowledge and opinions about the criteria to be selected	5. Identification of selection criteria	• List of criteria • Criteria classified into categories
• Experts knowledge and opinions • Business goals of the organization	6. Determination of utility and weights for chosen criteria	• Utility functions for each criteria • Weight for each criteria
• Categorized criteria • Criteria weights and utility functions	7. Assessment of alternative technologies	• List of ranked technologies • Technology selection decision

Figure 3.11 Ruder et al. technology selection framework
(Source: Ruder et al. 2008)

3.4 The Recently Developed Models/Frameworks

In recent years, research concerned with RP/AM deployment has become increasingly popular. The following RP/AM technology adoption frameworks have been developed by other researchers during the course of this study, which demonstrates the high level of significance of this research as a response to an existing shortcoming in the knowledge in this particular field.

Saberia and Yusuffb (2011) reported that, although numerous efforts have been made to identify and examine the advantageous consequence of AMT and its future influence on businesses, there is still an absence of models or frameworks that combine research that methodically construct on what has been done more willingly than to be out-of-the-picture and that should guide executives and AMT implementers in enhancing their business performance. They also stated that the main driver of effective AMT adoption seems to be the association of applicable influences and their incorporation in such a way that they will bring in the greatest profits at the commencement of AMT deployment (Saberia and Yusuffb 2011).

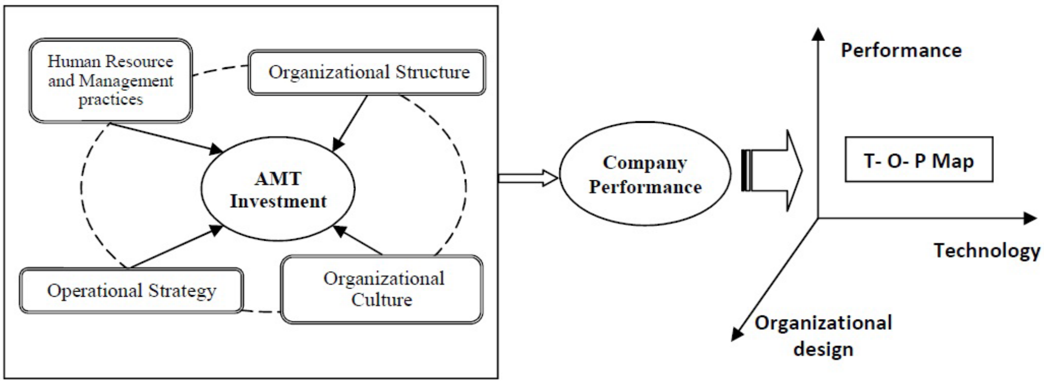

Figure 3.12 Saberia and Yusuffb proposed framework
(Source: Saberia and Yusuffb 2011)

Saberia and Yusuffb (2011, p.146) have suggested a framework (Figure 3.12) based on five propositions that needed to be addressed to enable the appropriate deployment of AMT, as follows:

"***Proposition_1*****:** The performance of companies with investment in AMT is higher compared with companies that have less AMT investment.

Proposition_2**:** Flatter, less complex structures with maximum administrative decentralization companies who have invested in AMTs, have higher performance compared with companies with more centralization, formalization and complexities.

Proposition_3: The organization with flexibility-oriented culture, whether internal or externally -oriented, achieved higher performance in implementing AMTs.

Proposition_4**:** Performance of the companies implementing AMT that simultaneously focused on flexibility, delivery, quality and cost strategies will be higher compared with other companies which focus on one of the strategies only.

Proposition_5**:** Firms with more emphasis on human resource and management practices have higher performance in applying AMT compared with others".

Mellor et al. (2012) indicated that the researchers in the area of AM organisation have suggested several product features that have great impact on the nature of products which are appropriate for AM manufacture. Mostly, the product features belong to products that can be customised, products that with design optimisation can improve functionality, and products produced for low volume. They have also found that the adoption of AM technology needs to be regulated by the planning arrangement of the company, and its manufacturing and R&D strategies (Mellor et al. 2012). In addition to thist, the technology advances should be associated with what is required of the manufacturing process, the results required by the company strategy, and looked at as a market-driven strategy for AM adoption.

Mellor et al. (2012) also reported that there is a form of hereditary selection which forms a psychosomatic barrier to the acceptance of certain types of RP technology, as executives will only select the 'technology-class' which they perceive to be appropriate to their needs (Mellor et al. 2012). They proposed a framework (Figure 3.13) which suggests that external factors and internal policy equally motivate the seeking of AM technology as a method of manufacture, and the process of AM implementation will be affected by influences that can be clustered into five groups (strategic factors; organisational factors; operational factors; supply chain factors; and technological factors) (Mellor et al. 2012).

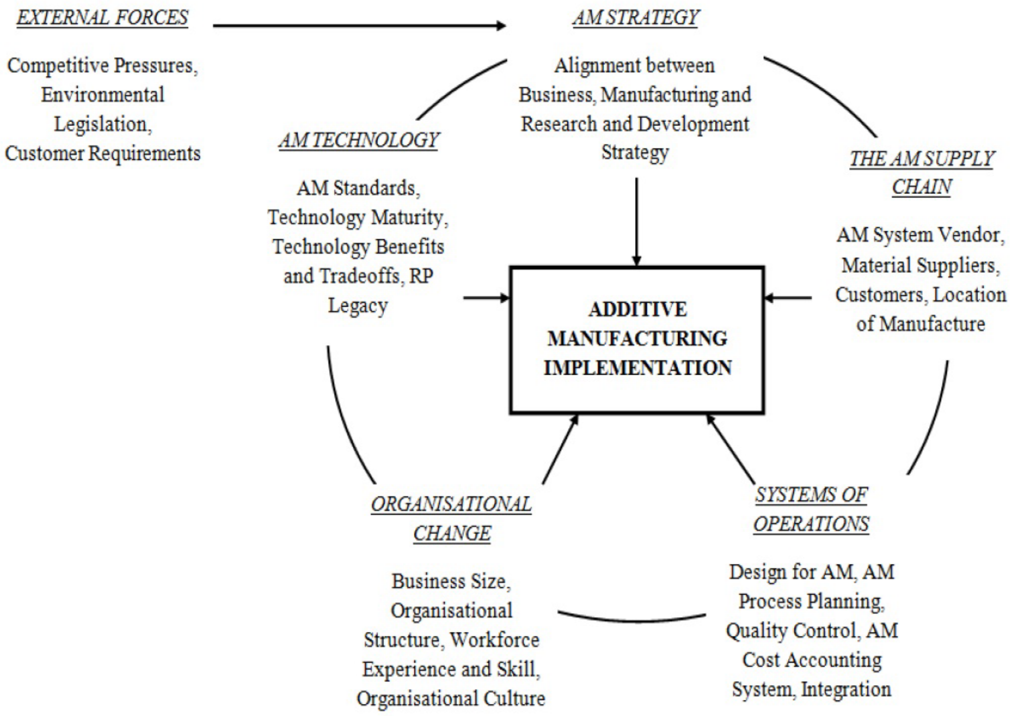

Figure 3.13 Mellor et al. proposed framework of AM implementation
(Source: Mellor et al. 2012)

Ahmad (2012) reported that the lack of a comprehensive implementation model is one of the key reasons why SMEs are uninformed about the considerable advantages obtainable through RP technology. It was also indicated that the development of his proposed framework (Figure 3.14) was based on the essential influencing elements that affect the selection of technology progression. Ahmad (2012) points out that these influencing elements were identified from a literature review and evaluated by obtaining expert-opinion from manufacturers and academics. He grouped the extracted mutual influencing elements together to create the structure of his proposed framework, which resulted in four main factors being recognised: ‘identify’; ‘analyse’; ‘compare’; and ‘specify’ (Ahmad 2012).

Ahmad (2012) claims that his proposed framework methodically recognises the SMEs' difficulties and associates them with the nominated RP technology characteristics to guarantee that the designated RP method is completely suited to the company and is totally utilised.

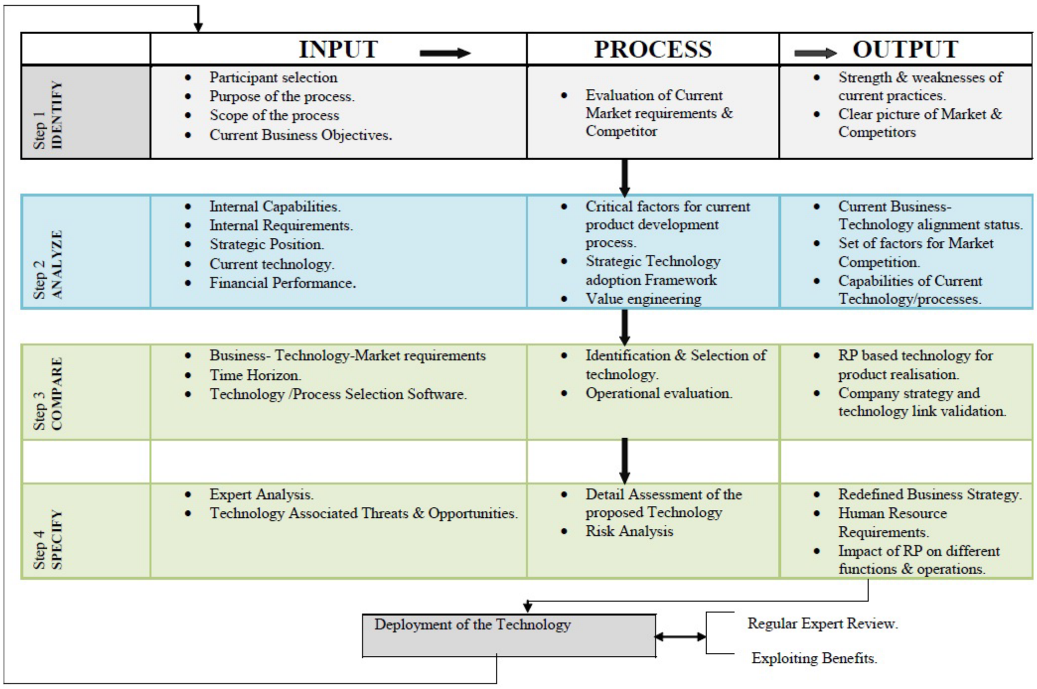

Figure 3.14 Ahmad's proposed RP technology adoption framework
(Source: Ahmad 2012)

Repeatedly, these recent RP/AM deployment models/frameworks have failed to identify and prioritise the barriers to RP/AM technology, and in particular, the generic barriers that hinder the adoption of AMT in general. Rather, they build upon the work of earlier researchers in the field of AMT implementation; for instance, the proposed framework by Ahmad (2012) is a revised version of the frameworks proposed by Farooq (2007), Shehabuddeen et al. (2006) and so on. Therefore, work to identify and prioritise the barriers affecting RP technology is essential in order to develop a strategy that answers all the previously discussed concerns that affect its deployment within SMEs. The key obstacle in implementing AMT is the unavailability of an appropriate rationalisation approach (Goyal and Grover 2012).

3.5 Chapter Summary

This chapter has presented an inclusive contextual setting for the generic barriers to technology, in addition to the feasible RP technology deployment barriers which are the focus of this research. A list of the hindrances to technology adoption was generated for investigation, in order to identify and prioritise precisely those barriers that hinder the deployment of RP technology within SMEs. Moreover, this chapter has also provided a detailed overview of the developed models and frameworks for technology adoption in general derived by other researchers in the last decade, as well as more recently developed models and frameworks, specifically for the selection of RP/AM technology. This has shown that even the recently developed and proposed models and frameworks for deploying RP technology still lack the crucial customisation of particular technologies to specific purposes in the SME sector. The next chapter provides a comprehensive discussion with regard to the research methodology adopted in the study.

Chapter 4

Research Design and Methodology

4.1 Chapter Overview

Chapter 3 identified the barriers which hold back any new technology adoption within SMEs based on the findings of an extensive literature review which was reported upon in Chapter 2. The research design and methodology and implementation are explained in this chapter. Figure 4.1 shows the chapter structure.

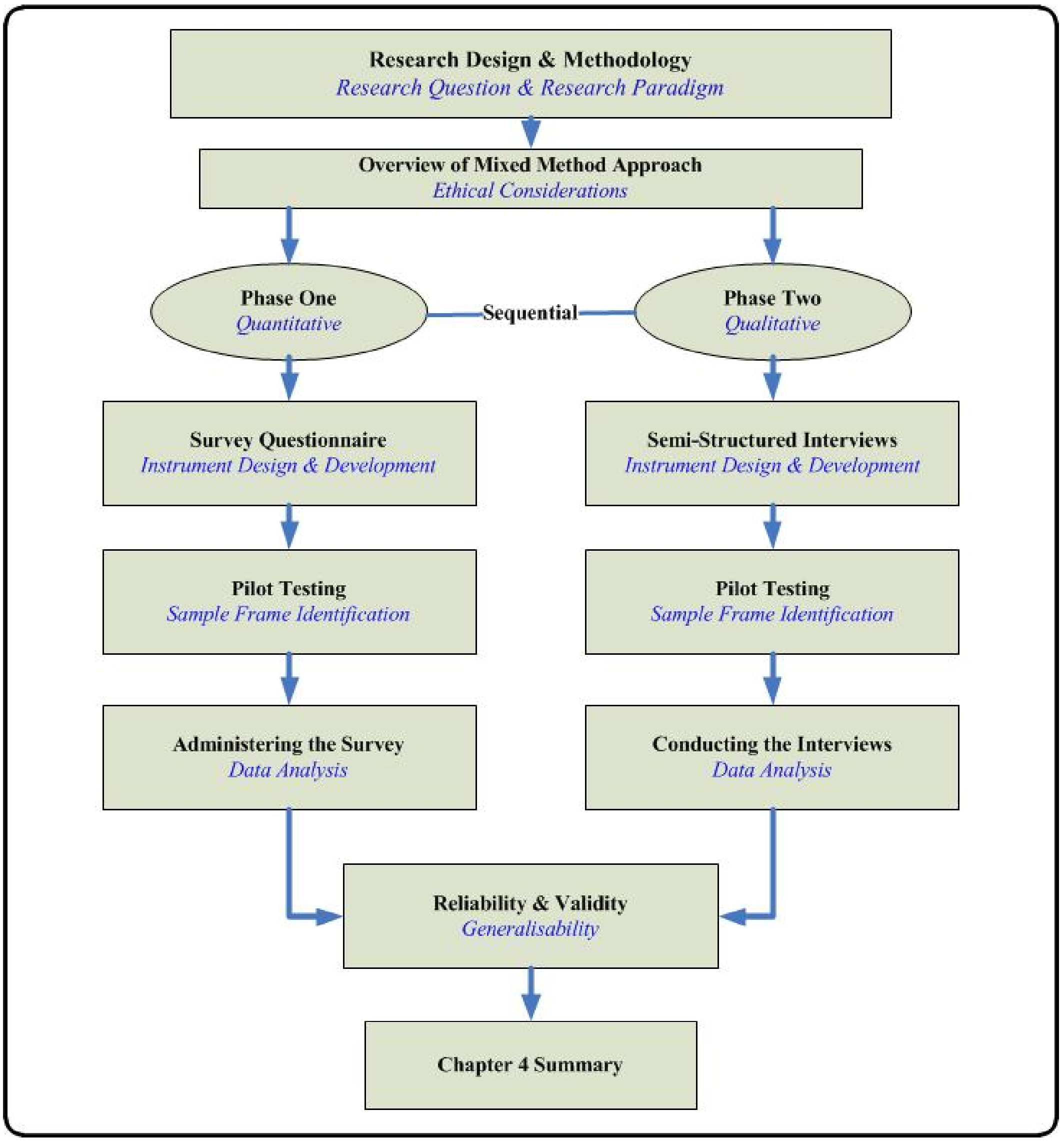

Figure 4.1 Chapter 4 structure

4.2 The Research Question

The literature review conducted in the field of deploying new technologies within SMEs has resulted in developing an inclusive list of existing barriers which extensively and generally affect any technology deployment process within SMEs. Nevertheless, when investigating these barriers with respect to their impact on the deployment of RP technology in particular, the literature offers little help. That shortcoming in the literature is identified as the foundation to the research question. Of particular importance is which of these barriers actually affect the process of deploying RP technology and with what level of priority.

Consequently, the overall aim of the research is to answer:

What are the main barriers that hinder the deployment of RP technology within industrial/manufacturing SMEs in the South West of England, and can a deployment strategy to assist SMEs be developed?

In order to answer the above question the following key questions emerged though reviewing the literature, and are based on the identified above overall aim. This allows for consideration of other potential prompting elements throughout the research.

1. What is the level of awareness of SMEs of available new technologies?

2. To what extent is the RP technology recognisable within the SMEs?

3. To what extent are SMEs deploying RP technology, and how?

4. What are the common barriers that hinder the deployment of RP within SMEs, and which comes first?

5. What are the significant factors needed to develop a strategy for the deployment of RP technology within SMEs?

4.3 Research Paradigm

Research in industrial technology management that exclusively employs either a quantitative approach or a qualitative approach can present key challenges in the understanding of the results obtained. This challenge can be met throughout by increased awareness and discussion between the researcher and SME individuals or other stakeholders about the environment for data collection related to industrial technology management and changes in that arena. By integrating quantitative and qualitative research methods in a mixed method research approach, the researcher was able to better comprehend this possible prejudice of the collected data, to answer the research question. Studies employing mixed methods for this reason employ the pragmatist's paradigm. (Lewis et al. (2009, p.119) suggest that Pragmatism perceives that research questions encapsulate the crucial contributing factor of the epistemology, ontology and axiology that can be adopted within research. This factor contribution varies depending on the nature of the research. In addition, when either positivist or interpretivist philosophy explicitly cannot be implemented to provide an answer to the proposed research question, then the interpretation delivered by a pragmatist is potentially going to work distinctively within the researcher epistemology, ontology and axiology.

Denscombe (2008, p.275) has demonstrated that the Mixed Methods approach is commonly considered the philosophical 'significant other' of Pragmatism, as knowledge deductions can be delivered through the pragmatist's view in such a way that they reinforce and prevent the method from reaching the extremes of being either purely quantitative methods that are represented by (post) positivism or purely qualitative methods that are represented by interpretivism or constructivism.

Tashakkori and Teddlie (1998, p.30) have also argued that as a researcher one has to "study what interests you and is of value to you, study in the different ways in which you deem appropriate, and use the results in ways that can bring about positive consequences within your value system". As an underpinning philosophical approach for this research, and as reported by Lewis et al. (2009, p.109) and Tashakkori and Teddlie (1998) "pragmatism is intuitively appealing, largely because it avoids the researcher engaging in what they see as rather pointless debates about such concepts as truth and reality". Moreover, Denscombe (2008, p.279) has arrived at the conclusion that "the mixed methods approach does not exercise exclusive rights over the use of mixed methods in research or the use of pragmatism as the philosophical foundations for research".

4.4 Overview of Mixed Methods Approach

A Mixed Methods Approach is defined by Erling et al. (2008, p.30) as "an intellectual and practical synthesis based on the combination of qualitative and quantitative research methodologies and results. It recognizes the importance of both quantitative and qualitative research methods but also offers a powerful third mixed research methodology that potentially will provide the most informative, complete, balanced and useful research results". Mixed research actually has a long history in research practice because practicing researchers frequently ignore what is written by methodologists when they feel a mixed approach will best help them to answer their research questions (Johnson and Onwuegbuzie 2004).

Mixed research is research in which quantitative and qualitative techniques are combined in a single study. It is the third major paradigm, adding an attractive alternative (when it is appropriate) to quantitative and qualitative research (Johnson and Christensen 2007). Mixed methods are a way to come up with creative alternatives to traditional or more monolithic ways to conceive and implement evaluation. It is likely that these alternatives will not be able to represent radical shifts in the short term. However, they are a genuine effort to be reflexive and more critical of the evaluation practice and, ideally, more useful and accountable to broader audiences (Sydenstricker-Neto 1997). Johnson et al. (2007, p.119) stated that "mixed methods research is a systematic integration of quantitative and qualitative methods in a single study for purposes of obtaining a fuller picture and deeper understanding of a phenomenon. Mixed methods can be integrated in such a way that qualitative and quantitative methods retain their original structures and procedures (pure form mixed methods). Alternatively, these two methods can be adapted, altered, or synthesized to fit the research and cost situations of the study (modified form mixed methods)".

Table 4.1 Strengths and weaknesses of mixed research

Strengths

- Words, pictures, and narrative can be used to add meaning to numbers.
- Numbers can be used to add precision to words, pictures, and narrative.
- Can provide quantitative and qualitative research strengths (i.e., see strengths listed in Tables 3 and 4).
- Researcher can generate and test a grounded theory.
- Can answer a broader and more complete range of research questions because the researcher is not confined to a single method or approach.
- The specific mixed *research designs* discussed in this article have specific strengths and weaknesses that should be considered (e.g., in a two-stage sequential design, the Stage 1 results can be used to develop and inform the purpose and design of the Stage 2 component).
- A researcher can use the strengths of an additional method to overcome the weaknesses in another method by using both in a research study.
- Can provide stronger evidence for a conclusion through convergence and corroboration of findings.
- Can add insights and understanding that might be missed when only a single method is used.
- Can be used to increase the generalizability of the results.
- Qualitative and quantitative research used together produce more complete knowledge necessary to inform theory and practice.

Weaknesses

- Can be difficult for a single researcher to carry out both qualitative and quantitative research, especially if two or more approaches are expected to be used concurrently; it may require a research team.
- Researcher has to learn about multiple methods and approaches and understand how to mix them appropriately.
- Methodological purists contend that one should always work within either a qualitative or a quantitative paradigm.
- More expensive.
- More time consuming.
- Some of the details of mixed research remain to be worked out fully by research methodologists (e.g., problems of paradigm mixing, how to qualitatively analyze quantitative data, how to interpret conflicting results).

(Source: Johnson and Onwuegbuzie 2004)

Johnson and Onwuegbuzie (2004) described the strengths and weaknesses of mixed research methods (Table 4.1). This research benefited from maximising the strengths of using a mixed methods approach explained above, together with minimising the weaknesses of using a mixed methods approach. That was achieved by implementing a sequential approach and in depth learning about mixed methods research. In addition, conducting the research within a pragmatic paradigm has supported a positive deployment of mixed methods; as stated by Johnson et al. (2007, p.125), “many (or most) mixed methods writers have argued for some version of pragmatism as the most useful philosophy to support mixed methods research”.

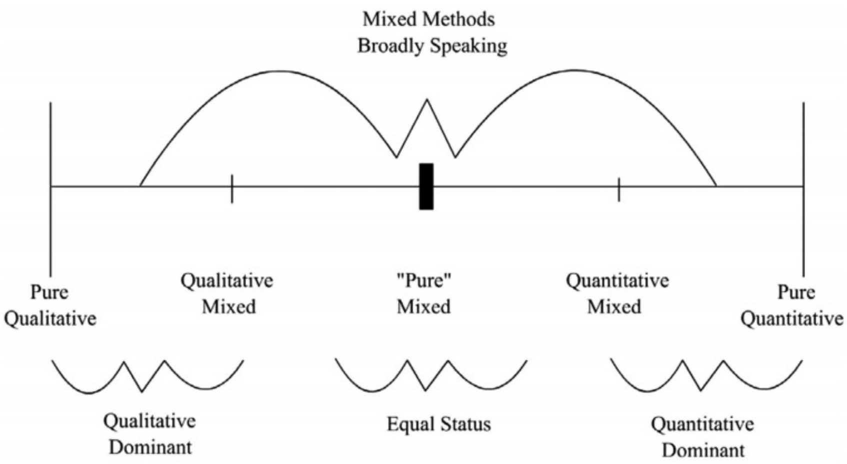

Figure 4.2 Graphic of the three major research paradigms,
including subtypes of Mixed Methods Research
(Source: Johnson et al. 2007)

Johnson et al. (2007, p.122) argue that a mixed methods approach can fall into one of three main mixed methods approaches (Figure 4.2). These three approaches are qualitative dominant; quantitative dominant; and pure mixed. They identified the first two as follows: “qualitative dominant mixed methods research is the type of mixed research in which one relies on a qualitative, constructivist-poststructuralist-critical view of the research process, while concurrently recognizing that the addition of quantitative data and approaches are likely to benefit most research projects”; and “quantitative dominant mixed methods research is the type of mixed research in which one relies on a quantitative, post positivist view of the research process, while concurrently recognizing that the addition of qualitative data and approaches are likely to benefit most research projects”. This study adopted a pure mixed methods approach as indicated by Johnson et al. (2007, p.123). Thus, “the area around the centre of the continuum, equal status, is the home for the person that self-identifies as a mixed methods researcher. This researcher takes as their starting point the logic and philosophy of mixed methods research. These mixed methods researchers are likely to believe that qualitative and quantitative data and approaches will add an insight as one considers most, if not all, research questions”. This research aimed to firstly identify and prioritise the specific barriers that hinder the deployment of RP technology and then secondly investigate the potential to challenge these barriers. Therefore, a pure quantitative approach was needed to survey as many as possible of the SMEs in the South West of England to identify and prioritise the barriers, followed by a pure qualitative approach to investigate the identified and prioritised barriers with the executive managers of the SMEs. The only way to combine both pure approaches was using a mixed method that was also supported by the pragmatic philosophy paradigm.

Examples of mixed methods approaches are numerous, especially in masters and PhD theses, although research periodicals discourage articles which adopt mixed methods because of restrictions on the numbers of pages. In a recent article by Molina-Azorín et al. (2012) the authors state that they have reviewed and identified 81 mixed methods studies out of 955 articles in total. Their study revealed that entrepreneurship research investigating challenges may benefit from advanced opportunities linked with the application of mixed methods. In their research, the cited articles applied a mono research method mostly in the form of surveys, as most of the articles were studying one dimension of the investigated problems, whereas in this research more than one dimension was investigated through firstly identifying, prioritising and examining the barriers. Instead, this research has provided a detailed rationalisation on benefits obtained through using mixed methods. The mixed methods were also applied in research investigating problems such as the adoption of new IT or new technologies for education.

Building on the foundational aim of this research, and to answer its identified question, a mixed method approach, relating to barriers hindering the deployment of RP technology within SMEs, was adopted. The inclusive generic barriers shown in Chapter 3 were investigated and the relevant ones identified in relation to RP technology. They were then prioritised to develop a specific barriers list according to their influence on the deployment of RP technology in particular through the quantitative phase. To allow for the generation of relevant in-depth data and scrutiny in the second qualitative phase, regarding the fairly unmapped area of deploying RP technology within SMEs, this study used the customised RP technology list obtained from the results in Phase One. As such, this approach is considered to be a sequential explanatory mixed method research as classified by Johnson and Onwuegbuzie (2004). As a consequence, this study sets out to design a strategy to deploy the RP technology from which SMEs will benefit, based on the new emerging knowledge and the findings revealed by both the quantitative and qualitative phases.

4.5 Ethical Considerations

As advised by Lewis et al. (2009, p.168) "without paying careful attention to how you are going to gain access to the data you require and acting ethically, what seem like good ideas for research may flounder and prove impractical or problematic once you attempt to undertake them. In thinking about these aspects you need to be aware that most universities, as well as an increasing number of organisations, require researchers to obtain formal Research Ethics Committee approval for their proposed research, including their data collection methods, prior to granting access".

In advance of this research, an ethics checklist was submitted to the University Research Ethics Committee (UREC) at Bournemouth University, and the research project was granted ethical approval. The ethical challenges were acknowledged in the work done by Patton (2002). Ten significant ethical issues were outlined as follows:

1) Explaining purpose
2) Promises and reciprocity
3) Risk assessment
4) Confidentiality
5) Informed consent
6) Data access and ownership
7) Interviewer mental health
8) Advice
9) Data collection boundaries
10) Ethical versus legal

Explaining purpose: the purpose of the research was clearly explained, as were the methods used, in a precise understandable manner, when the participants were invited to take part in the study. This involved the use of practical language and included details of how the research would progress.

Promises and reciprocity: it was recognised, without doubt, by the participants that their valued contribution to this study would help to design a new strategy from which their companies would benefit. All participants were given the chance to be informed about the results of the study.

Risk assessment: the risk associated with this study was low, as there was no potential to put people under any kind of pressure. Participation was on a voluntary basis and it was explained clearly to the participants that they could withdraw at any time with no obligations. Despite this, none of the participants wanted to withdraw at any stage of this study.

Confidentiality: all the participants who were involved in this research have been guaranteed confidentiality by a signed agreement, through which all their individual/business information was protected. As Phase One was a survey questionnaire, the returned surveys were anonymous, with the exception of those received from people who gave consent to be included in the second phase of the research. With Phase Two participants, the individual and business information were coded to sustain confidentiality and were kept in a secure place.

Informed consent: both phases incorporated signing an informed consent letter, which was considered essential for this research. All related information was clarified in both phases: the covering letter (written) in Phase One, and (verbally) in Phase Two. In addition, the volunteer participants were advised that they could withdraw at any point before submitting their responses.

Data access and ownership: no one had access to the data apart from the researcher, and his supervisory team through the researcher. The researcher has present at all times when anonymous data was available to the supervisory team, and data used in conferences and publications was anonymised.

Interviewer mental health: was not considered a serious issue, as there was no potential risk associated with the study.

Advice: was maintained within the research team, and no information was needed at all times from an external consultancy.

Data collection boundaries: participation in the study was on a completely voluntary basis, so there were no data collection boundaries.

Ethical versus legal: for the purposes of legality, this research was informed and directed by the Code of Practice for Research Degrees (Policy, Procedure and Guidelines).

4.6 Phase One: Quantitative Approach

4.6.1 Overview

Phase One represents the quantitative approach of this study as a part of the mixed methods research implemented within the adopted methodology. This phase involved the design, development, management and analysis of a self-administered postal survey questionnaire. The instrument was designed and developed based on the concluded generic technology deployment barriers presented in Chapter 3, with the aim of running a preliminary test to customise and prioritise the barriers that emerged from the literature on RP technology. In addition to the main aim, the survey questionnaire instrument shed light on the most relevant features characterising the deployment of RP within SMEs. Also the survey questionnaire helped to obtain overall data on RP awareness, which was useful for developing an understanding of the factors which affect the process of deploying RP within SMEs in the South West of England.

4.6.2 The choice of Survey Questionnaire

In Lee and Broderick (2007, p.68) it was shown that “two main types of data collection methodology; communication and observation. Communication is defined as any data collection method where we must ask our research participants to give us the data we need, such as interviews or survey”. The term survey questionnaire has been used herein to refer to the instrument used for data collection. Lewis et al. (2009, p.360) indicate that “although you probably have your own understanding of the term ‘questionnaire’, it is worth noting that there are a variety of definitions in common usage”. They also argue that “some people reserve it exclusively for questionnaires where the person answering the question actually records their own answers. Others use it as a more general term to also include interviews that are administered either face to face or by telephone". A questionnaire was ultimately utilised for completion within the survey approach (Lewis et al. 2009). Since a questionnaire was used as the data collection technique, this study implemented the term survey questionnaire. Lewis et al. (2009, p.144) also found that "surveys are popular as they allow the collection of a large amount of data from a sizeable population in a highly economical way. Often obtained by using a questionnaire administered to a sample, these data are standardised, allowing easy comparison. In addition, the survey strategy is perceived as authoritative by people in general and is both comparatively easy to explain and to understand". As reported by Creswell (2008) the sequential exploratory strategy is reasonably appropriate for this kind of studies as to use the survey questionnaire instrument which has been developed.

4.6.3 Instrument Design and Development

Designing a good questionnaire requires the initial decision of what to measure. This step appears straightforward and clear but if ignored will possibly result in the creation of low value questionnaires (Fowler, 1998). The design of survey questionnaires, as stated by Sekaran (2006), relies on a number of important factors which are described in the text below. These factors are the phrasing of questions, categorisation and coding as well as the questionnaire overall layout. Lewis et al. (2009, p.387) stated that "for paper-based surveys, the use of colour will increase the printing costs. However, it is worth noting that the best way of obtaining valid responses to questions is to keep both the visual appearance of the questionnaire and the wording of each question simple (Dillman 2007)". The process of developing the survey questionnaire first involved precisely considering the wording, which needed to be in the same style as it emerged from the reviewed literature and was re-checked for suitability, clarity and quality by academics and industrialists. Secondly, the process of categorising the variables was based upon an explorative and thorough organisation of the overall factors affecting the research aim and objectives. Thirdly, the overall layout was evaluated by academics and industrialists. This was considered an essential part of the pilot study. Reliable and valid answers can only be obtained when the questions are designed properly. Within this research, the survey questionnaire was developed upon the elements that were derived from the literature and using the general rules, as provided by Fowler (2008) and Sekaran (2006), on the fundamental features of questions and answers, which are essential to a good measurement procedure.

The survey instrument was referred to as the Rapid Prototyping Deployment Survey (RPDS), and it contained four sections (a complete copy of the survey questionnaire is enclosed in Appendix B). The first section comprised collecting nominal demographic data relating to the company description including home region of the company, areas of business, major products of the company and number of employees. The following two sections were developed for the assessment of priorities and investment levels within the company relating to: In-House Design Practises; In-House Research and Development; RP Technology processes; Computer Aided Design (CAD); CNC machining; Innovation processes; Cost; Quality; Timing; and Market share. Participants responded using Likert-style scales (rating likely type for significance, and rating amount type for investment). The final section of the survey questionnaire included the barriers identified and developed from the literature, which were outlined previously in Chapter 3. To these, the participants responded using rating agreement type Likert-style scales.

The survey instrument adopted a five-point Likert-style scale to give a midpoint to allow for respondents who were uncertain of how to answer. Midpoint Likert-style scales can be used to challenge excessive situations (Albaum 1997). Furthermore, respondents are normally unenthusiastic about choosing an extreme view even though they may have one; they are more likely to take the sensible route, suggesting a communally satisfactory answer (Lee and Choi 2003). In the last part of the questionnaire there was a box for other comments, and each participant was asked to tick a box if he/she wanted to be informed about progress and the results of the study, in addition to whether he/she would be willing to take part in the second phase interviews. Dillman (2007), Lewis et al. (2009, p.392) and others have demonstrated that “the messages contained in a self-administered questionnaire’s covering letter will affect the response rate”. The purpose of the survey questionnaire was explicitly explained in a covering letter, which was placed on the first page of the survey as Lewis et al. (2009, p.207) and Dillman (2007) argue that "to achieve as high a response rate as possible, this should be done on the first page of the questionnaire in addition to the covering letter". The RPDS was verified by academics and industrialists, to address any issues relating to clarity of the instrument and to ensure that the survey would address the research questions in a suitable way.

4.6.4 Phase One Sample Frame Identification

Probability sampling was implemented since it is used extensively by researchers using survey techniques. As described by Lewis et al. (2009, p.214) "probability sampling (or representative sampling) is most commonly associated with survey-based research strategies where you need to make inferences from your sample about a population to answer your research question(s) or to meet your objectives". There were two key challenges facing this approach, the first was to find a unified standard definition of the geographical borders of the South West region. There were a few different governmental geographical definitions; consequently the study utilised the definition of the South West regional development agency. The second key challenge was to find an information database for the industrial/manufacturing SMEs in the South West of England.

There were too many databases, none of which were appropriate as they did not classify and differentiate between, for example, accountancy SMEs working with industry and a designing/engineering SME working for industry. This problem was highlighted by other researchers such as Lewis et al. (2009, p.214) who reported that: "as highlighted by research by Edwards et al. (2008), you need to be aware of the possible problems of using existing databases. In their work on multinationals in Britain, they found that: individual databases are often incomplete; the information held about organisations in databases is sometimes inaccurate; the information held in databases soon becomes out of date".

Consequently, and as indicated by Lewis et al. (2009, p.214), “where no suitable list exists you will have to compile your own sampling frame, perhaps drawing upon existing lists”, so a new and relevant database was created for the industrial/manufacturing SMEs in the South West of England. The companies’ information was collected from different sources such as online databases, yellow pages, telephones directories and paid databases. A regional database was created. While creating the database it was taken into account that it should be random, heterogeneous and representative to guarantee external validity, so that the results can be generalised. This database comprised 200 SMEs that have been or are involved in one or more activities that fall within the manufacturing, engineering and industrial product design sectors. These sectors are the main umbrellas that cover industries such as aerospace, automotive, medicine and academic research. The executive managers of these SMEs were invited to participate in the survey questionnaire on a completely voluntary and anonymous basis. In addition to that it was clarified in the covering letter that there were no foreseeable risks associated with the research. However, if they felt uncomfortable answering any questions, they could withdraw from the survey at any point. Sample size is a subject of continuous debate amongst researchers, as reported by Lewis et al. (2009, p.218), who commented that “the final sample size is almost always a matter of judgement as well as of calculation”. Therefore the reliability of this research was not affected by the sample size due to the fact that it used an exclusively created database.

4.6.5 Pilot Testing Phase One Instrument

As reported by Lewis et al. (2009, p.610), “the purpose of the pilot test is to refine the questionnaire so that respondents will have no problems in answering the questions and there will be no problems in recording the data. In addition, it will enable you to obtain some assessment of the questions’ validity and the likely reliability of the data that will be collected. Preliminary analysis using the pilot test data can be undertaken to ensure that the data collected will enable your investigative questions to be answered”. Based upon the valuable feedback from academics and industrials, as Lewis et al. (2009, p.612) advised, “initially you should ask a group of experts to comment on the representativeness and suitability of your questions. As well as allowing suggestions to be made on the structure of your questionnaire, this will help establish content validity and enable you to make necessary amendments prior to pilot testing with a group as similar as possible to the final population in your sample. For any research project there is a temptation to skip the pilot testing". The RPDS was rectified prior to the pilot testing.

The instrument was sent by post to 20 SMEs to complete the survey questionnaire and return it using the enclosed pre-stamped self-addressed envelopes, and 8 responded representing a response rate of 40%. The returned survey questionnaires were all completed and one of the participants provided feedback relating to the simplicity of the instrument and how it was surprising to find parts of the survey matched some internal concerns they had recently flagged up for consideration. The respondent's completion of the survey was acknowledged as there were no issues with the wording of the instrument, and this was an indication that the questionnaire was clearly worded and well laid out. Using SPSS predictive analytics software, a data file was constructed to check for any unexpected structural and format issues. The result was that there were no problems arising from the pilot study. The complete analysis and outcomes of the survey questionnaire are included in Chapter 5.

4.6.6 Administering the survey questionnaire

To start the data collection process the survey questionnaire was sent by post to be filled in by the participants. They were posted to respondents who returned them by post after completion using the enclosed pre-stamped self-addressed envelopes. The potential strengths and weaknesses of postal surveying were considered before the decision was made to use this method. The main strengths were described by Oppenheim (2000), as this can be an effective, low administration cost, technique for collecting data from a large and widespread sample. An additional strength is that data collected using survey questionnaires is free of any bias effects, as the researcher is not present while the participants answer the questions. Therefore the participants will not intentionally or unintentionally be influenced by the researcher, in one way or another, to answer in any specific direction. The possible weaknesses of postal surveys where identified by Lewis et al. (2009) and Oppenheim (2000), and include issues related to the fact that the researcher will not be present when the questionnaire is filled out. This means that the participants do not have an opportunity to clarify anything which is ambiguous, and they may respond in the wrong order or incompletely or ask someone else to fill in the questionnaire. That was avoided in this study by the careful and clearly worded design of the questions and the well laid out appearance.

Despite the fact that the response rate of postal surveys is subject to different factors, the return rate is likely to be lower the more time and effort it takes to complete a questionnaire. However, in this study the response rate was likely to be higher, due to the importance and state-of-the-art of the investigated research question. The responses included replies from 21% product/industrial design based SMEs, 30% engineering based SMEs and 49% manufacturing based SMEs. Out of the 55 returned surveys, 50 valid surveys were initially utilised in this study with a 28% response rate which is above the typical response rate for this type of study. Based on the literature findings, the typical response rate for strategic studies is 10-12% (Carey et al.; Kargar and Parnell 1996; Mckiernan and Morris 1994; O'Regan and Kling 2011; Pearce et al. 1987; Raymond and Croteau 2006). Those excluded were partially uncompleted questionnaires.

4.6.7 Data Analysis

In order to address the research question, and the key questions 1-4, Phase One results were statistically analysed to identify the following issues:

1. The level of awareness within SMEs of the available new technologies.
2. The extent to which RP technology is recognised within the SMEs.
3. The extent to which SMEs are deploying RP technology.
4. The common barriers that hinder the deployment of RP within SMEs, and which comes first?

Of primary importance was to prioritise the barriers hindering the deployment of RP technology within SMEs in the South West of England. The statistical analysis was done using SPSS predictive analytics software. The results which emerged from Phase One are explained in Chapter 5, however the analysis techniques which were used, together with their rationales, are made clear in this chapter. The data collected through the completed questionnaires were manually entered into an Excel™ spread sheet, which was time consuming but useful because it gave good insight into the data collected. The use of postal surveys as a method significantly reduced the time and effort needed to sort out missing data as any uncompleted responses were eliminated from the data set before starting the data preparation process. The data was then managed in Excel™ before it was uploaded to SPSS. An SPSS database was created from the uploaded Excel™ file, and was reviewed for any missing data.

Subsequent to the data inspection process, the initial analysis took place by classifying the categorical statistics data into two types: descriptive data and ranked data. The descriptive data was associated with all variables with nominal scales, such as the demographic questions, and the ranked data was associated with those variables with ordinal scales, such as the ranking questions. It is essential when conducting a quantitative analysis to understand the nature of data in order to analyse it correctly as stated by Lewis et al. (2009, p.593): "understanding differences between types of data is extremely important when analysing your data quantitatively, for two reasons. Firstly, it is extremely easy with analysis software to generate statistics from your data that are inappropriate for the data type and are consequently of little value. Secondly, the more precise the scale of measurement, the greater the range of analytical techniques available to you".

Central tendency and dispersion values were calculated for both data types. This initial analysis provided the study with an opportunity to explore the overall trends in the analysed data. Lewis et al. (2009, p.606) and Tukey (1977) argue that "exploratory data analysis (EDA) approach useful in these initial stages. This approach emphasises the use of diagrams to explore and understand your data, emphasising the importance of using your data to guide your choices of analysis techniques”. As soon as the ranking results for the barriers were available, a correlation analysis was then conducted to determine whether an association relationship existed between them. The trends which emerged and details of the analysis are clarified in Chapter 5.

4.7 Phase Two: Qualitative Approach

4.7.1 Overview

Phase Two represents the qualitative approach of this study as a part of the mixed methods research implemented within the adopted methodology. This phase involved the design, development, administration and analysis of semi-structured interviews to address the identified and prioritised RP technology adoption barriers identified in the course of Phase One. This phase was conducted through a number of interviews with executive managers within the SMEs in the South West of England. The interviews took place in their business locations, and each lasted for approximately one hour. The interviews were one-to-one, face-to-face as described by Lewis et al. (2009, p.321): “interviews may be conducted on a one-to-one basis, between you and a single participant. Such interviews are most commonly conducted by meeting your participant ‘face to face’, but there may be some situations where you conduct an interview by telephone or electronically via the Internet or an organisation’s intranet”. Prior to conducting Phase Two, a pilot test was administered to test the interview process; it involved two interviewees from different companies. The pilot analysis results showed that no improvements were needed to the interview process. The following sections provide detailed information on the adopted methodology, participants, data collection and analysis.

4.7.2 The Choice of Semi-Structured Interviews

Carruthers (1990, p.65) argues that “the interview is used to gather descriptive data in the subject's own words so that the researcher can develop insights on how subjects interpret some piece of the world”. Qualitative researchers use interviews to find out people’s experiences, perceptions, values, and opinions. Interviews typically offer descriptive, second-hand knowledge via intermediaries (Lee and Broderick 2007). A semi-structured interview approach is widely used to conduct qualitative research, therefore they are often referred to as ‘qualitative research interviews’ (Lewis et al. 2009). According to Humphries-Smith (2010), “semi-structured interviews have the advantage of being more naturalistic and therefore less likely to obtain data is influenced by the interviewee giving what they consider to be the correct answer. Also as conversation is not directed the connection of certain events/issues by the interviewer can be illuminating and new information that was not anticipated by the interviewer can come to light because the interviewee in part directs the conversation”. Lewis et al. (2009, p.320) stated that “in semi-structured interviews the researcher will have a list of themes and questions to be covered, although these may vary from interview to interview”. This particular advantage of semi-structured interviews rendered them flexible tool which helped in managing the interviews efficiently.

Semi-structured interviews were highly recommended in this specific study due to their nature, as indicated by Lewis et al. (2009, p.323), who stated that “increasingly authors also emphasise how semi-structured or in-depth interviews, may also be used as part of mixed methods research, such as a means to validate findings from questionnaires”.

The combination of the survey questionnaire plus the semi-structured interviews was deployed to maximise the potential for a much clearer understanding of the research questions, as per Carruthers (1990, p.66) statement: “questionnaires plus interviews may not reflect a perfect picture but they reflect a clearer image than do questionnaires alone”. Likewise as reported by Tashakkori and Teddlie (1998) and cited by Lewis et al. (2009, p.323), “semi-structured interviews may be used to explore and explain themes that have emerged from the use of a questionnaire”.

In fact, the semi-structured interview approach has the strength that it gives a more complete understanding of the survey questionnaire findings. This was pointed out by Carruthers (1990, p.67), as “the interview findings never contradicted the findings from the questionnaires but there were indications of differences of emphasis. Such is the warmth that interviews can add to cold data". Semi-structured interviews give interviewees a chance to think aloud in a way they may not have experienced before, as well as providing the researcher with an opportunity to 'probe' answers, as a tool for elaboration, offering a chance for interviewees to clarify, or to develop their responses (Lewis et al. 2009). This particular study is positioned within the main research categories as an explanatory mixed methods investigation (Table 4.2). All interviews were digitally-audio- recorded after consent from the participants was obtained, and some notes were taken by the interviewer concerning unplanned issues and points which arose.

Table 4.2 Uses of different types of interview in each of the main research categories

	Exploratory	Descriptive	Explanatory
Structured		✓✓	✓
Semi-structured	✓		✓✓
Unstructured	✓✓		

✓✓ = more frequent, ✓ = less frequent.

(Source: Lewis et al. 2009)

4.7.3 Interview Questions

The aim of Phase Two was to further investigate the identified and prioritised barriers that hinder the deployment of RP technology within SMEs. Through the use of semi-structured interviews as an appropriate data collection method, as described by Lewis et al. (2009, p.176), "an interview will undoubtedly be the most advantageous approach to attempt to obtain data in the following circumstances: where there are a large number of questions to be answered; where the questions are either complex or open-ended; where the order and logic of questioning may need to be varied. A semi-structured or in-depth interview will be most appropriate for the latter two types of situation".

The questions used in the interviewing process were developed from the literature review and Phase One findings. The key objective while conducting the interviews was to identify the factors which help the barriers to flourish and the potential drivers to eliminate these barriers in common agreement between participants. Probing questions are important in interviews, as described by Lewis et al. (2009, p.598): “probing questions can be used to explore responses that are of significance to the research topic. They may be worded like open questions but request a particular focus or direction”. In qualitative research interviews, probing questions cannot be prepared prior to the interview. They are vital to make sure that all scrutinised themes are covered while the interviews progress, but it is unmanageable to anticipate what associated themes the participants might discuss. Nevertheless some probing questions were prepared for use in case any relevant issues were discussed, and within the interviews other probing questions were asked by the interviewer depending on what was raised while conducting the interview. It was taken into account that the unplanned probe questions should be used on an unbiased basis. Each participant was asked at the end of the interview to highlight and summarise the main concerns discussed (a complete copy of the interview questions is enclosed in Appendix C).

4.7.4 Phase Two Sample Frame Identification

At the end of the survey questionnaire, participants were given a tick box in which to indicate their interest in the research and to give their consent to be invited to the second phase of this study. In total, ten executive managers’ consent was obtained, and those who indicated a passionate interest and provided their consent were identified from the personal information they willingly provided. Lewis et al. (2009, p.266) reported that “we have found that managers are more likely to agree to be interviewed, rather than complete a questionnaire, especially where the interview topic is seen to be interesting and relevant to their current work. An interview provides them with an opportunity to reflect on events without needing to write anything down”. A personal telephone call was made to each one of them, firstly to thank them for their response to the survey questionnaire and secondly for agreeing to participate in the second phase. At the start of Phase Two, another personal telephone call was made to inform them about the interview process, and to check their availability in the following few weeks. Each participant’s date/time needs were met, and the researcher travelled to conduct the interviews at the business locations of nine out of ten respondents, although one of the participants was visiting Bournemouth and suggested coming to Bournemouth University for the interview.

The only concern which emerged was deciding on the sample size, but due to the fact that selecting the participants was totally subject to their willingness to volunteer, the second phase study implemented a convenience sampling technique which Lewis et al. (2009, p.592) described as “convenience sampling (or haphazard sampling), and involves selecting haphazardly those cases that are easiest to obtain for your sample”. Whilst this could be seen as a limitation, it was considered to be a benefit, since it made access easier to the participants and provided the necessary consent even before conducting the interviews.

Moreover when the seventh interview was conducted, it was recognised that no new data was emerging and, as indicated by Lewis et al. (2009, p.241), “the sample selection process is continued until your required sample size has been reached”. The interviewer decided to continue conducting interviews with all the volunteers in the sample, firstly as an appreciation of the participants who had set aside their time to be interviewed, and secondly to confirm that the second phase of the data collection had indeed accomplished its aims.

4.7.5 Pilot Testing the Phase Two Interviews

Piloting the interview process is fundamental to building competency, which provides an essential visualisation relating to the research progression. The pilot study should involve the data collection and analysis techniques, so that the objectives of the study can be met and the anticipated research results attained. Lewis et al. (2009, p.610) reported that “preliminary analysis using the pilot test data can be undertaken to ensure that the data collected will enable your investigative questions to be answered”. Furthermore, the pilot test can be used to assess the validity and reliability of the interview process (Lewis et al. 2009). In this study, once the interview questions and process were developed, a pilot test was conducted. Two executive managers representing two different companies out of ten executive managers who had shown an interest in participating in the second phase and had provided consent during the first phase were interviewed to test and assess the clarity and suitability of the interview questions. The pilot study showed that there was no need to revise the interview questions or the interview process. Subsequently it was decided to include these two pilot interviews in the main sample due to the small number of consents that were obtained in the first phase of the study.

4.7.6 Conducting the Interviews

The interviews were conducted to provide more data on the barriers hindering the deployment of RP technology within the SMEs. They also provided a wide range of relevant data which revealed why RP technologies are not appropriately deployed within SMEs. Part of the interview discussed the outcomes of the Phase One survey questionnaire, where the participants had indicated that they were a good reflection of what is really hampering the process. Also they supported the consideration of these barriers by providing their detailed perception with regard to what keeps these barriers active and also their insight on how to disengage them from the practise. The researcher began the interviews by expressing his gratitude for their agreement to participate in this study and introduced himself by providing detailed information about his qualifications, level of knowledge, and why he was conducting this research. Also he explained to the interviewees that their confidentiality and anonymity would not be compromised in any way, and asked them for consent to the use of digital-audio-recording equipment to record the interviews. Lewis et al. (2009, p.321) argue that “by audio-recording your interview, you will be able to concentrate more fully and listen attentively to what is being said and the expressions and other nonverbal cues your interviewee is giving when they are responding”; also they set out the advantages and disadvantages of recording interviews (see Table 4.3). This study maximised most of the advantages and minimised all the disadvantages as all of the interviewees gave their consent without hesitation. Two recording devices were used to eliminate the possibility of a technical problem. The time required to transcribe the audio-recording was huge, but the researcher benefited from this because he gained deep insight into the data. All interviewees were asked, at the end of this stage in the interview, to sign an information sheet indicating their acceptance of the points discussed above, and all were happy to do so.

Table 4.3 Advantages and disadvantages of audio-recording the interview

Advantages	Disadvantages
• Allows interviewer to concentrate on questioning and listening • Allows questions formulated at an interview to be accurately recorded for use in later interviews where appropriate • Can re-listen to the interview • Accurate and unbiased record provided • Allows direct quotes to be used • Permanent record for others to use	• May adversely affect the relationship between interviewee and interviewer (possibility of 'focusing' on the audio-recorder) • May inhibit some interviewee responses and reduce reliability • Possibility of a technical problem • Time required to transcribe the audio-recording

(Source: Lewis et al. 2009)

Following this stage, the interviewees were invited, at the start of the interview, to introduce themselves and to state their qualifications and role within the business. This information was important as as its correlation with the identified barriers was to be tested. The developed interview key questions were designed to directly identify the issues which relate to technology adoption within SMEs and in particular the drivers and barriers to RP deployment within SMEs. Then the researcher transcribed all the recorded interview audio files and reviewed them to check the content as well as detect any inaccuracies. For themes to emerge, this required a deep understanding of the data, therefore all transcripts from both the pilot study and main study were analysed manually by the researcher. Manual analysis was adopted due to the fact that the total number of interviews was relatively small.

4.7.7 Data Analysis

This study adopted the thematic analysis technique, which Fereday and Muir-Cochrane (2008, p.82) describe as follows: "thematic analysis is a search for themes that emerge as being important to the description of the phenomenon. The process involves the identification of themes through 'careful reading and re-reading of the data'. It is a form of pattern recognition within the data, where emerging themes become the categories for analysis". The codes which emerged from the data collected were underlined with different colours and then categorised with different text highlights. One of the strengths of thematic analysis for qualitative data is the fact that it is a flexible route to analysis, which allows the researcher to alter its use in line with the needs of the study (Lewis et al. 2009).

Although the transcription process took a great deal of time, the coding started naturally while transcribing and, whilst the codes were not yet well established, this allowed the initial analysis process to start at the early stages of data collection. This continuing method of transcription and coding meant that the data analysis and transcription were to a certain extent simultaneous, which had a great impact on the development of a balanced analytical process. After the transcription process, a familiarisation stage took place which involved continually listening to the audio-recorded interview files and simultaneously and carefully reading from the transcripts. This was needed to help the researcher to come to grips with the content of the discussions and to discover promising clues for potential associations.

Ten interview transcripts were analysed and coded to identify the potential common themes, the emerging codes were reviewed and some codes were combined and/or refined. Some other codes were allocated to more than one category during the process where the content they characterised was found to be adequately suitable, and these codes were cross marked so that they could be tracked without difficulty. Then a charting stage took place, which resulted in 468 topic codes which were derived from the data and were grouped for similarity of content into 22 categories that were then further grouped into five main themes. Following the charting stage, an interpretation phase began so as to identify the explanation for prospective outcomes. These themes showed correlations with the issues identified from the literature review and Phase One outcomes. The consistent and significant issues impacting on the deployment of RP technology within SMEs were identified. These findings supported the results obtained in Phase One and are presented in detail in Chapter 6.

4.7.8 Reliability and Validity

As indicated by Lewis et al. (2009, p.560), "reducing the possibility of getting the answer wrong means that attention has to be paid to two particular emphases on research design: reliability and validity". Validity and reliability were considerable issues in this methodological approach, as were the choices made with regard to how the data was collected and analysed. Reliability "refers to the extent to which your data collection techniques or analysis procedures will yield consistent findings", while "validity is concerned with whether the findings are really about what they appear to be about" (Lewis et al. 2009).

The threats to reliability may be one or more out of four, namely: subject or participant error; subject or participant bias; observer error and observer bias, as specified by Lewis et al. (2009). With regard to subject or participant error, Lewis et al. (2009, p.452) define it as "errors that may occur when research subjects are studied in situations that are inconsistent with their normal behaviour patterns, leading to atypical responses". Therefore, by knowing that the sample was carefully chosen and the data collection methods were conducted within the normal performance patterns of the SMEs this threat was minimised. With reference to subject or participant bias, Lewis et al. (2009, p.228) identifies this as "bias that may occur when research subjects are giving inaccurate responses in order to distort the results of the research", which is a valid concern. However, in this research this was not applicable due to the fact that neither the researcher nor the participants had any interest in directing the results in a particular way. The other two threats did not apply to this investigation, thus in this study the four threats were minimised. In addition, as previously discussed, both data collection methods was prudently planned, carefully designed, well worded, and tested before use. Furthermore, recommended procedures were followed in relation to confidentially, anonymity and ethical issues for both phases.

On the other hand, the threats to validity are: history, testing, instrumentation, mortality, and maturation. These threats were also minimised as the historical background was not affected by any up-to-date events which could have influenced the participant's responses. Likewise, testing was not an issue, as there was no disadvantage to the company from participating in the research. Finally with regard to instrumentation, mortality and maturation, these were not seen to be threats because participation in the study was voluntary. Therefore reliability and validity threats were minimised. As reported by Lewis et al. (2009, p.365), “the design of your questionnaire will affect the response rate and the reliability and validity of the data you collect. Response rates, validity and reliability can be maximised by careful design of individual questions; clear and pleasing layout of the questionnaire; lucid explanation of the purpose of the questionnaire; pilot testing; carefully planned and executed administration”.

4.7.9 Generalisability

It is hard to claim that this research can be easily generalised, due to the sample region boundaries, but at the same time it is hard to claim that it cannot be generalised, simply because of the random selection of participants. Also, SMEs globally - not only in the UK - have many features in common, as indicated by the literature. Therefore it is extremely important to test the robustness of the conclusions of this research by exposing them to other SMEs in different regions/countries in follow-up studies to measure their generalisability. It would not be a surprise to find that they apply perfectly, with or without additional customisation, which would be subject to the companies’ circumstances.

4.8 Chapter Summary

This chapter provided a detailed description of the methodology used within this research, plus an explanation of the research design and the methods applied to achieve the aim of this study and to answer the research questions. This included an outline of the mixed methods approach utilised by this research, and justifications for the two sequential phases in this study. Phase One, the quantitative approach, employed a survey questionnaire, and the entire process of design, development, administration and analysis was explained. Phase two, the qualitative approach, employed semi-structured interviews along with thematic analysis technique addressing the aim of this study. All data collection stages were explained, starting with choosing the sample and ending with the analysis. Similarly, ethical considerations were addressed as applicable to the study. Reliability, validity and generalisability were also discussed. The next chapter presents the findings of Phase One.

Chapter 5
Phase One Findings

5.1 Chapter Overview

This chapter presents the findings from the first phase of this study, the quantitative approach, which was designed to identify and prioritise the barriers hindering the deployment of RP technology within SMEs which emerged from the review of literature in the early stages of this study. This chapter also provides specific details about the research participants, data collection and data analysis. The methods used for this research were rationalised in the comprehensive discussion provided in Chapter 4. Figure 5.1 shows the chapter structure. A large part of this chapter has been peer reviewed and published in the International Journal of Knowledge, Culture and Change Management, Annual Review. The article is enclosed in Appendix A.

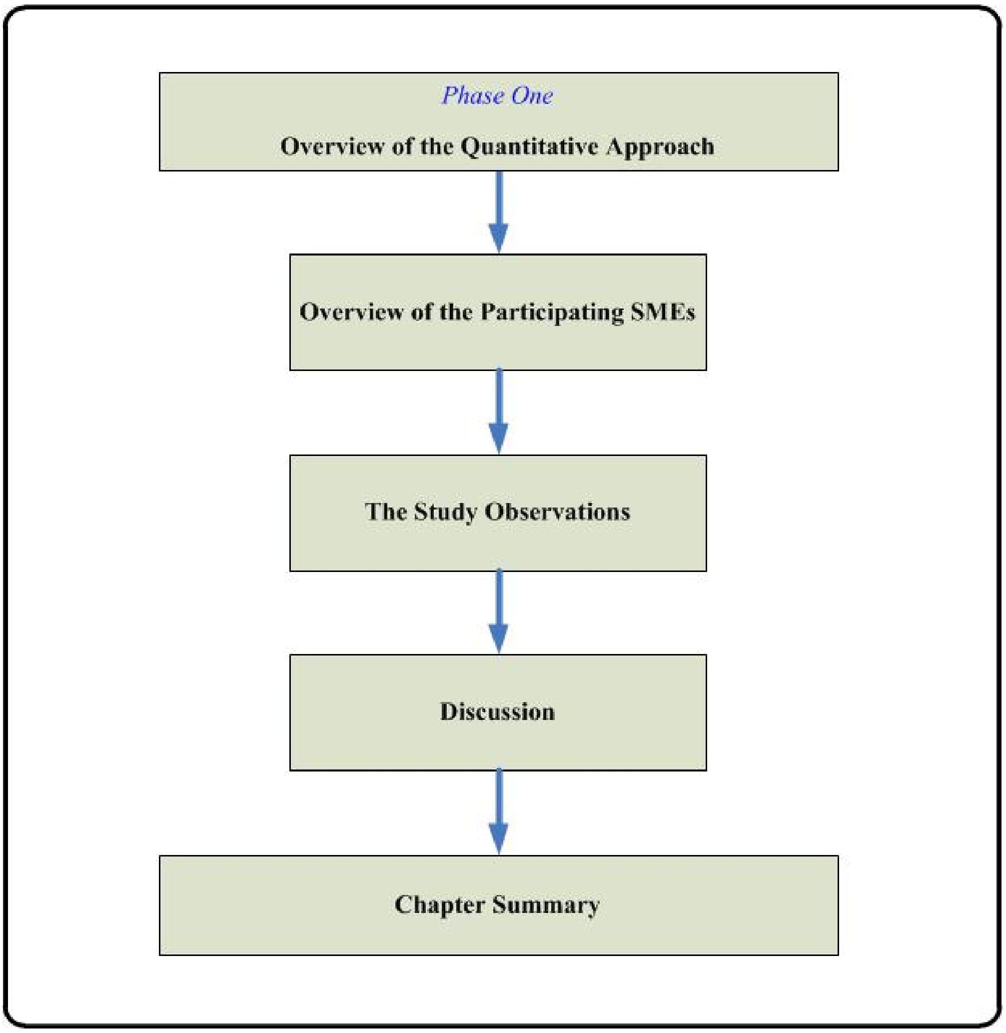

Figure 5.1 Chapter 5 structure

5.2 Overview of the Approach

This study implemented a quantitative data approach using a self-administered postal structured survey questionnaire, delivered to potential participants with a pre-addressed/pre-stamped return envelope. This approach was used because surveys of this kind are able to study large samples, to look at large numbers of variables, and are cost effective in relation to geographical coverage (Axinn and Pearce 2006; Fowler 1998, 2008; Humphries-Smith 2010). The detailed methodological discussion is provided in Chapter 4.

A representative sample region was selected on the basis of regional development, where the South West of England (SW) was found to be the most appropriate region for this particular study. Harrison (2010) stated that the South West continues to derive more employment and turnover from SMEs than any other region. The industry data shows variations in dependence on SMEs by industry. In some industries, such as manufacturing, the South West shows a particular dependence on SMEs. Cooling (2011) describes businesses in the South West as leading innovation and being the most optimistic about job creation in the coming year. In 2009 data for the South West, 99.4% of enterprises were classified as small (UK 99.3%) – see Figure 5.2. The majority of these had four or fewer employees (91.6% of South West enterprises, UK 91.2%). Only 0.4% of South West enterprises were classed as medium-sized (UK 0.6%). Only 480 enterprises in the South West were classed as large, making up less than 0.1% of total South West enterprises (UK 0.2%) (Harrison 2010).

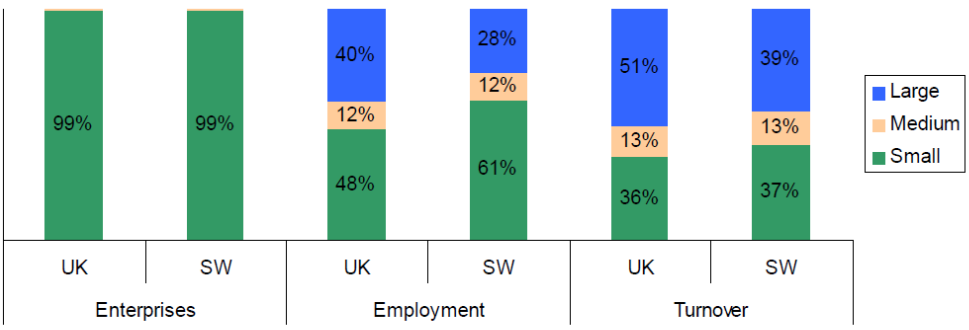

Figure 5.2 Percentage shares of SMEs and large enterprises (Source: Harrison 2010)

SMEs in the South West have seen the greatest increase in headcount over the last three years; SMEs in the South West have the most confident outlook on growth out of all regions, followed by those in London and Wales (Cooling 2011). The South West has the fifth highest number of enterprises within the regions, but has the third highest number of enterprises per 10,000 adults (1,084), behind London (1,352) and the South East (1,097) (Harrison 2010). Even though shares of SMEs are similar regionally and nationally, as Figure 5.2 shows the South Wests's economy is far more dependent on SMEs than the UK average in terms of both employment and turnover (Harrison 2010). This has made the region of South West of England of adequate nature, and its statistical findings with a very high significance. Therefore the probability that the results can be generalised is high.

There were two key challenges facing this approach, the first of which was to find a unified standard definition of the geographical borders of the South West region. There were a number of governmental geographical definitions, but the study utilised the definition of the South West Regional Development Agency (SWRDA), which included only the following areas: Bournemouth, Dorset and Poole; Cornwall and the Isles of Scilly; Devon; Plymouth and Torbay; Gloucestershire; Somerset; Swindon and Wiltshire; and the West of England (Figure 5.3). The RDA was set up in 1999, and was closed down in September 2011 after the new Coalition Government announced the abolition of RDAs in June 2010 and Local Enterprise Partnerships (LEPs) were announced as their replacements. It was decided not to consider this governmental procedure as a concern with regard to the adopted definition of the South West of England, as this has no effect on the geographical borders of the region. Also at the time when the RDA was wound down, the questionnaire survey had been completed.

Figure 5.3 South West of England regional border as defined by the SWRDA
(Source: South West RDA-Short History-Published:
September 2011-Doc Ref: Goodbye1)

The second challenge was to find an information database for the product design, industrial design, engineering, and manufacturing SMEs in the South West of England. There were too many databases, none of which were appropriate as they did not classify and differentiate between, for example, accountancy SMEs working with industry and design/engineering SMEs working for industry. Therefore, it was decided to create a new and specific database for the SMEs involving design/industrial/manufacturing practices within South West of England. The data needed to produce this database was collected from various sources such as online databases, yellow pages, telephone directories and paid databases. A regional database of 200 SMEs was created. While building the database it was taken into account that it should be random, heterogeneous and representative to guarantee external validity, so that the results could be generalised.

The survey consisted of questions in four sections. The first section asked about the company profile, the second discussed the significance of priorities within the company, the third looked at the particular investment level within the company, and the fourth investigated the barriers which the respondents believed to be the main difficulties. In addition to the four sections, the survey included a free text space for other comments, to allow the respondents to freely express and address any other related issues. The survey was tested and piloted for significance, clarity and completeness. Due to the nature of SMEs, it was determined that executive managers were the required informants who could appropriately respond to the survey. As choosing the correct informants can rational any possible general means of conflict issues (Miller and Roth 1994; O'Regan and Kling 2011; Phillips 1981).

5.3 Overview of the Participating SMEs

The SMEs which participated in Phase One were the enterprises located within the previously identified borders of South West England and operating within the design, engineering and manufacturing sectors. Responses to the Rapid Prototyping Deployment Survey (RPDS) 2011 presented a breakdown of the three major sectors as follows: manufacturing 54.76%, engineering 30.59%, and product and industrial design 14.29%. Figure 5.4 shows the percentage of SMEs responding per business sector, but when calculating the combined percentage of the SMEs involved in two sectors or more, the total percentage became 21% product/industrial design based SMEs, 30% engineering based SMEs and 49% manufacturing based SMEs.

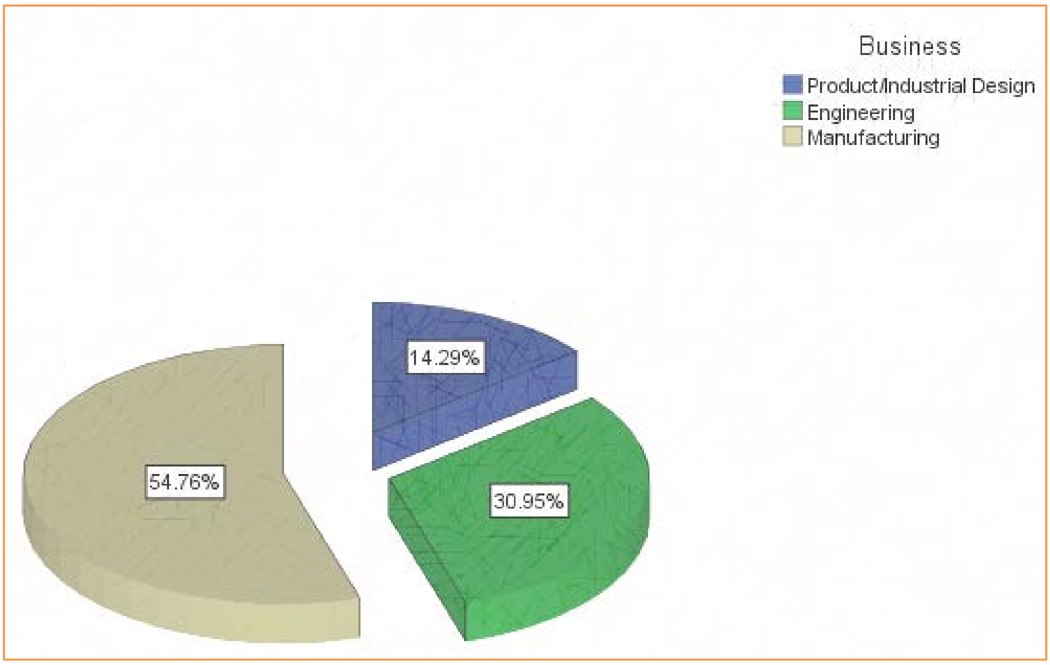

Figure 5.4 Percentage of SMEs responding per business sector

These SMEs cover a very wide range of industrial and manufacturing practices, as well as a broad base of products which varied as follows:

- Ultrasound Thickness Gauges
- Air Bearing Products for the Electronics Industry
- Semi-Conductor Industries
- Wheelchair Accessible Vehicles
- Hydraulic Power Units and Electronic Controllers
- Metal Sewing Machines
- ID Card Printers
- Design and Build Model Rail Products
- Land Based Robotics
- Sound Mixers
- Cosmetic Packaging
- External Prosthetic Products
- Orthotic Products Special Seating
- Various Pump Manifolds
- Under Water Survey Equipment
- Sub-Contract Precision Engineering
- Aerospace Components

- Bicycles
- Marine Exhaust Systems Manufacture
- Watch Straps and Bands
- Anaerobic Dry Glove Box Systems
- Media Platforms, IVR, Telephony Boards, Messaging Gateways
- Heavy Duty Industries
- Castors and Wheels
- Electrode Holders for the Glass Industry
- Fertiliser Spreaders
- Aerospace Parts
- Marine Industries
- Railways
- Industrial Fans
- Dynamic Movement
- Hydrophones
- Ultrasound Transducers
- Heating and Ventilation Controls
- Access Control Systems
- Food Spray Equipment
- Deep Water Equipment
- Environmental Monitors Under Water
- Metal Detectors
- Hydraulic Pumps
- Hydraulic Valves
- Subcontract Precision Engineering
- Rocket Fuel Valves

With regard to the representation of each area in the study, Figure 5.5 shows the percentage of responses to the RPDS for each area of the South West. In terms of size, the whole spectrum of SMEs was represented, and Figure 5.6 shows a break-down of SME participants by company size.

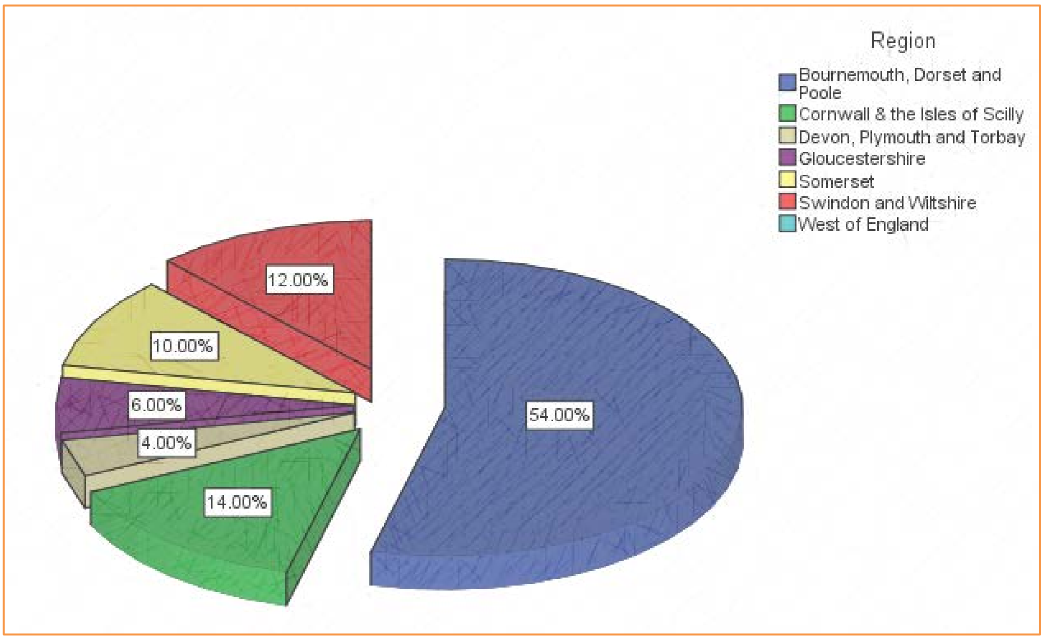

Figure 5.5 Percentage responding to the survey for each area of the SW of England

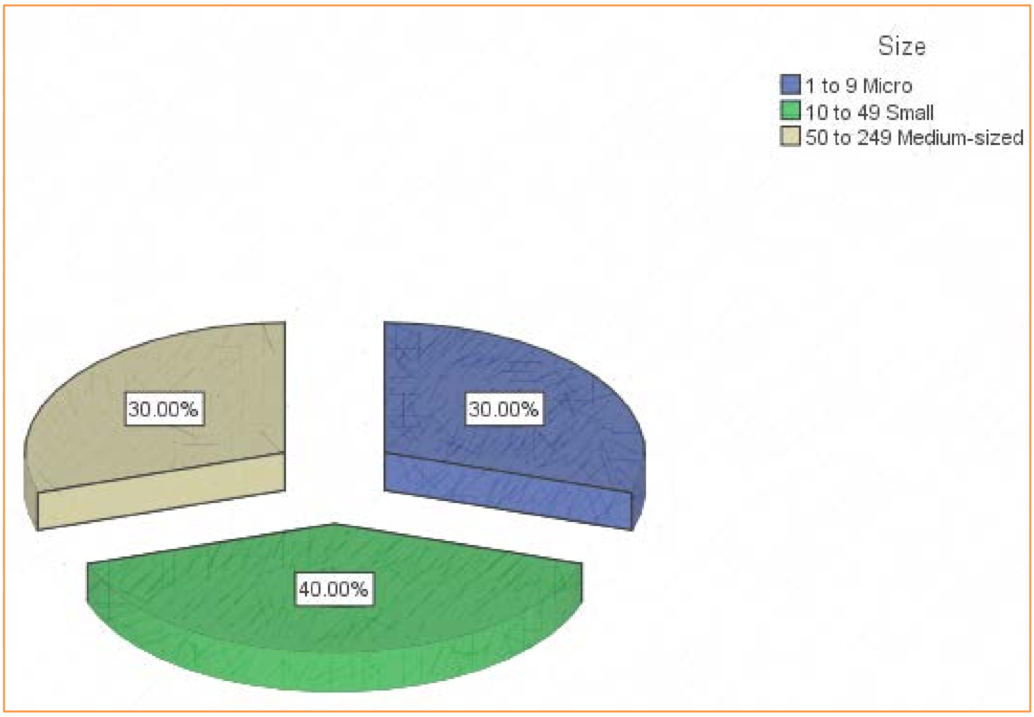

Figure 5.6 Percentage participation of each SME size category in the study

The survey questionnaire administered for Phase One was mailed to the 200 SMEs in the South West. The survey envelope included a covering letter inviting the executive managers to voluntarily participate in the RPDS and an information sheet informing them of the nature of the study while emphasising that their confidentially/anonymity was guaranteed. A total of 55 responses were received, excluding those which were incomplete. As soon as no more responses had been received for 14 consecutive days, it was decided to start the analysis process, and the data were manually entered into an Excel™ spread sheet. The data was then managed in Excel™ before it was uploaded to SPSS software.

An SPSS database was created based upon the uploaded Excel™ file, and was reviewed for any missing data. This data provided a comprehensive ranking for the barriers which hamper the deployment process of RP technologies within SMEs in the South West region of England, along with key enabler points which were further investigated in the second phase of this study.

5.4 The Study Observations

The survey statistical aggregated findings are presented below:

• 82% designated in-house design practices as significant to their companies while only 42% of them invested in this area of their business (Figure 5.7).

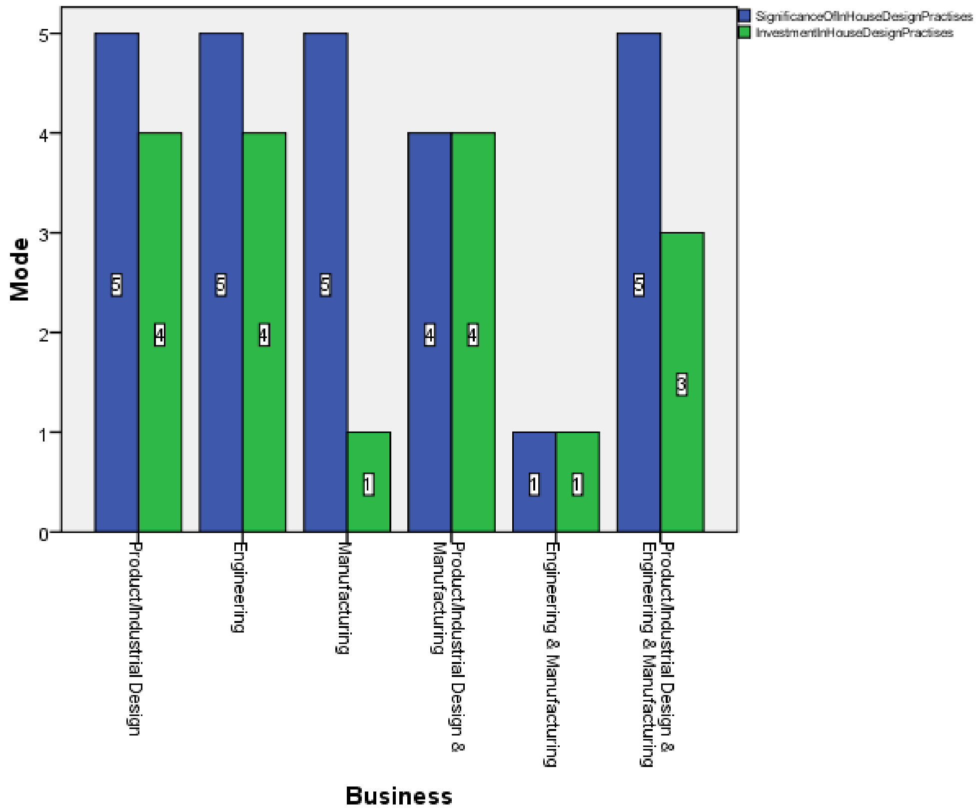

Figure 5.7 In-house design practices: levels of significance and investment

The company size influenced the in-house design practices, as they were: most significant but with no investment within micro sized (1 to 9 employees) enterprises; very significant with moderate investment within small sized (10 to 49 employees) enterprises; and most significance with moderate investment within medium-sized (50–249 employees) enterprises (Figure 5.8).

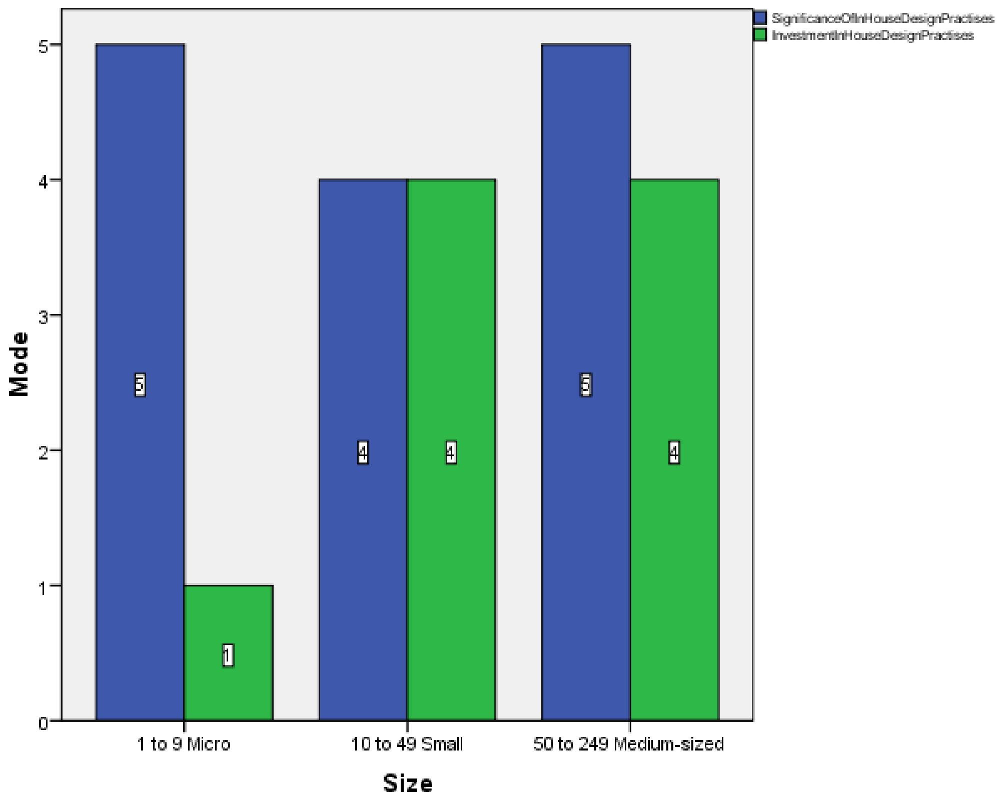

Figure 5.8 Business size influence on in-house design practices

• 82% designated in-house research and development as significant to their companies while only 34% of them invested in in-house research and development (Figure 5.9).

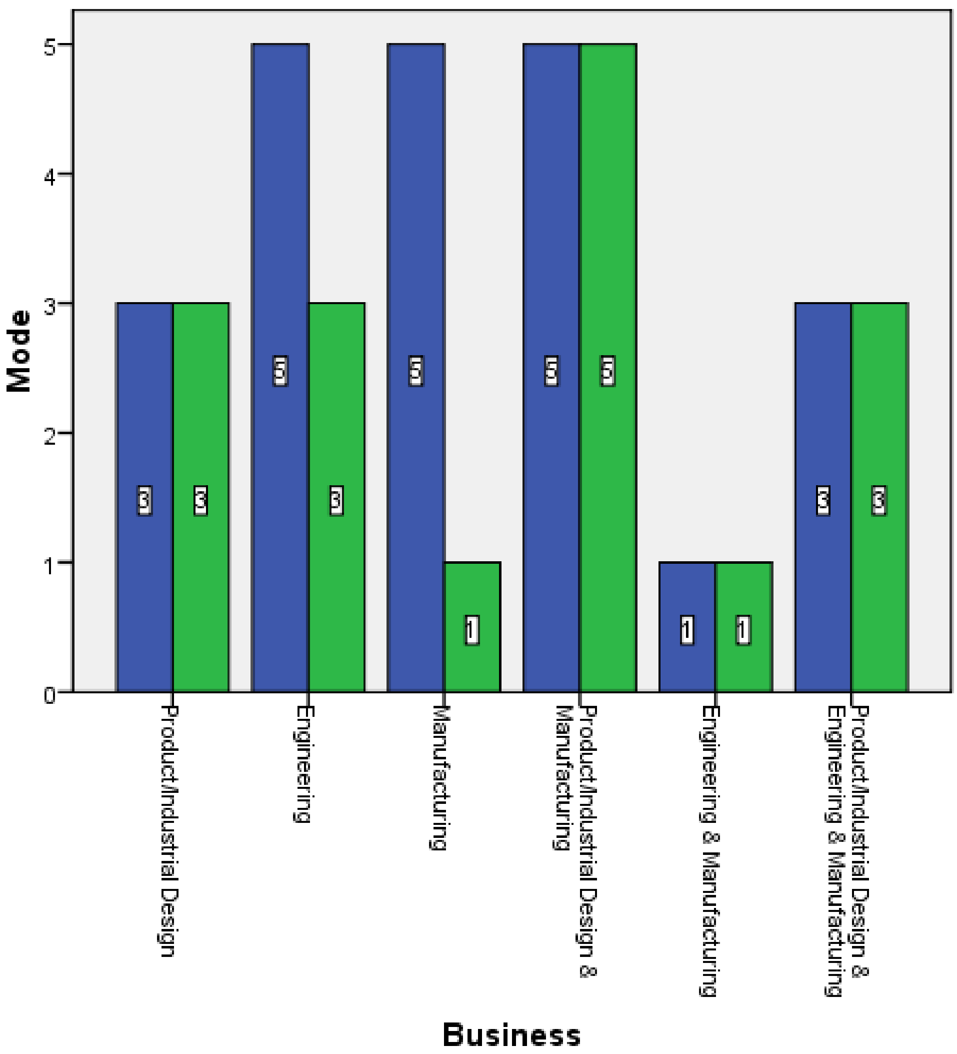

Figure 5.9 In-house research and development levels of significance and investment

The company size influenced the in-house research and development, as it was: most significant with no investment within micro sized enterprises; significant with no idea with regard to investment within small sized enterprises; and most significant with no idea about investment within medium-sized enterprises (Figure 5.10).

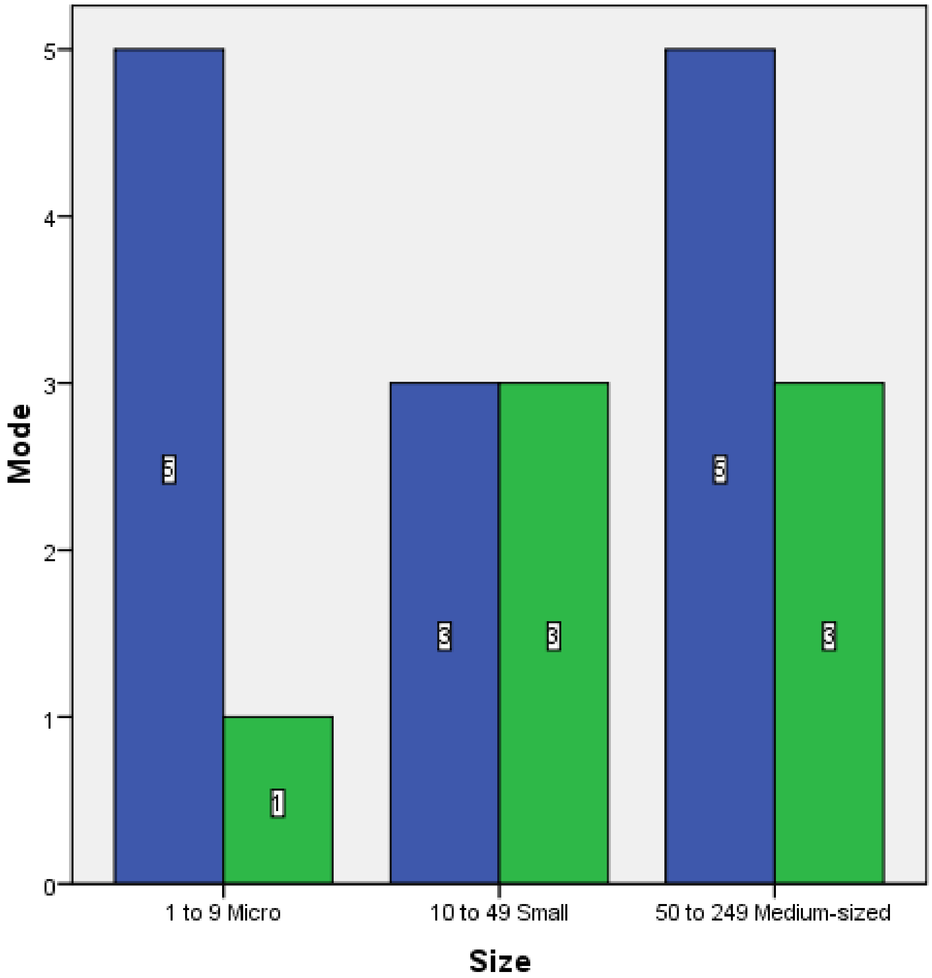

Figure 5.10 Business size influence on in-house research and development

• 30% designated RP technology processes as significant to their companies when only 10% of them invested in RP technology processes (Figure 5.11).

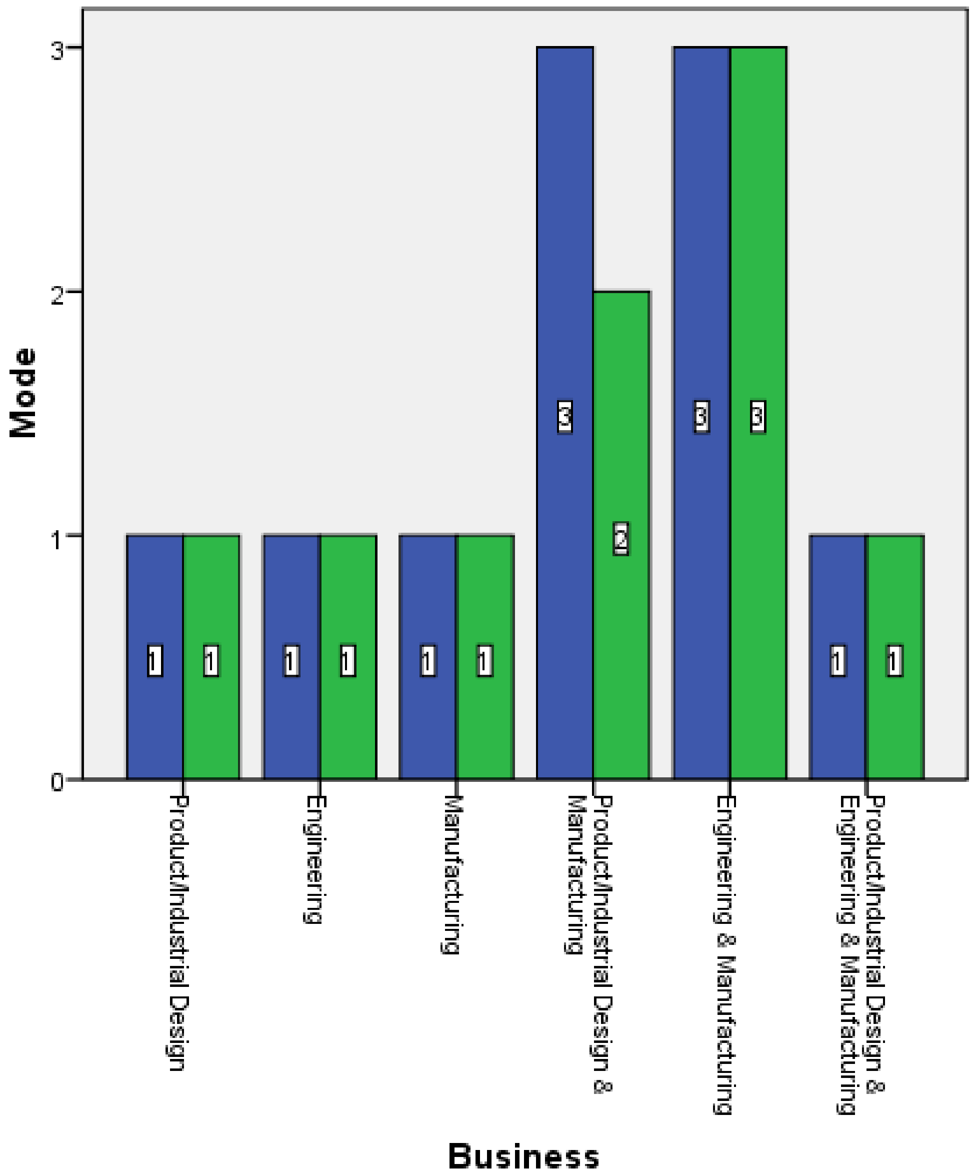

Figure 5.11 RP technology processes: levels of significance and investment

The company size has no influence on RP technology processes, as it was not significant, with no investment, within micro sized, small sized and medium-sized enterprises. This shows that RP technology should be considered across the whole spectrum of SMEs, as such technology can be used for the development of a company regardless of size (Figure 5.12).

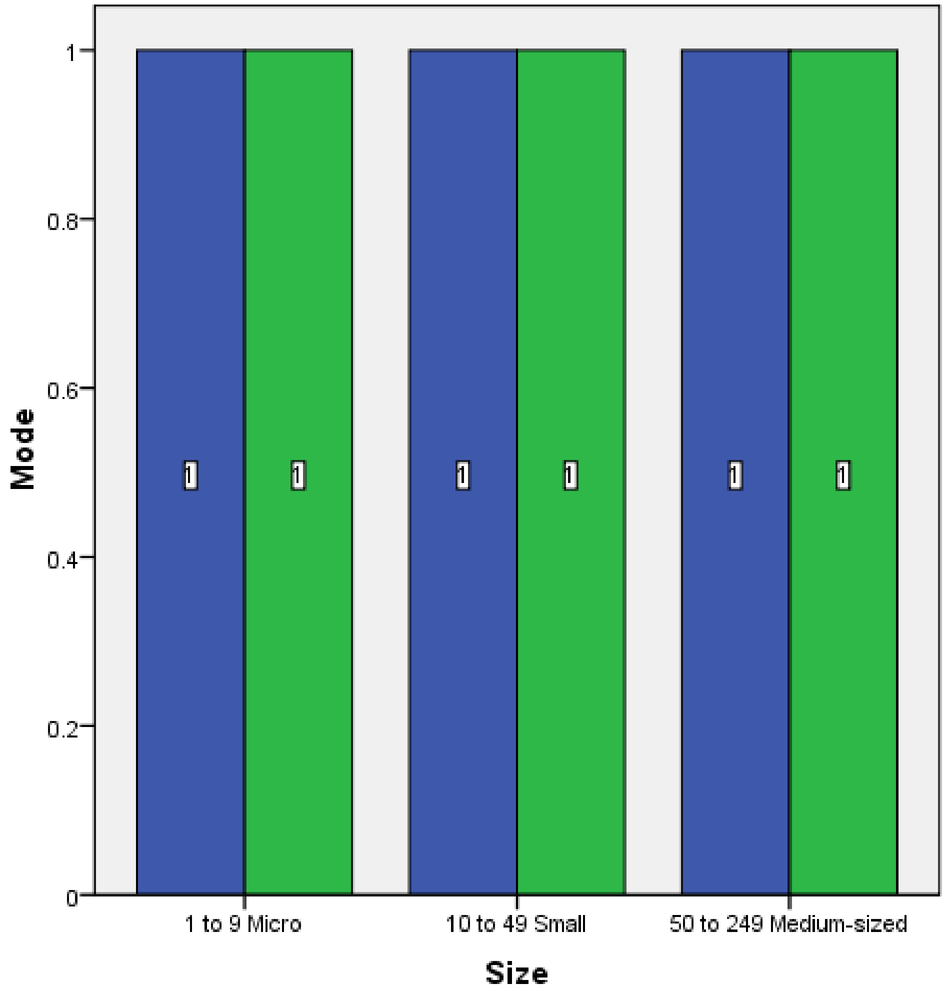

Figure 5.12 Business size influence on RP technology processes

• 82% designated computer aided design (CAD) as significant to their companies when only 48% of them invested in CAD (Figure 5.13).

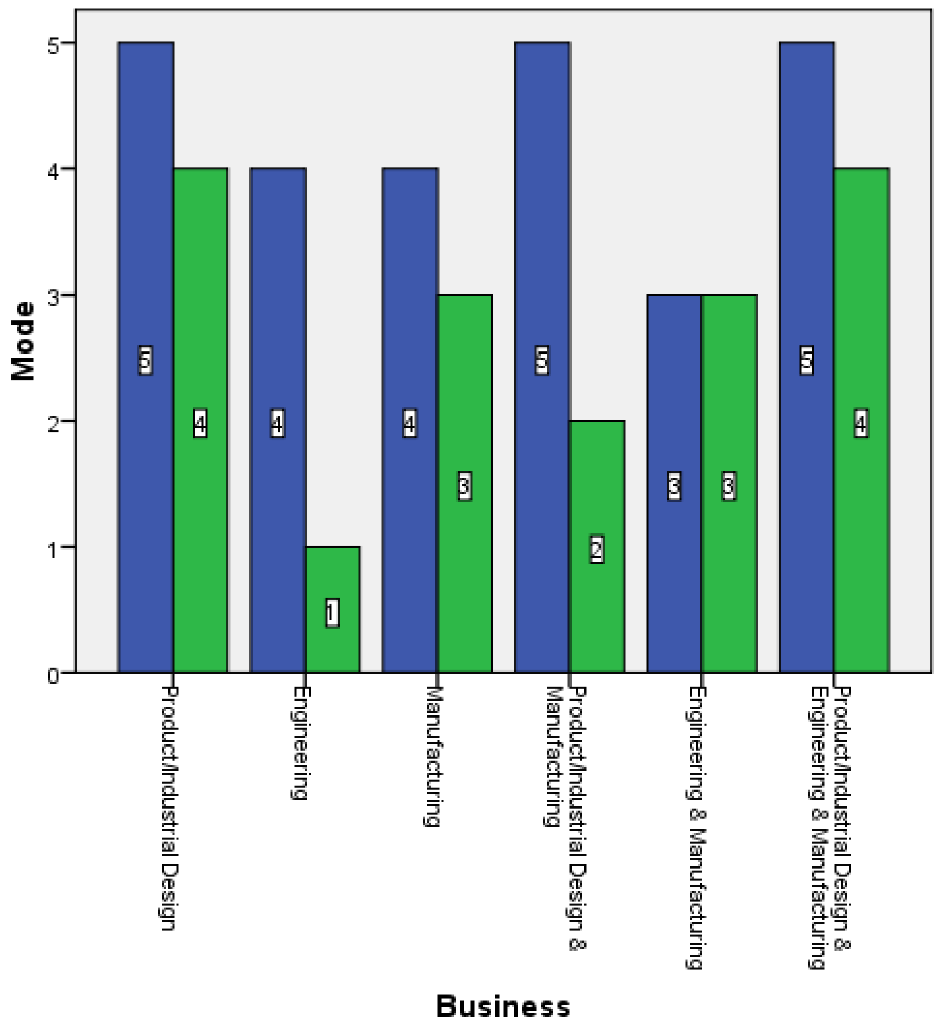

Figure 5.13 Computer aided design: levels of significance and investment

The company size influenced CAD, as it was: very significant with no investment within micro sized firms; most significant with no idea about investment within small sized firms; and very significant with heavy investment within medium-sized enterprises (Figure 5.14).

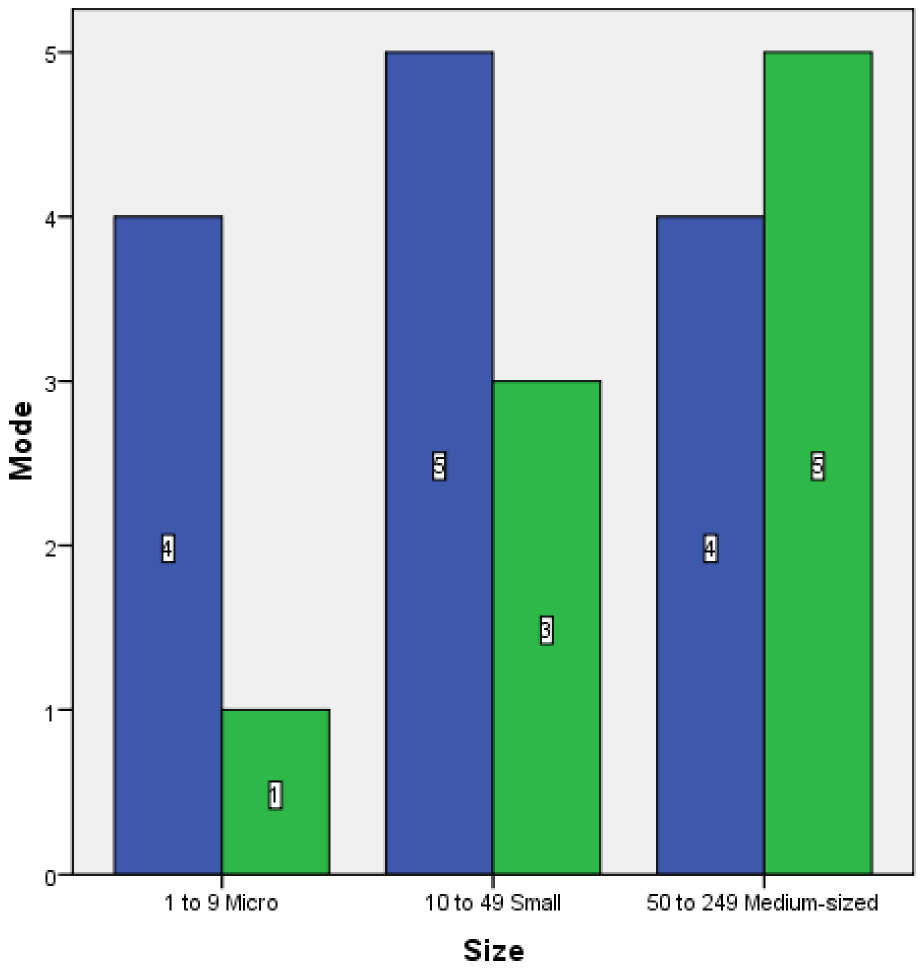

Figure 5.14 Business size influence on computer aided design

• 60% designated CNC machining as significant to their companies when only 26% of them made investments in this area' or 'invested in it (Figure 5.15).

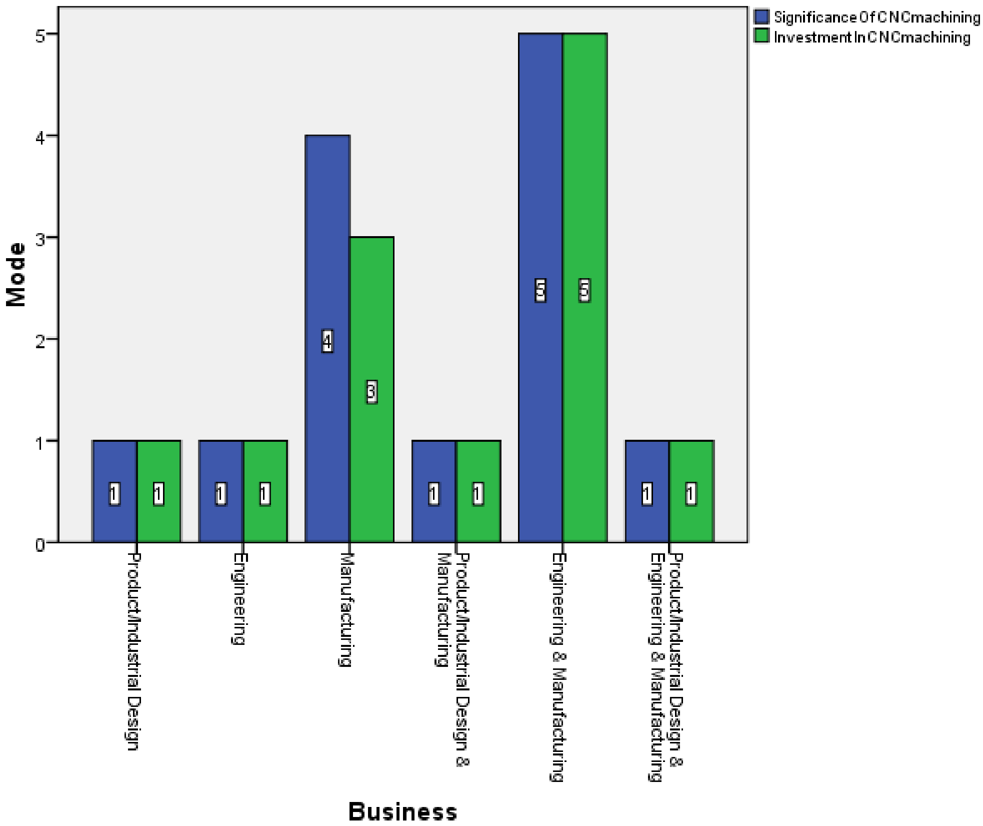

Figure 5.15 CNC machining: levels of significance and investment

The company size influenced CNC machining, as it was: most significant with no investment within micro sized and medium-sized enterprises, but not significant with no investment within small sized enterprises (Figure 5.16).

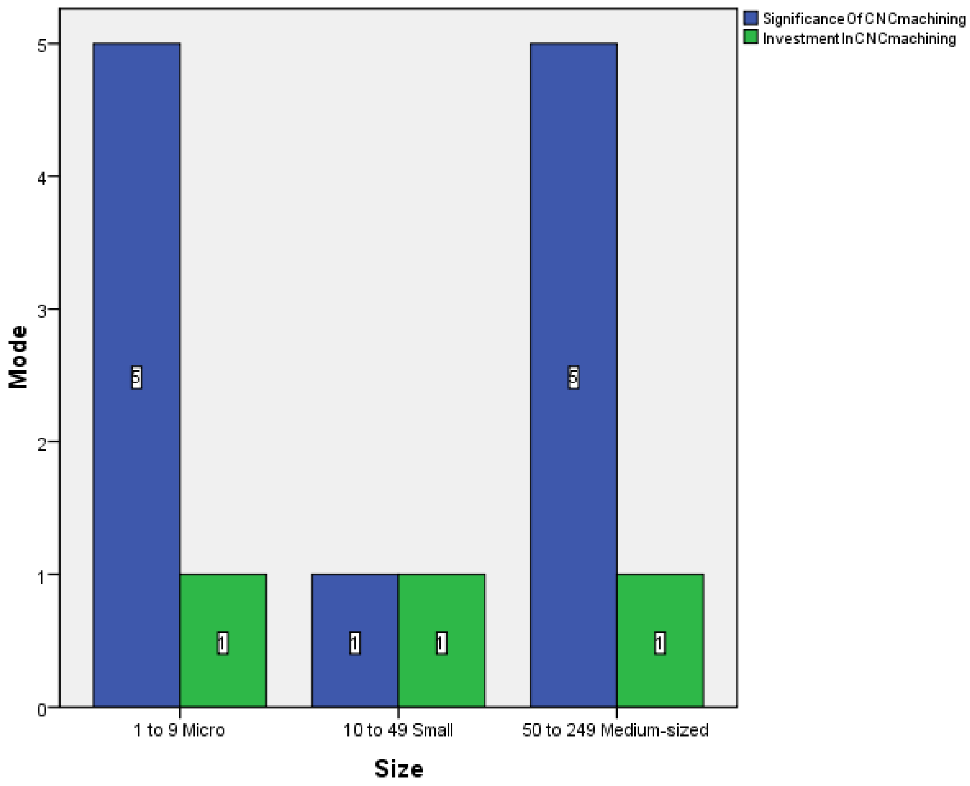

Figure 5.16 Business size influence on CNC machining

Also, 84% designated innovation processes, 98% designated cost, 94% quality, 96% timing, and 84% market share as significant to their firms (Figure 5.17).

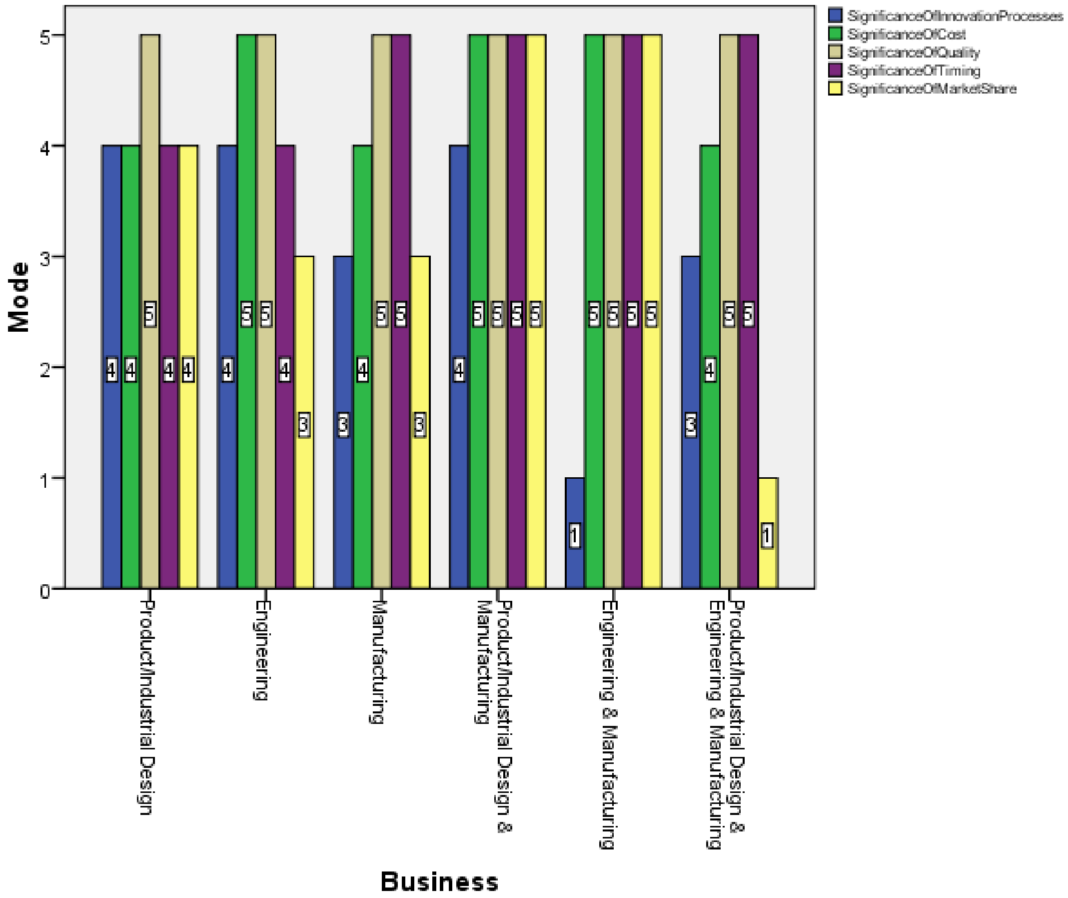

Figure 5.17 Innovation processes, cost, quality, timing and market share: levels of significance and investment

Furthermore, the micro sized firms demonstrated that cost, quality and time are most significant, when they considered innovation processes and market share as significant. Small sized firms demonstrated that quality is most significant, cost and time are very significant, innovation processes are significant and market share is not significant. Finally the medium-sized firms demonstrated that all are most significant (Figure 5.18).

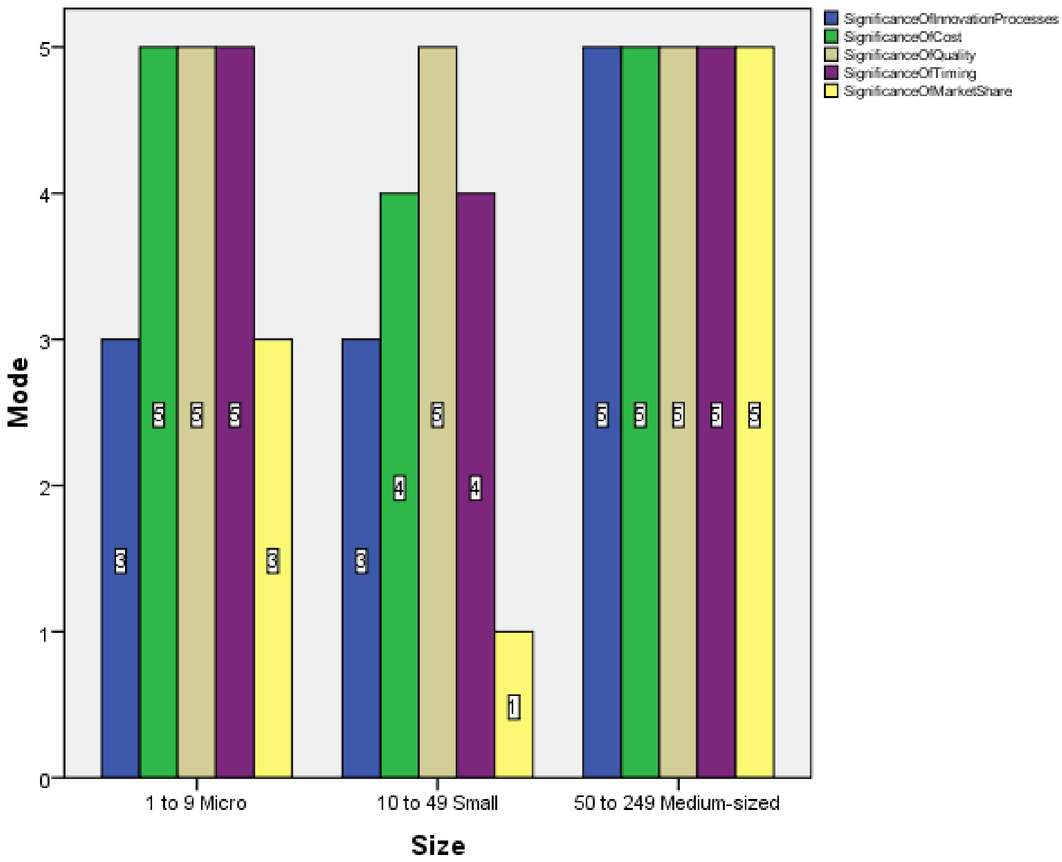

Figure 5.18 Business size influence on 17 innovation processes, cost, quality, timing and market share

For an overview of the barriers, Table 1 reports descriptive statistics (25th percentile, 50th percentile/median and 75th percentile) for the investigated RP technology deployment barriers, as measured by a 1 to 5 Likert scale. This was used to evaluate the extent to which the executive mangers agreed or disagreed with the existence of each barrier within their companies, where 1=strongly disagree, 2=disagree, 3=neither disagree nor agree, 4=agree, and 5=strongly agree. The results show that the following are the main barriers.

- Lack of resources;
- Lack of professional qualifications;
- Resistance to change;
- Rapid prototyping limitations.

From the 50th percentile/median and 75th percentiles, the executive managers verified that they either agree or strongly agree that these barriers are the inhibitors of RP deployment within their SMEs.

Table 5.1 Descriptive Statistics

	N	Percentiles		
		25th	50th (median)	75th
Lack of Proper Practice	50	2.00	3.00	3.25
Culture and Performance Issues	50	1.00	3.00	3.00
Lack of Resources	**50**	**3.00**	**4.00**	**5.00**
Lack of Professional Qualifications	**50**	**3.00**	**4.00**	**5.00**
Prioritisation System	50	2.00	3.00	4.00
Decision Making Level	50	2.00	3.00	3.25
Resistance to Change	**50**	**3.00**	**4.00**	**5.00**
Lack of Education	50	2.00	3.00	4.00
Rapid Prototyping Limitations	**50**	**2.00**	**4.00**	**5.00**
Lack of Imagination	50	1.00	2.00	3.00
Vested Interests that Stifle Innovation	50	1.00	2.00	3.25

In order to examine the internal consistency, the RP technology deployment barriers were tested for internal reliability using Cronbach's alpha. Cronbach's alpha is a test of internal reliability, which measures the coefficient of inter-item correlation; that is, the closeness of the relationship between a cluster of items. An alpha value of 0.7 is commonly held to be an indicator of reliability. Tables 5.2, 5.3 and 5.4 show the results of Cronbach's alpha measure.

Table 5.2 Reliability Statistics

Common Variance	**1.552**
True Variance	.720
Error Variance	.831
Common Inter-Item Correlation	.464
Reliability of Scale	.905
Reliability of Scale (Unbiased)	.909

Table 5.3 Cronbach's Alpha Coefficient

Reliability Statistics		
Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	N of Items
.905	.907	11

Table 5.4 Case Processing Summary

		N	%
Cases	Valid	50	100.0
	Excluded[a]	0	.0
	Total	50	100.0

a. Listwise deletion based on all variables in the procedure.

In addition to checking the reliability, a factor analysis test was carried out to investigate the dimensionality of the scale as a high alpha does not imply that the measure is one-dimensional. Knowing that Likert scaling is a one-dimensional scaling method, the findings obtained from it should be verified for dimensionality. The results thus obtained from the factor analysis test are compatible with the Likert scale dimensionality type. As may be seen in Table 5.5, the value for the first barrier is considerably larger than the value for the next barrier (5.84 vs. 1.33). Moreover, the first barrier accounts for 53% of the total variance, which indicates that the scale items are one-dimensional.

Table 5.5 Factor Analysis Results

Total Variance Explained						
Component	Initial Eigenvalues			Extraction Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	5.846	53.141	53.141	5.846	53.141	53.141
2	1.339	12.175	65.316	1.339	12.175	65.316
3	.966	8.786	74.102			
4	.674	6.125	80.227			
5	.547	4.969	85.196			
6	.400	3.639	88.835			
7	.390	3.549	92.385			
8	.352	3.197	95.582			
9	.196	1.780	97.361			
10	.153	1.387	98.749			
11	.138	1.251	100.000			
Extraction Method: Principal Component Analysis						

Following the examination of the data for internal reliability, and in order to see the whole picture, the results were collected together and summarised in one table. Table 5.6 summarises the data of the overall statistical findings of the first phase of this study. Rows represent the individual barriers' actual existence, and columns represent SME business nature and company size. In addition, the table includes the previously explained levels of significance as well as investment within the SMEs which have been investigated.

Table 5.6 Summary of the effective presence of each barrier according to business nature/size of each SME

Product/Industrial Design based SMEs

Barrier	Effective presence	1 to 9 Micro	10 to 49 Small	50 to 249 Medium	NS/NI	S/NI	NS/I	S/I
Lack of a Proper Practice	✓	•			ABD	AB		
Culture and Performance Issues						AB		
Lack of Resources						AB		
Lack of Professional Qualifications	✓	•			ABD	AB		
Prioritisation System	✓	•			ABCD	AB		
Decision Making Level	✓	•			ABD	AB		
Resistance to Change	✓	•			ABCD	AB		
Lack of Education						AB		
Rapid Prototyping Limitations						AB		
Lack of Imagination						AB		
Vested Interests that Stifle Innovation						AB		

Engineering based SMEs

Barrier	Effective presence	1 to 9 Micro	10 to 49 Small	50 to 249 Medium	NS/NI	S/NI	NS/I	S/I
Lack of a Proper Practice					ABD			
Culture and Performance Issues					ABD			E
Lack of Resources	✓	•		•	ABCDE	AE		E
Lack of Professional Qualifications	✓	•			ABCD	AE		E
Prioritisation System	✓	•			ABD	AE		E
Decision Making Level					ABD	A		E
Resistance to Change	✓	•		•	ABD		C	E
Lack of Education	✓	•			ABD		C	E
Rapid Prototyping Limitations	✓	•		•	ABCD	AE	C	E
Lack of Imagination					ABD			
Vested Interests that Stifle Innovation	✓			•	ABD		C	E

Manufacturing based SMEs

Barrier	Effective presence	1 to 9 Micro	10 to 49 Small	50 to 249 Medium	NS/NI	S/NI	NS/I	S/I
Lack of a Proper Practice						E		C
Culture and Performance Issues						DE		C
Lack of Resources	✓	•			C	ABDE		BCDE
Lack of Professional Qualifications	✓	•			C	ABDE		
Prioritisation System						ADE		
Decision Making Level	✓	•				DE		
Resistance to Change	✓	•				ABDE		C
Lack of Education						BDE		
Rapid Prototyping Limitations	✓			•	C	ABD		
Lack of Imagination						DE		
Vested Interests that Stifle Innovation						ABD		

A = Significance of In-House Design Practices vs. Investment in In-House Design Practices
B = Significance of In-House Research and Development vs. Investment in In-House Research and Development
C = Significance of Rapid Prototyping Technology Processes vs. Investment in Rapid Prototyping Technology Processes
D = Significance of Computer Aided Design CAD vs. Investment in Computer Aided Design CAD
E = Significance of CNC machining vs. Investment in CNC machining
NS = No Significance; NI = No Investment; S = Significance; I = Investment

Table 5.7 Summary of the effective presence of each barrier according to business nature/size of each SME (focused on the main barriers)

Barrier	SMEs	✓	1 to 9 Micro	10 to 49 Small	50 to 249 Medium	NS/NI	S/NI	NS/I	S/I
Lack of Proper Practice	Product/Industrial Design based SMEs	✓	•			ABD	AB		
	Engineering based SMEs								
	Manufacturing based SMEs								
Culture and Performance Issues	Product/Industrial Design based SMEs								
	Engineering based SMEs								
	Manufacturing based SMEs								
Lack of Resources	Product/Industrial Design based SMEs								
	Engineering based SMEs	✓	•		•	ABCDE	AE		E
	Manufacturing based SMEs	✓	•			C	ABDE		BCDE
Lack of Professional Qualifications	Product/Industrial Design based SMEs	✓	•			ABD	AB		
	Engineering based SMEs	✓	•			ABCD	AE		E
	Manufacturing based SMEs	✓	•			C	ABDE		
Prioritisation System	Product/Industrial Design based SMEs	✓	•			ABCD	AB		
	Engineering based SMEs	✓	•			ABD	AE		E
	Manufacturing based SMEs								
Decision Making Level	Product/Industrial Design based SMEs	✓	•			ABD	AB		
	Engineering based SMEs								
	Manufacturing based SMEs	✓	•				DE		
Resistance to Change	Product/Industrial Design based SMEs	✓	•			ABCD	AB		
	Engineering based SMEs	✓	•		•	ABD		C	E
	Manufacturing based SMEs	✓	•				ABDE		C
Lack of Education	Product/Industrial Design based SMEs								
	Engineering based SMEs	✓	•			ABD		C	E
	Manufacturing based SMEs								
Rapid Prototyping Limitations	Product/Industrial Design based SMEs								
	Engineering based SMEs	✓	•		•	ABCD	AE	C	E
	Manufacturing based SMEs	✓			•	C	ABD		
Lack of Imagination	Product/Industrial Design based SMEs								
	Engineering based SMEs								
	Manufacturing based SMEs								
Vested Interests that Stifle Innovation	Product/Industrial Design based SMEs								
	Engineering based SMEs	✓			•	ABD		C	E
	Manufacturing based SMEs								

A = Significance of In-House Design Practices vs. Investment in In-House Design Practices
B = Significance of In-House Research and Development vs. Investment in In-House Research and Development
C = Significance of Rapid Prototyping Technology Processes vs. Investment in Rapid Prototyping Technology Processes
D = Significance of Computer Aided Design CAD vs. Investment in Computer Aided Design CAD
E = Significance of CNC machining vs. Investment in CNC machining
NS = No Significance; NI = No Investment; S = Significance; I = Investment

In Table 5.6, each row represents one of the barriers against each business type column, with regard to business nature, business size, and business associated features' levels of significance and investment. It can be clearly seen whether a barrier exists for a particular type of business and for what company size within that type - micro, small or medium. Where the barrier is confirmed within an SME type, there is a tick to indicate its presence in the business type overall and a black dot to indicate its presence in a particular company size. Additionally for each barrier that is confirmed, the table rows also show the degree of significance and level of investment for in-house design practices, in-house research and development, rapid prototyping technology, computer aided design, and computer numerical control machining within each type of SME. A more focused and refined summary may be seen in Table 5.7, where the most active barriers are highlighted due to their extensive presence within the whole spectrum of the studied SMEs. As an overall indicator of how the companies perform while these barriers are active, it has been found from the analysis that:

- Resistance to change is effectively confirmed within micro sized product/industrial design based SMEs, micro and medium sized engineering based SMEs and micro sized manufacturing based SMEs.
- Lack of professional qualifications is effectively confirmed within micro sized product/industrial design based SMEs, micro sized engineering based SMEs and micro sized manufacturing based SMEs.
- Lack of resources is effectively confirmed within micro and medium sized engineering based SMEs and micro sized manufacturing based SMEs.
- Rapid prototyping limitations are effectively confirmed within micro and medium sized engineering based SMEs and medium sized manufacturing based SMEs.

This has substantiated the prioritisation of the barriers: resistance to change, lack of professional qualifications, lack of resources, and rapid prototyping limitations, as the most effective hindrances to the adoption of RP within SMEs in the South West of England.

Additionally to measure the strength of association between the barriers, a correlation test was conducted, using Spearman's rho correlation coefficient, and the results are given in Table 5.8 (Schmid and Schmidt 2007). The correlation coefficients ranged between -1.00 and +1.00. An ideal negative correlation is represented by the value -1.00 while an ideal positive correlation is represented by +1.00. A lack of correlation is represented by 0.00. For example there is a high degree of positive correlation between the lack of resources and the lack of professional qualifications; a medium degree of positive correlation between resistance to change and the decision making level; a low degree of positive correlation between the rapid prototyping limitations and the lack of proper practice; and finally, probably no correlation between the vested interests that stifle innovation and the prioritisation system.

Figure 5.19 demonstrates the association between barriers, figuratively explained on the general basis of the parallel structure of the brain as a functional aspect of biological neural networks. In neural networks there is an inter–connection between the neurons in the different layers of the system; metaphorically this study simulates the barriers as layers. Where the main barriers are the input layers, the other barriers are the hidden layers which work and affect the process but by eliminating the input layers most of the hidden connected layers will be subsequently eliminated and finally the output layers represent the suggested way forward to reduce the effect of the input barriers. In the output layers a predicted elimination factor could be Human Development, by incorporating the resistance to change and lack of professional qualifications into one process, along with the integration of lack of resources and rapid prototyping limitations into a process of Research and Development. This could stimulate a progression towards the desired transformation approach. Such an approach should build a gradual organisational change, which would engage a strategic as well as technological change as a reflection of the human development in the research and development process. This was introduced to the interviewees of the second phase of this study; the details of their comments will be discussed in the next chapter.

Table 5.8 Correlation Test Results

			Lack of Proper Practice	Culture and Performance Issues	Lack of Resources	Lack of Professional Qualifications	Prioritisation System	Decision Making Level	Resistance to Change	Lack of Education	Rapid Prototyping Limitation	Lack of Imagination	Vested Interests that Stifle Innovation
Spearman's rho	Lack of Proper Practice	Correlation Coefficient											
		Sig. (2-tailed)											
		N											
	Culture and Performance Issues	Correlation Coefficient	.460**										
		Sig. (2-tailed)	.001										
		N	50										
	Lack of Resources	Correlation Coefficient	.405**	.422**									
		Sig. (2-tailed)	.003	.002									
		N	50	50									
	Lack of Professional Qualifications	Correlation Coefficient	.631**	.428**	.727**								
		Sig. (2-tailed)	.000	.002	.000								
		N	50	50	50								
	Prioritisation System	Correlation Coefficient	.407**	.413**	.325*	.548**							
		Sig. (2-tailed)	.003	.003	.021	.000							
		N	50	50	50	50							
	Decision Making Level	Correlation Coefficient	.459**	.460**	.532**	.599**	.552**						
		Sig. (2-tailed)	.001	.001	.000	.000	.000						
		N	50	50	50	50	50						
	Resistance to Change	Correlation Coefficient	.327*	.619**	.260	.287*	.240	.523**					
		Sig. (2-tailed)	.020	.000	.068	.044	.093	.000					
		N	50	50	50	50	50	50					
	Lack of Education	Correlation Coefficient	.561**	.640**	.477**	.568**	.470**	.682**	.600**				
		Sig. (2-tailed)	.000	.000	.000	.000	.001	.000	.000				
		N	50	50	50	50	50	50	50				
	Rapid Prototyping Limitation	Correlation Coefficient	.371**	.188	.341*	.356*	.191	.174	.202	.448**			
		Sig. (2-tailed)	.008	.190	.015	.011	.185	.226	.159	.001			
		N	50	50	50	50	50	50	50	50			
	Lack of Imagination	Correlation Coefficient	.332*	.562**	.383**	.382**	.382**	.546**	.627**	.509**	.148		
		Sig. (2-tailed)	.019	.000	.006	.006	.006	.000	.000	.000	.305		
		N	50	50	50	50	50	50	50	50	50		
	Vested Interests that Stifle Innovation	Correlation Coefficient	.333*	.538**	.336*	.256	.186	.416**	.486**	.624**	.131	.384**	
		Sig. (2-tailed)	.018	.000	.017	.072	.196	.003	.000	.000	.364	.006	
		N	50	50	50	50	50	50	50	50	50	50	

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

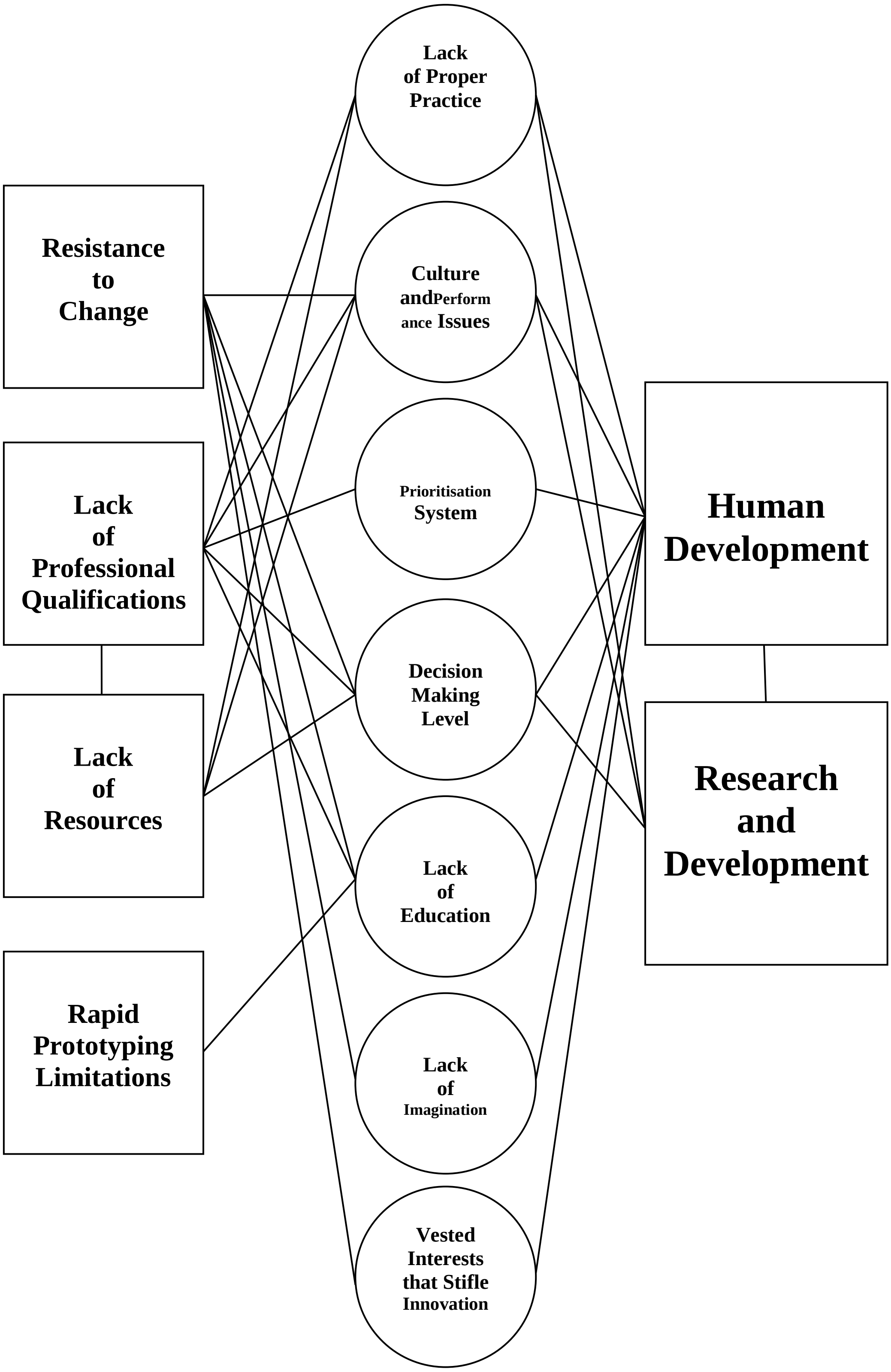

Figure 5.19 Metaphorical relationships between barriers as a biological neural network

5.5 Discussion

This study has presented a new perception of the barriers that hinder the deployment of RP within SMEs in the South West of England. In addition to the identification of these barriers, it has provided a new understanding of their relative influence which needs to be taken into account when attempting to overcome them. The study findings which were obtained through the quantitative analysis of the survey questionnaire should help SMEs because they highlight two key issues:

Q. What are the barriers that prevent SMEs from being ‘RP technology enabled’?
A. SMEs are not able to effectively take on new technologies such as RP, and this study has identified the barriers that most hinder the adoption of RP within SMEs.

Q. Which of these barriers should an SME tackle first to become ‘RP technology enabled’?
A. This study has analysed aspects such as the actual existence of each barrier against the size and nature of the SME, and this has proved to be a practical and effective approach to ranking each of the barriers.

The results of this study have shown that lack of resources, lack of professional qualifications, resistance to change and rapid prototyping limitations are the important barriers. Two of them are human related, and the other two are process related. This suggests the following recommendations as a first step towards an effective and balanced strategic and technological transformation (Figure 5.20):

• Incorporating and tackling the human related barriers, which are resistance to change and lack of professional qualifications, in the form of Human Development.
• Integrating and dealing with the process related barriers, which are lack of resources and rapid prototyping limitations, through Research and Development.

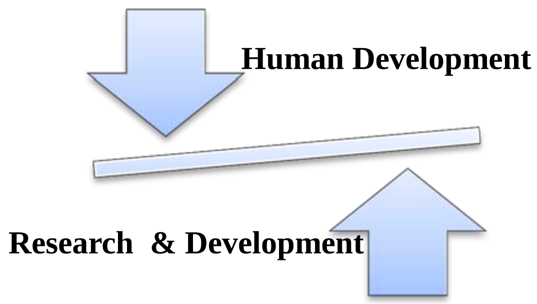

Figure 5.20 A suggested balanced approach between Human Development and R&D

This approach was suggested in the course of the second phase of data collection to the executive managers, where they were given the opportunity to describe their own perceptions with regard to Human Development and Research and Development. The details of their responses are discussed in Chapter 6, the analysis of the qualitative approach. Similarly, and as explained before, the survey questionnaire included a box for further comments. The participants commented with regard to their own confidence concerning RP technology, and the way they see their businesses in that context. Some of them were confident that there were no plans to deploy RP technology within their companies for various reasons, be they financial or related to requirements, as shown by the following quotations:

“We don't currently have any requirement for RP in our Business”

“RP opportunities are limited within our business. We carry out a large amount of CAD/CAM/FEA analysis and this is the supplemented by applications testing. The manufacture/assembly of representative prototypes is relativity straight forward”

“We are a small company making very small batches of products. Almost all are treated as prototypes”

“Too expensive, cheaper to machine from solid”

“R.P. can be useful but is too expensive to use extensively. We have considered small production number of plastic parts made by R.P. but these have not so far proved economical”

“Although RP is of interest to the company, its deployment as a full manufacturing tool is some way off due to extensive design demands with our current processes our business does not require RP technology. Any innovation we develop is not required to be post tracked to market. We have B2B suppliers with all our customers overseas. Most of our equipment is manufactured by sub-contractors”

Some other SMEs do outsource to RP technology, as follows:

“Although our company does not produce RP products, we do source out of house and use RP offer with the latest advances in the field. We can manufacture very strong and durable RP test products”

“Design and Innovation are undertaken in UK, Shanghai and US offices. Component Manufacture and Production is undertaken in factories in China (3), USA (2) and Mexico. We have significant in-house CAD and Modelling Capability, but also uses outside subcontractors”

Whilst others have already deployed RP technology within their SMEs, as follows:

“We use SLA and SLS on a subcontract basis. All of our products go on RP stage”

“Far too much invest shown in the aerospace and defence industries. We have many other engineering skills and outlets, but the idea of our leaders appears to be focused on these industries”

The above quotes influenced the way in which the interview questions were designed and the interviews conducted, as discussed in the next chapter.

5.6 Chapter Summary

This chapter provided the detailed observations and results obtained from analysis of the quantitative data. These included the statistical analysis findings and their implications. Reliability and validity of the outcomes were also tested, and ethical considerations were addressed. In addition, an initial proposal was derived for tackling the identified and prioritised barriers through a combination of Human Development training in conjunction with Research and Development practice. The next chapter presents the findings of Phase Two, the qualitative approach.

Chapter 6

Phase Two Findings

6.1 Chapter Overview

This chapter shows the findings associated with the aim of the second phase of this research; thematic analysis of qualitative data. The methods used for this research was rationalised in the comprehensive discussion provided in Chapter 4. This analysis presents an inclusive image of SME business technology related traditions, awareness, and future visions based on the participants' views of the deployment of the RP technology within their SMEs derived from their own words. Explicit details of Phase Two interviews including participants, data analysis and findings will be given in this chapter. The Phase Two approach aimed to promote a deeper understanding of the identified and prioritised RP technology adoption barriers which were explained in Chapter 5, as suggested by the Phase One results.

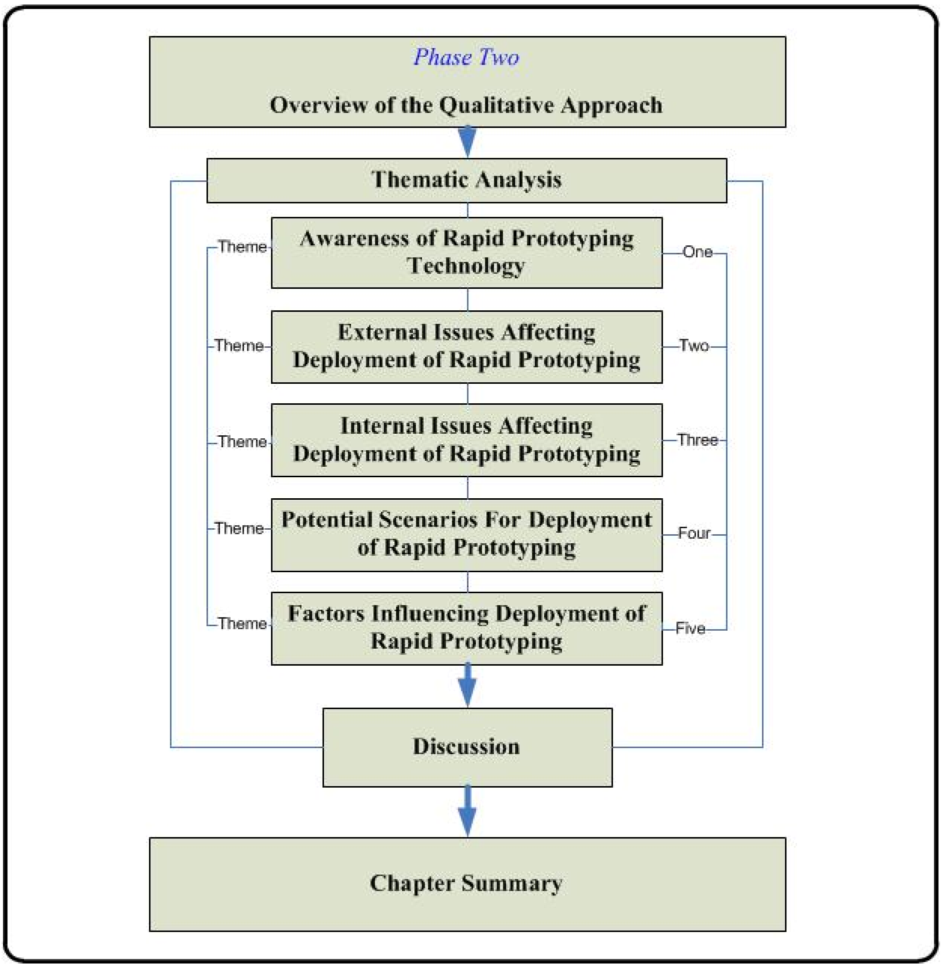

Figure 6.1 Chapter 6 structure

In addition, interviewees were given the opportunity to add other related influencing factors which could affect the deployment of RP within SMEs. Figure 6.1 shows the chapter structure. The aim was to complete the answer to the research question, which was whether an appropriate strategy could be developed for the deployment of RP technology within SMEs. Phase Two was planned to further investigate the drivers and barriers that hinder the deployment of RP technology within SMEs, in an attempt to uncover the considerations for developing a strategy for deploying RP technology. This phase has adopted a qualitative approach in the form of semi-structured, face-to-face, one-to-one interviews to clarify the genuine causes behind the adoption barriers, possible drivers, and to offer key, evidence based answers, on the assessment of the need to deploy RP within SMEs.

All the questions from the interviews as well as verbalisation were transcribed literally to an appropriate high level of detail, and transcripts have been checked against the audio files for accuracy. This has resulted in four hundred and sixty eight topic codes being derived from data and grouped for similarity of content into twenty-two categories that were then further grouped into five main themes. Codes, categories and main themes were tagged consistently with their content. Five main themes were generated from the data, as follows:

1. Awareness of Rapid Prototyping Technology;
2. External issues affecting deployment of Rapid Prototyping;
3. Internal issues affecting deployment of Rapid Prototyping;
4. Potential scenarios for deployment of Rapid Prototyping;
5. Factors influencing deployment of Rapid Prototyping.

In this chapter, each theme is defined; the categories assigned to each theme are described and then exemplified with quotations of transcribed data. Each main theme is introduced in the following sections with a figure to designate the categories linked to the theme as well as the nature of the information that relates to each category. The information was generated directly from the transcribed participants’ views. The codes were carefully checked and rechecked word for word, data and codes with each other, to ensure the best fit of data to codes. The constant comparison method (Boeije 2002; Glaser 1965) was used to check all codes for each associated category twice and the content of the codes allocated to categories was described and made clear. To ensure transparency while allocating codes to categories, criteria for inclusion of each code to a category were inductively constructed as derived from the data collected from the participants.

6.2 Awareness of Rapid Prototyping Technology

The first theme, Awareness of Rapid Prototyping Technology, was generated from categories wherein participants articulated their knowledge of RP technology; design and manufacturing practices; current RP technology adoption and RP technology rejection as in Figure 6.2 below.

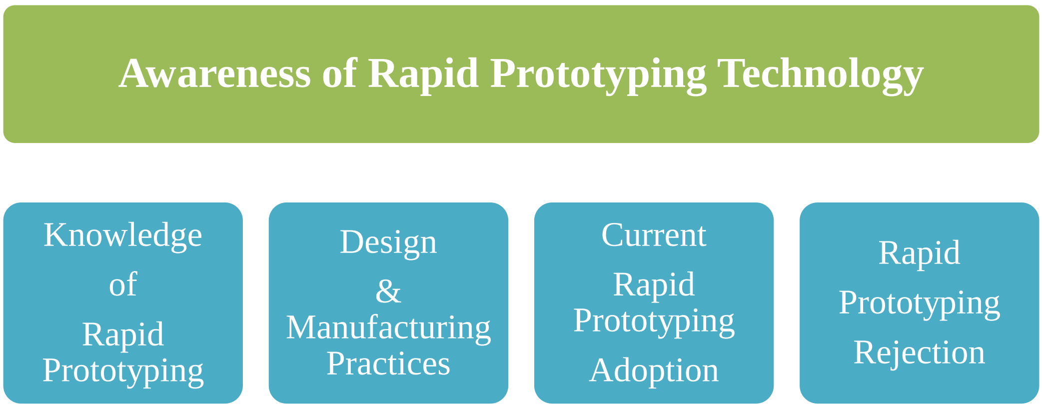

Figure 6.2 Theme One and its associated categories

Participants' level of RP technology awareness varied between good, moderate and poor. Lack of RP technology awareness was highlighted; therefore, SMEs need to have a desire to recognise their position and their potential ability to incorporate RP technology, based on identified information, in order to decide whether or not to make such an investment.

6.2.1 Category One: Knowledge of Rapid Prototyping

The codes allocated to the knowledge of Rapid Prototyping category were those that showed the different levels of knowledge that reflect the extent to which the participants were familiar with the term 'Rapid Prototyping'. Confident, good levels of knowledge were stressed in the participants' words, as follows:

> ***Company A***
>
> *"I was obviously aware of rapid prototyping, but sort of, haven't really seen it as relevant to me. So I think all I can really do is put it in front of people's noses"*
>
> ***Company B***
>
> *"3D rapid prototyping unit, all it is, is a printer with a Z-bed base on it. So even I with the basic knowledge I have can still understand how the devil these things work. I've got involved with looking at them probably as much as ten years ago. The first one out as called Leonardo and it was based at a university at somewhere like reading or Bracknell. It was a cardboard one, but the software was the driver for it. So you did your pictures and you created this block of material by sectioning it, and whatever the thickness of the cardboard was, the software automatically made the next bit of cardboard so that if you wanted a circle, it would be made up of a sandwich of – so you made one bit of cardboard then another bit, then another"*
>
> ***Company C***
>
> *"We've used a number of processes such SLA's, SLS, vacuum casting; we've also in the past used sand casting and conventional machining"*
>
> ***Company E***
>
> *"We have got a couple of products that we considered rapid prototyping, but we did go eventually for injection moulding and the traditional way"*

Some other participants revealed, in their own words, a level of knowledge which fell in a wide range between moderate, limited and out-of-date, as follows:

Company D
"I have some knowledge in rapid prototyping"

Company F
"You have only got to look at the CAD systems now, which is one version of rapid prototyping"

Company G
"As far as I understand with rapid prototyping... it is a limited run, isn't it? And there are high costs"

Company H
"It is rapid and it is a prototype and we look for mainstream production, unless it was one of the short run"

Company I
"I don't feel that I know enough about the subject to be of any great value. As much as I am interested in this sort of side of the business, I can't really devote the time to feel that I could contribute anything really very meaningful"

Company J
"With the rapid prototyping, our product consists of many components anyway, so whether or not you have one component prototyped, you then know that you have a wide range of other components that also need to be manufactured"

When the interviewees were asked what might be the reason for their lack of knowledge, they said:

Company D

"Well, to be fair, none of the staff had any experience of new technology when I first started"

Company F

"Lack of knowledge from senior management"

Company G

"I think it is probably something may be to do with age and experience, of the individuals"

Company H

"I guess all the engineers like myself didn't have access to rapid prototyping at universities, so we have had to pick up information through experience"

Company I

"It's spreading that knowledge and that familiarisation and I think it's... I don't know whether there is a fear or whether there is just a bit of unknown out there"

Company J

"There is no one here who has really taken the time into researching rapid prototyping into a great depth"

For participants who showed low levels of knowledge, when asked about their intentions to increase that level of knowledge, they said:

Company H

"I would have a closer look at it and gain a greater understanding"

Company I

"We don't use 3-D printing, because our product itself is very much 2-D"

Company J

"I haven't done a vast amount of research, but there seem to be plenty of people who are very keen to let you hire their kit"

Whereas others with moderate knowledge said:

Company D

"When you know enough about it to be able to produce something from it – because once again, because any new type of operation requires a knowledge base"

Company F

"My role, apart from being the MD, my area is the strategy and obviously research and development. I did my masters in research up at the UEA, so I know what is required and I also know what we need to do to get it out there"

Company G

"We as an organisation somehow need to connect more readily to those who offer that service in a way that it becomes more readily accessible"

6.2.2 Category Two: Design and Manufacturing Practices

The codes that explained the manufacturing processes, and that were allocated to the Design and Manufacturing Practices category, arose when discussing how SMEs adopt technology in general within the design and manufacturing stages. This category showed that the take–up of new ideas in terms of industrial performance is slow within some companies, as follows:

Company I

"The level of take-up of new ideas is slow, and that is across the industry"

But constant within some others, as follows:

> ***Company D***
> *"We work closely with technicians; we are often getting new ideas"*

Also, the take-up of new ideas depends on the nature of the business. If the business is not end-user products orientated in nature, the situation changes dramatically, as follows:

> ***Company F***
> *"If somebody has an idea to develop a new type of product, if somebody else has the same idea and you know about it, then you have got to be first to market. Those kind of developments in business to business is don't normally occur"*

In addition to the above issues, the culture of future planning within some companies gives the impression that there are no intentions in the near future to accept new ideas, as follows:

> ***Company G***
> *"The challenge was, basically, when I first set up, I made very clear routes for where I wanted the company to go and how I wanted it to run. The biggest thing was the fact that they always liked to have three months work in a box on the wall. The first thing I said to the factory manager, who was the supervisor, is that I want three days; she just looked at me and said, 'you're kidding me?' And I said 'I don't kid in this sort of thing'. Two months later, she managed to get it down to 3 days and I believe that is one of the reasons why our company is growing at the rate it is at the moment"*

The Design and Manufacturing Practices involved four approaches, of which the companies adopted one or more during their design and manufacturing process. These four approaches are as follows:

1. <u>Research and Development approach</u>

Company F

"Most small to medium enterprise developments is somebody taking that from that area of expertise or industry and something over there and putting it together to make something immediately new"

Company D

"We have a design and research development team who are trying to get all the patterns onto the machine digitised so that we can reproduce what we do"

Company A

"We are doing development work at the moment with a couple of companies looking at 3-D scanning using infrared scanners"

Company I

"We solve problems by applying the appropriate technology, but there does not always us to look at new technology; it is maybe, we just use our existing skills and experience to solve a problem in front of us"

Company C

"Once we get into the mainstream projects, we are probably spending... this is only an estimate... somewhere between £6000-£15,000. But that only occurs once every 18 months or 24 months is what our job is all the time - is problem solving"

CompanyB

"We develop it; get it fully to production and then move on to the next product"

Company E

"Regarding the research and development funding, I suppose that was a bit unfortunate, because we just didn't find any help there at all. More

recently, literally in the last few months, as a result of, believe it or not, a picture in a paper of a company expanding; we have been contacted by one of the government support agencies in the south-west and they are offering training for management and marketing skills and also funding for another researcher, we could probably get money for that providing we pay so much of their salary they would put something in. So it is a bit strange that you would take a photograph in the paper showing how we have expanded for them to pick up on the fact that we are actually growing. I suppose you could blame us for not actually going looking for it, but having said that, based on their experiences seven years ago, I didn't see there was much point, because we were just wasting a lot of time and money to get nothing"

2. <u>In-house Innovation approach</u>

Company C

"The whole product is designed in-house, with just purchase the piece parts and we assemble and then we ship worldwide"

Company E

"The design is done in-house"

Company B

"Most of our technology, I suppose, is developed in-house using a known method"

Company A

"We have a unit that is all machined from a design that is designed here"

Company F

"We are an innovative organisation, we create innovation"

3. <u>RP approach</u>

Company A

"Obviously the first one we refer to as a functional prototype, which is the engineer's first attempt. Then there is the ongoing iteration's to improve design flaws, performance... and finally we do one more which we call confirmation prototype. Basically we would remake of the parts as per final design, prove the design and then we would commit to hard tooling. Then after that point there is no more rapid prototyping"

Company B

"Our product design philosophy is such that, obviously it is a normal stage and gate process, but we normally build three functional prototypes which are consisting of sheet metal rapid prototype parts"

Company C

"Design is where it starts - rapid prototyping. Getting the design, getting it in 3-D... there are dime a dozen nowadays"

4. <u>Customer Based approach</u>

Company D

"Basically, customers will provide a list of what they want for a specification and we will make it to that specification. However, the specification is our specification; we have designed them - we have researched them over the last 15 years"

Company H

"We tend to be quite focused. We look at target markets, so we have a different target market"

6.2.3 Category Three: Current Rapid Prototyping Adoption

The codes allocated to the Current Rapid Prototyping Adoption category were those that reflected the real situations where RP was already adopted, and the reasons behind that adoption of RP. Those who had already adopted RP, showed that the decisions were made as an answer to the following:

1. To fulfil a need or to solve a problem that could not be postponed

Company B

"I probably came to that through two ends, really. One was a little bit of knowledge and understanding of what's possible. So we came to the University, had a bit of a tour; I went to Cardiff University as well and saw what other guys are doing. Subscribed to professional engineering magazine so that you could read articles about what other people are doing. And then you are faced with a problem, a practical problem that you think well how do I solve that and particularly on obsolescence management apps, that is an issue. I have got this component, I can't make any more or I can't source any more through this organisation; it is a vital part of my business, how do I solve that and it is a real obsolescence... you know, if you have got on obsolescence issue that is going to hit you in a year's time, it is different to one that will hit you tomorrow, because something is literally... you phone up a supplier and say 'I want one of these, it was last on a week's leave time'... 'We don't do that anymore.' 'Okay, well I have got a production slot that I need to fill.' So, it was a combination of the two, kind of a push and a pull. It led us to, well, okay; we can do something on the rapid prototyping, let us go and dunk our feet in here and see what we can do. It was needs-based, definitely"

2. <u>To use and fit RP where appropriate with the support of management</u>

Company C

"We are fully supported and we have no problem from our management to use rapid prototyping as we see fit"

3. <u>To deploy RP within the design process and presentation stages</u>

Company D

"Our setup has been designed, basically, to put into rapid prototyping, because every product is different, every presentation is different"

4. <u>To build parts at a sensible price</u>

Company A

"What happened was that I look on the net and if I am halfway through designing my current part, as it were, and I have got a company... sort of rapid prototyping company or at least a plastic moulding company which uses rapid prototyping to quote for moulding my existing part and it was a... I can't remember the numbers now, but it was a sensible price"

5. <u>To benefit from other peers' successful experiences</u>

Company A

"They are now using rapid prototyping and they can make a better product for less money"

6. <u>To use RP only when sale of the product is guaranteed</u>

Company G

"On that one the only time you can do that is when you know that you have a customer that will buy it from you"

Company C

"The initial philosophy was you are only producing small volumes, it does not justify going away from conventional methods and the associated risk... so as the sales expanded and the products changed and we wanted to produce things quicker, we then started to embrace rapid prototyping and evaluate the merits"

6.2.4 Category Four: Rapid Prototyping Rejection

The codes allocated to the Rapid Prototyping Rejection category were those that revealed the participants' genuine reasons for not deploying RP within their companies. The reasons were diverse and described as follows:

1. <u>RP is limited in what it can do</u>

Company J

"As far as I know about rapid prototyping, it can't achieve what we actually need"

Company I

"On the manufacturing side, I don't believe that there are any rapid prototyping techniques that are going to be probably better than we already do and already achieve"

2. <u>Lack of need for RP within the company</u>

Company H

"The need for going into that side technology is irrelevant to us. Whilst we know it is there, we don't have a need to move into it. That is about it"

Company F

"Most people don't need rapid prototyping"

Company J

"I would probably say lack of need really"

Company E

“I think what we have done is said that rapid prototyping is not for us and that is what we have always done”

3. <u>No interest due to the business nature</u>

Company F

“We have always been very innovative, but because it is in a business to business environment in a conservative industry, rapid prototyping is not necessarily something that interests us”

4. <u>Business size and production volume cannot justify RP</u>

Company E

“There is a certain element of speed, there is a... I have always felt there has been sort of cost element on the small batch, but again my perception always was that on the larger batch, then rapid prototyping wasn't really the way to go”

Company F

“Most of our orders for six or for 12 off, so we can evolve our product rather than rapidly prototype it”

Company H

“We don't really make enough of anything to really justify it”

Company I

“We are not big enough for feasibility studies”

Company J

“It is a consumer product and rapid prototyping is only needed really for retail where you want to sell large numbers of items”

5. <u>Resistance to change</u>

Company F

"It is not rapid prototyping; it is a question of having a plan about how to protect yourself"

Company H

"If the method of construction was tried and tested and it worked, why reinvent the wheel?

Company I

"We are not looking to do anything different; we are just looking at this as a means of making some money and earn a retirement fund really. We wouldn't want to gamble anything that is already in place. It would be very difficult to allocate the time to trying something new and spending money, because whatever you go into will cost you money; there is obviously a price to pay. I wait or not saying that's the price over the cost... the reinvestment wouldn't work out, but it's a gamble. Maybe if we were a little bit younger and there would be time to recoup any advantages or any expansion... both my partner and I are a little bit cautious in that area"

6.3 External Issues Affecting Deployment of Rapid Prototyping

The second theme, External Issues Affecting Deployment of Rapid Prototyping, was generated from categories wherein participants articulated their concerns with regard to the customer effect, national legislation, offshore competition, and the South West Region effect on their business's strategic performance, as in Figure 6.3 below.

Figure 6.3 Theme Two and its associated categories

6.3.1 Category Five: The Customer Effect

The codes allocated to the customer effect category were those that the customers were stated as factors affecting the process of development within the company. This effect was sometimes a driver, as follows:

> ***Company C***
> *"We are customer driven, basically. The customers have a requirement for a product and they will tell us of their requirement and we try to meet their requirement. So, there is not a lot of new technology going in to the products that we provide"*

At other times, comments indicated deep concern over the risks of satisfying only one type of customer, as follows:

> ***Company B***
> *"Too many companies are only one Product Company. And that is stupid. You need to diversify, because if you lose that customer or that technology overtakes you; you're dead"*

Or in the case of a business to business relationship, the company is limited by being dependent on the other business customer's needs, as follows:

> ***Company F***
> *"The majority of our work is subcontract and we are always dependant on everyone else, which means your customer base is quite narrow"*

6.3.2 Category Six: National Legislation

The codes allocated to the national legislation category were those exploring the consequences of legislative actions planned by the government and affecting the SMEs' performance. These legislative actions were as follows:

<u>National Insurance</u>

> ***Company F***
> *"Because the government is worried about people not paying National Insurance, they are clamping down on contractors, the way contractors are treated; you have got to take them on permanently. That is huge disincentive for us to create more jobs. It is outside of your field, but it is also a huge block to human development and getting innovation into industry"*

Funding schemes

Company B

"If your name was Jaguar and you want to open up a factory; how much would you get from the government, do you think? You must have been listening to the news in the last twenty four hours. Hello, my name is Tata,we're going to open up a factory in Wolverhampton. Oh, are you? OK, well here's ten million… Hi, I'm …………… Engineering. We've got a small company down the road. Who, sorry… Oh no. No money!"

Company G

"Because you are constrained by taking a risk on somebody if you want to develop something. If I wanted to develop something, if it does nt go anywhere, okay sorry mate, you go. But you can't do that. I know there are schemes, graduate secondments... I know there are some schemes, but the trouble is, those graduates in that think they are going to get a highflying job and wants a huge amount of money"

Administrative bureaucracy

Company D

"Grants coming from central government - they need to be much easier to understand. I appreciate they need certain information, but as part of our work with the government, we have to put online the last three years financial figures……… Now if that information is available already, why do they need us to fill out so many bits of paper saying the same thing?"

Company A

"The problem with the legislation and rules at the moment on contractor's and temporary's is a huge break to human development and industrial development"

Company C

"The governments have begun to realise that there were too many catches here"

Revenue system

Company E

"If it was made here, it would be double the price – because of the labour rate, the tax and the service you pay for – the whole lot is lifted up by a lot more"

Company H

"It is a pity we have to pay so much money to get researches done"

Low professional level of government bodies' performance

Company I

"There was a lot of advertising by government agencies saying that you can get all of this money to help you set up. But when you read the small print, the catch was that you had to have them do your business plan for you. We already had a business plan, so we didn't need another one. And guess what? You paid for that business plan! And then, they would tell you if it was possible for you to get hold of some funding"

Company J

"The regional development agency had these great ideas, but when you look at it there was just nothing there"

6.3.3 Category Seven: Offshore Competition

The codes allocated to the Offshore Competition category were those expressing the threats from offshore challenges, such as lower costs resulting in cheaper prices which are more desirable in the market, as follows:

Company B

"China is a threatening thing – once they learn how to innovate and create – they have only, in the last century or so, had glass. All their windows used to be paper"

And concerns over the copying of products, such as this:

Company C

"The Japanese after the war, they used to take things and then copy them. In the fifties, Austin, the car manufacturer, used to send cars over to Japan and they virtually copied them"

Also concerns over the local market versus the world market were flagged up, as follows:

Company F

"We have customers in Australia and the US. So when we are asleep, the other side of the world is not"

Company B

"Also you are restricted because it is a smaller market than the world market – they could make millions of them in China and bang them out and that is the end of it"

6.3.4 Category Eight: The South West Region Effect

The codes allocated to the South West Region Effect category were those showing how the participants see the effect of the region on their business. As the majority of the companies in the South West are small businesses, the region was viewed as having a positive culture in which businesses were prepared to invest in technology, as follows:

Company A

"This is where a lot of the smaller companies grow, because they do invest in the technology for manufacturing... piece part manufacturer"

Company H

"I think it is great, I think most of the companies down here are small and very specialist because we are not a big industrial region, like Birmingham or London. The companies that are set up down here are through small individuals who have had an idea and exploited that idea and there are more family run businesses"

Company D

"Our company is looking to clone what we do in the south-west. So the south-west will always be our research and development centre. We are looking to clone in North America and in the Far East"

Others see that the South West is no longer as it used to be:

Company B

"The South West is not the centre of the universe nowadays. People come here for the warm weather and retire"

Or that RP technology is not for the South West region, as follows:

Company G

"If you were in Birmingham there are more companies that want rapid prototyping services"

6.4 Internal Issues Affecting Deployment of Rapid Prototyping

The third theme, Internal Issues Affecting Deployment of Rapid Prototyping**,** was generated from categories wherein participants explained their visions relating to business size, adopted decision making strategies, the identified and prioritised barriers and their job responsibilities along with their qualifications, as shown in Figure 6.4 below.

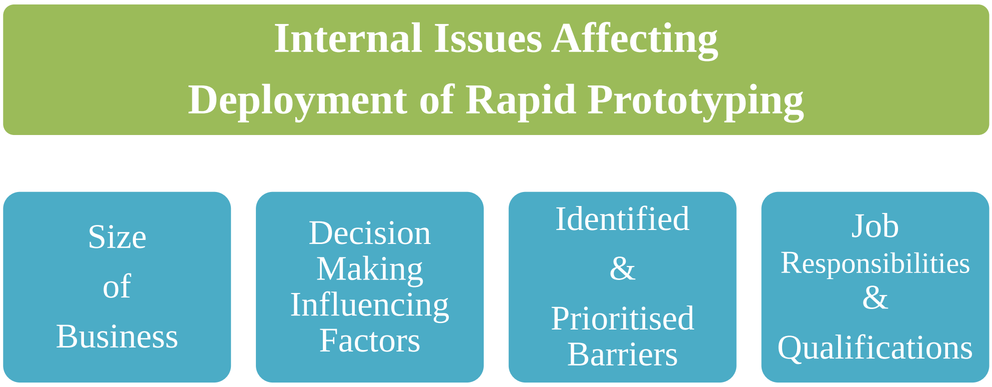

Figure 6.4 Theme Three and its associated categories

6.4.1 Category Nine: Size of Business

The codes allocated to the Size of Business category were those which articulated how size influences the business in many ways, as follows:

<u>Size versus Cost</u>

> ***Company F***
>
> *"The cost of the technology is an issue for the smaller ones"*

<u>Size versus Possibilities</u>

> ***Company H***
>
> *"The way that we exploit the transformation in new materials or techniques; it is probably limited, because we are only a small company"*

Company E

"Maybe if we had two or three more people work on it, it would move along quicker"

Company A

"We are not big enough for feasibility studies"

<u>Size versus Growth</u>

Company F

"There is not enough thinking in terms of how you can innovate and how you grow"

Company D

"When we set the company up seven years ago, we employed 15 members of staff. As of last month we employed 42. Now we have taken on 20% more this year than we had from last year"

<u>Size versus Innovation</u>

Company F

"I have worked in large and small. Generally speaking, small to medium enterprises are not innovative enough. That is the problem"

Company H

"Small, for innovation and design, is probably the quickest route through, but I wouldn't say it is the best route through, because, obviously, you throw caution to the wind sometimes"

Company G

"Small niche suppliers like us; I believe need to innovate and to generate new products"

Size versus Decision Making

Company F

"In a small and medium enterprise, it is very often owner run and that is potentially the biggest block. I have always done it this way, it is my business, it is my money... why do I want to do that? That is the biggest single block"

Company H

"If a small company like us, if we want to make a change, we will make that change; we don't compromise, we make the change, whether it be for good or bad and we learn from it. The trouble is with the bigger companies, innovation is stifled, because not everybody sees it in the same light or in the same way. And the process takes an awful long time, sometimes you miss that moment by doing all the research and all the testing and all the prototyping, where a small company... they just do it. There is no paperwork, there is no reams of forms to fill in, there is no delegation, there is no review committees - it gets done"

Company B

"If there is only one person, that one person needs to, unfortunately, have more than one talent. If you're not very good at the other ones, you have to get a grip around them and understand them. That is a major problem with SME's really"

Size versus Risk

Company C

"Obviously, when you are a smaller company, you do run that risk. You don't always see every aspect of the problem, you have blinkered vision"

6.4.2 Category Ten: Decision Making Influencing Factors

The codes allocated to the Decision Making Influencing Factors category were those that revealed what factors determine the decision making course within the

SMEs. This has shown that experience, individuals, planning, knowledge, cost, engineering, evidence and personal philosophies have an impact on the way the SMEs' executive managers make their decisions, as follows:

Influenced by their experience

Company I

"In our approach we can be quite conservative"

Company B

"No, we did take the leap and changed over. Some would say that this was foolish, but some would say we were brave, which I think we was"

Company F

"If you want to get promoted, find six people who can do your job to work for you and you'll get promoted because everyone will see that you've got bright young things. That is the way I have based my career - I have always been lucky enough to find real smart people that make me look even better"

Company E

"Because of my finance background. Also because of my experience in this kind of business; I have been in this business over 20 years, so I have... you know, I have seen a lot of products being developed and I'll use my experience and judgement. So I always look for a long-term solution, not a short term... and rapid prototyping, to me, is a short term solution for a particular issue, but not necessarily a long-term... you know, you could put me right on that"

Company A

"Usually the people who are working for me make their opinions known and I do listen to it, yes. But I'd take the decision"

Company D

"You know it takes 20 years to build up a reputation and 20 seconds to lose it"

Company C

"I think that experience has taught me that an engineer has a very good understanding of a lot of processes, but as with everything, if you go to the professionals and the specialists, they can help you overcome any potential problems that are down the line"

<u>Influenced by their individualities</u>

Company F

"You get the right kind of guy and it is the biggest driver. You can't change that"

Company E

"We were guided by one individual who we think understands the various methods, but we are not entirely sure that always get the proper sort of information. So we are maybe led by what he wants to do rather than anything else"

<u>Influenced by planning</u>

Company F

"It is not rapid prototyping, it is a question of having a plan about how to protect yourself"

Company B

"I don't want to see myself in a mass production format"

Influenced by knowledge

Company C

"I am a great believer that we need to keep in touch with universities and find the innovation to see what we can use"

Company G

"Using new technology is the way forward"

Influenced by cost

Company H

"Well one of the guys in our technical team, who did the drawing for our instrument case, he has a level of knowledge that's beyond mine. But my decision is always based on costs. So if he said 'we should go for... I have come up with this design; we should go for rapid prototyping' and I would say, 'how much does it cost' and he would say 'X' and I would say 'well, I'm sorry, we are not going to do that, we are going to go straight...', which is what we did, we went straight to the manufacturer and had a tool made and then that worked out very well"

Influenced by engineering

Company J

"It is literally the engineer's choice as to how he produces the part"

Influenced by evidence

Company D

"We are very much an evidence-based company, so we will not go out and market anything unless I have got the evidence to prove that it works"

Company F

“I am always looking out for things that develop”

Influenced by personal philosophies

Company A

“If someone else can do something, then I feel I can do it as well”

Company B

“I am one that tends to believe that you have to speculate to accumulate”

Company C

“The one thing you need to do as a company every so often is to refresh yourself”

Company D

“I believe in the company first - me last. I don't just sit there draining the company that every pound that it earns - no way!”

Company I

“Probably most of what I have done is wrong, I don’t know… but that’s how I do it”

Company J

“Obviously, to a certain extent, I would love to learn but it gets to a certain point where it would be no point in me learning”

6.4.3 Category Eleven: The Identified and Prioritised Barriers

The codes allocated to the Identified and Prioritised Barriers category were those debating the results obtained from the Phase One survey questionnaire. The identified and prioritised barriers that hinder the deployment of RP technology where presented to the participants, allowing them to point out their level of agreement or disagreement.

Company E

"Yes, I think we ticked all of those, ha, ha... I thought it was a great list, I was very impressed by it and I thought we could qualify on just about all of those, ha, ha...It touched a nerve actually, that list. Yes, pretty much all of those... apart from the limitations of rapid prototyping, which I touched on anyway, because although it does what it says on the tin, does not it"

Each of the barriers is presented below with its codes, as follows:

Resistance to Change

Some of the interviewees agreed with the results, that resistance to change is the main barrier.

Company A

"We have been here since 1950, but haven't really expanded, simply because from both my father, who started the company, and my point of view, a big company immediately becomes one tends to lose control"

Company C

"Resistance to change came back from the management where they wouldn't fund the step from conventional machining to injection moulding; so perhaps resistance to change and lack of resources are both interlinked"

Company D

"When I took the company up, we employed a lot of people who had been in the corporation, they had quite clear minds as to what they would do, particularly in the administration - this is what I have always done, why should I change?"

Company F

"The biggest problem generally is resistance to change. Particularly I think this country, in my opinion, is very resistant to change. There are pockets that aren't. But, there is huge resistance to change"

Company G

"I think you'll probably find that it is the majority of the companies... not from our point of view. You are talking a generalisation here, I reckon that is probably your worst one"

Company H

"Absolutely, that is exactly correct, the resistance to change - why change something that has always worked? Absolutely, yes"

Company I

"I would agree with the way that you've drawn that with resistance to change and lack of professional qualifications being the two highest. They are the two biggest barriers"

Others partially agreed, indicating that the process for implementing change is very slow.

Company E

"I don't find that we have necessarily resistance to change, but we are very slow to implement those changes"

Whilst other participants identified themselves as not resistant to change.

Company B

"We don't have any resistance to change"

Company J

"I think that every company needs to change and update their processes. Because otherwise, before you know it, you have been left, if you like"

Lack of Professional Qualifications

The situation with this barrier was different, as half of the interviewees disagreed with lack of qualifications as a barrier, based upon themselves. However, the Phase One results showed that 46% of the respondents indicated lack of qualifications as a barrier. The codes represent the following:

> ***Company A***
> *"I am of the opinion that engineers are born, rather than made. You know, you can always learn how stuff works. So I don't think that's a major factor frankly"*
>
> ***Company B***
> *"With qualifications, we have the young lad with his HND, so there's the ability to learn"*
>
> ***Company C***
> *"I only work really with a small number of companies and most of those are either design consultancies or companies across the road on the industrial estate here. Most of the larger companies, which still fall into the SME category, are very good on training - ultra spends... I won't say how much... but a lot of money on training and, within reason, any course that you want to do, as long as you can justify it, they will fund it. Whether that is in-house, or a way for a week, or whatever, if there is a requirement there and business is going to benefit, they will fund it. So, lack of professional qualifications in this particular instance, I don't think is that applicable"*
>
> ***Company D***
> *"I think professional qualifications isn't necessarily what we need; we do need lateral thinkers who can think out of the box, so they have an experience"*

Company H

"Lack of professional qualifications; I think probably is not quite so important here, because my partner and I are both qualified; we are both ONC/HNC. We have got CAD, we have got qualifications we require to make modifications or investigate new technologies, but the business does not warrant anything at the moment"

Company J

"Probably I would disagree with, because you could have many professional qualifications, but none that maybe specialise in rapid prototyping"

Other interviewees explained that lack of professional qualifications is not so much the problem. What is a problem is the failure to use those qualifications to gain up-to-date knowledge through research and expertise, as follows:

Company E

"We have some qualified people, but I sometimes think it's knowledge in that particular area"

Company F

"look at Dyson. You know, he is not resistant to change. In fact, he likes change, its challenges... He had difficulty getting going with lack of resources; now his problem is this... lack of professional qualifications"

Company I

"I think that the level of... the academic level is right. It's more about skills and knowledge and that's limited and less than it should be"

<u>Lack of Resources</u>

There was a high level of agreement between most of the interviewees with regard to lack of resources as a main barrier to RP technology deployment.

Company B

"It is always going to cost you more than you need to pay. That is always the bit that is going to screw up most SME's"

Company C

"Trying to get capital to buy a machine and the cost of the running of the machine isn't very easy as you could appreciate"

They pointed to how lack of resources is a problem.

Company B

"In our case, all that holds us back is really time and money"

Company C

"Obviously, resourcing is the issue really"

Company E

"Lack of resources is always a problem for us, because we are a small company. And whenever I think of resource, I think of financial resource, because other resources, if you have the money, you can buy them in"

Company F

"Small and medium companies don't have a lot of money and that is an issue for them"

Company H

"Yes, if you want to hit lack of resources, yes. A small business, there are only two of us, so sometimes... yeah, you have to understand that there are priorities. The priorities are about to maintain a business you have to have money coming in and to get money coming in you have to manufacture; it is a vicious circle. And when there is only two of you, you can't always put the time to one side to see if you can do something better or something easier or something quicker"

Also the interviewees referred to how lack of resources hampers processes such as tooling and prototyping.

> ***Company C***
> *"I think the lack of resources was an issue because originally we had great difficulty in getting finance for simple one off tooling"*

> ***Company H***
> *"We don't always have the resources to do prototyping and development of new products"*

On the other hand, some interviewees showed confidence in their resource position.

> ***Company A***
> *"Lack of resources, well I'm sure the rapid prototyping people would be very keen to help"*

> ***Company D***
> *"We are running at 30% gross - even in a recession"*

> ***Company G***
> *"We were fortunate because we had a pot of money and were able to go out and buy most of it and we paid a bit off over a couple of years"*

> ***Company J***
> *"I think if we get away... the lack of resources, if we have people that were more capable, then the lack of resources wouldn't matter so much"*

RP Limitation

The interviewees showed agreement that RP limitations are a main barrier to RP deployment. This was despite...decade, and thus reflected on the level of up-to-date knowledge of the interviewees with regard to the development of RP technology.

> ***Company E***
> *"Rapid Prototyping Limitations – that's your key"*

> ***Company F***
> *"You can't just go and turn it on"*

> ***Company I***
> *"There are obviously limits to rapid prototyping; it's still developing. It is quite difficult to make a finished product with rapid prototyping, except in certain very specific things"*

> ***Company J***
> *"I definitely would say that rapid prototyped limitation is the largest factor of what is stopping us. But, of course, the limitations kind of go back hand in hand with what we actually need"*

Some other interviewees show a more updated knowledge with regard to the RP technology improvements.

> ***Company A***
> *"I don't think there is any limitation... this rapid prototypes limitation - there are plenty of technologies are available"*

> ***Company C***
> *"Rapid prototyping limitation in the early days around about 2000, I think it was still fairly limited; it has made massive leaps forward since about 2004 – 2005; some big changes there"*

Following the review of the Phase One survey questionnaire results, the interviewees were presented with, and asked to comment upon, a diagram which associated the identified and prioritised barriers with the functions of the brain and suggested tackling these barriers using a human development and research approach. Below are the codes presenting their views with regard to that suggestion, as follows:

Company C
"We probably do need some human development, whereas a lot of the younger people that have just left university will already have done certain syllabuses on rapid prototyping"

Company D
"I think research and development does encourage human development and I think the two are intimately linked. And it is not just the research team, it is the management team as well, because the research and development are always firing new ideas and the management team's job is to try and get it into production. And encourage the marketing team to try and get their head around and identify a market sources and then aim for that"

Company F
"I like to keep track of what you guys are doing at university; we were much closer industry with universities. We tap into what you guys are doing in your research and then see whether we can use it"

Company I
"I agree with the emphasis on human development - to exploit the techniques that are already out there. The development of rapid prototyping isn't going to stop and I am sure that, you know, the more it develops the better it will be. But, actually we are guilty of not exploiting what is already there"

Company J

"I would agree that human development is always important, because without human development and without new thinking then you are never going to achieve decent research and development techniques and new designs and so on. So, resistance to change and lack of professional qualifications is definitely a barrier within companies. Not with the design side or manufacturing, but you always hear about resistance to change in a company whenever new processes are introduced. There is always that resistance to that; even though it is possibly a good thing"

Whereas some other interviewees were conservative with regard to both approaches, as follows:

Company A

"I think that human development is a difficult area. I like finding future stars and I have done that on a number of occasions; find people who are better than you"

Company B

"The development of people needs very good mentoring and very good nurturing"

Company E

"Research and development is now either in the universities or private multinationals"

Company G

"Possibly, you need human development in order to bring your research and development up as well; I think the two go hand in hand"

6.4.4 Category Twelve: Job Responsibilities and Qualifications

The codes allocated to the Job Responsibilities and Qualifications category were those describing the level of education the interviewees had along with their daily duties and responsibilities, as follows:

Company A

"I am the proprietor of engineering company, where we manufacture instruments of various types"

Company B

"My strengths are basically mechanical design"

Company C

"I am a senior design mechanical engineer"

Company D

"I am a qualified state registered clinical specialist working in the health care profession. I also run a company as managing director"

Company E

"My main function is procurement and production manufacture of our products"

Company F

"I am the chief executive of this company"

Company G

"Mostly Finance. But I have got into this business, engineering testing thing, through default really over a period of time"

Company H

"I am an electronics engineer; I did an apprenticeship at Heathrow with BOAC, which eventually turned themselves into British Airways"

Company I

"I am a mechanical Engineer, I work primarily with robotics. So I specialised in land based and automation vehicles used by the military and the government"

Company J

"I am the product development engineer and I am also the team leader"

6.5 Potential Scenarios for Deployment of Rapid Prototyping

The fourth theme, Potential Scenarios for Deployment of Rapid Prototyping, was generated from categories in which participants articulated their thoughts with regard to possible solutions, intentions to adopt, drivers to change and adoption methods, as shown in Figure 6.5 below.

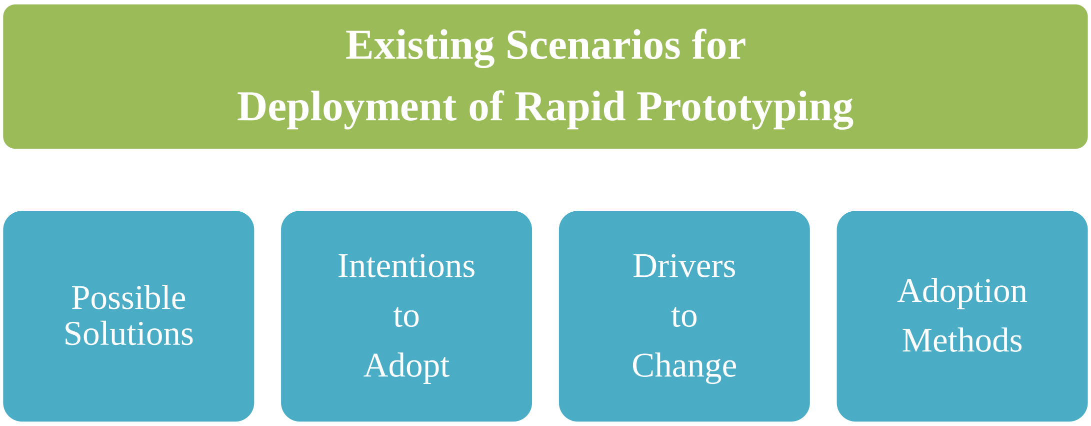

Figure 6.5 Theme Four and its associated categories

6.5.1 Category Thirteen: Possible Solutions

The codes allocated to the Possible Solutions category were those dealing with the interviewees' notions about the way to appropriately deploy RP technology within SMEs. Knowledge was at the top of the list, as most of them indicated knowledge as an essential factor for deploying RP technology. They also pointed to Knowledge Transfer Partnerships (KTP), which are already in place, yet not all of them were aware of this although some interviewees had mentioned them. Knowledge was perceived in their own words, as follows:

Company A

"It is just a little bit of extra knowledge"

Company D

"This has been done as a result of direct research work done with Plymouth University. We had KTP, are you aware of KTP's? We had young lass doing a KTP who is now on our staff"

Company E

"We are highly skilled and we have a high level of academic knowledge. But we need to increase the knowledge of the engineers in rapid prototyping, so that we reduce that barrier to going outside and using it"

Company F

"In terms of development and prototyping you need people that read about what is going on"

Company H

"Maybe more joined up approach between design engineers and those who are developing the rapid prototyping"

Company I

"To educate and involve..."

Company J

"I certainly keep aware on the news... you know, looking at the computer, there are certain new scientists forums and posts that you just look at and read just to see where technology is going. So you are aware of new innovation... I don't think we would be scared of using new innovation if it were proven to help us and to make things easier for us"

Also some interviewees indicated that the way ahead is to buy and use RP technology.

> ***Company B***
> *"The only way we can do it at the moment is to buy the machine and then start trying to sell the service"*

> ***Company C***
> *"Using new technology is the way forward"*

> ***Company G***
> *"You buy in the experts and pay them and off you go"*

6.5.2 Category Fourteen: Intentions to Adopt

The codes allocated to the Intentions to Adopt category were those showing the plans the interviewees have in place for the near future with regard to RP technology. The interviewees' plans were, either, to adopt RP technology at some point, as follows:

> ***Company E***
> *"Having said when we rejected it in the past, I wouldn't reject it in the future"*

> ***Company H***
> *"I think the nature of the machinery is such that the costs are now coming down and the user interfaces are becoming a lot easier. So, from that point of view I would think we would be looking"*

> ***Company I***
> *"I bought a laser and we bought a large CNC 3-axis machine. And we would like to buy a rapidprototyping unit as well – which we would like to get to that level"*

Or, to continue to deploy RP technology, as below:

Company A

"Our setup has been designed, basically, to put into rapid prototyping, because every product is different, every presentation is different"

Company B

"We've considered rapid prototyping for other issues"

Alternatively, they had no plans to adopt RP technology, as follows:

Company F

"The answer is, no I am not. So if you can work with me and find puncher or whatever, then I would be happy. The thing is, you do need... it is like anything else, to create a fire you need wood and a light; you need a match or something. To start that paying for itself... To make sure we are not burdened with that round our neck... because taking £20,000 out of what we have at the moment is criminal"

Company J

"There is no sense of putting money into it if you don't get something out of it"

6.5.3 Category Fifteen: Adoption Methods

The codes allocated to the Adoption Methods category were those showing the methods envisaged by the interviewees when making the decision to deploy RP technology within their companies. Those methods were to outsource through a service provider, to buy the RP technology, or to run it on-site, as follows:

<u>RP technology through Outsourcing</u>

Company A

"Near future would certainly consider outsourcing, but perhaps do it in a more structured way"

Company B

"One of the advantages of having it outsourced is that you can tap into a range of different techniques and sizes"

Company D

"Choice, it gives you the ability to choose, which again is quicker"

Company G

"I have outsourced manufacturing mainly, not the technology"

Company H

"I think we would outsource it, basically because we don't have the time to allocate to it. There are only two of us here and there will probably be somebody that is far more familiar with what they are doing than we are. We are very focused on running the business just on a day to day basis and there are probably experts out there who do it far quicker and advise us a lot better than... around"

Company I

"Until we felt our way a bit more and maybe been more consistent in our approach, actually we can carry on doing outsourcing. But, I could see an opportunity in the future where we go... actually we do this often enough and we can do enough of this particular size for this particular type to bring it in-house"

Company J

"To survive we have tended to outsource more and not manufacture internally"

Some of the interviewees explained the disadvantages of outsourcing as follows:

Company C

"Based upon that we obviously make the choice. We are limited with what we can do with the Prototyping Company"

Company E

"Outsourcing your ideas is wrong. Outsourcing individual components that can't be put together - very smart idea!"

Company F

"The minute you outsource, you have much less control and other people can run away with it"

<u>RP technology On-site</u>

Company C

"We prefer that, obviously because we would have in-house capability to design it and then the next morning to actually test the part"

Company E

"I think in-house if you have the right controls and you can keep people focused, it is probably better. But maybe using outside people you get a more professional job and more focus"

Company F

"Having on site you have more control, particularly about what you are doing and not letting it escape"

6.5.4 Category Sixteen: Drivers to Change

The codes allocated to the Drivers to Change category were those which identified the boost factors that could make, or had already made, a change to their companies. The interviewees described them as follows:

Company A

"Using new technology is the way forward"

Company B

"Well basically it is efficiency that drives these things"

Company C

"*When the managers could see the benefits and the way that industry was going and the competitors, of course, then we had no problem with using rapid prototypes to prove concepts before we went to hard tooling"*

Company D

"I think the key factor is empowerment"

Company E

"If you have got good development of people through innovation they will do your innovation and then they will find what they need to do on rapid prototyping"

Company F

"If the idea is good enough and the bloke is convinced of it, he will find a way"

Company G

"*We can do something on the rapid prototyping, let us go and dunk our feet in here and see what we can do. It was needs-based, definitely"*

Company H

"It is you keeping up with the demand for a lower priced product, or maintaining your prices, or improving your prices, or increasing your throughput, etc... It is sort of those things really"

Company I

"We want to be in a position that this is an opportunity to improve what we do, so let's have a good long think and an assessment of what our real requirement is and that will lead us to a better deployment of the technology"

Company J

"Your whole basis is on rapid prototyping, but it is really rapid development; prototyping is just one specialise... it is rapid development of systems and processes and items that you are manufacturing"

Also, one interviewee shared his own perspective on why a change needed to happen within his company, as follows:

Company D

"Survival I think is the big one. If you don't change... one of our competitors is actually losing business, or at best is stagnant and I think that is because they haven't grappled the situation of a fast turnaround at the right price and of good quality"

6.6 Factors Influencing Deployment of Rapid Prototyping

The fifth theme, Factors Influencing Deployment of Rapid Prototyping, was generated from categories in which the interviewees articulated their views with regard to the factors that potentially impact the deployment of RP technologies within their companies, as shown in Figure 6.6 below.

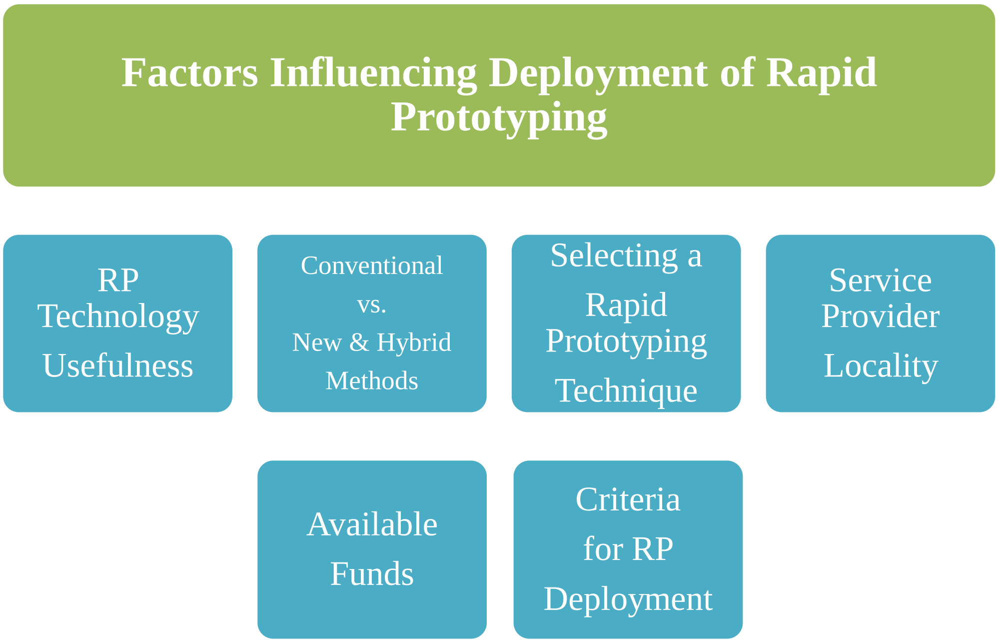

Figure 6.6 Theme Five and its associated categories

6.6.1 Category Seventeen: RP Technology Usefulness

The codes allocated to the RP Technology Usefulness category were those which stated the convenience of RP technology to their SMEs, as follows:

> ***Company A***
> *"Certainly, where we have used it, we have seen, not only the reduction in design to production time, but also we have seen a cost benefit as well"*

Company B

"We have seen an improvement in our own productivity and we've seen increased sales in areas that we weren't available for"

Company C

"When we look at our products now, we have a build time of 35 minutes against four hours. So you can see, you can almost build eight in that period of time"

Company D

"Rapid prototyping has dramatically opened up the market for us. It has enabled us to significantly improve our quality and it made assembly so much easier, so much quicker... we can react differently to product requirements... there was a time when we were having these for our builds, where we needed to give the customers leave time of about a week, or a week and a half. Now, although we don't offer it, we could literally offer it them the same day, within reason, because we could build the product at 8:30, we can test it by nine o'clock and it can being dispatched by 9:15 in its box waiting for the courier to collect it"

Company G

"Because you increase your performance. You either double your output, or you halve your time. Technologies are quite a quantum leap"

6.6.2 Category Eighteen: Conventional versus New and Hybrid Methods

The codes allocated to the Conventional versus New and Hybrid Methods category were those defining the way the interviewees integrate or replace technologies as industrial/manufacturing technological developments move forward, as follows:

Company A

"It was purely a matter of choice to me whether I wanted a product made from the rapid prototyping method and obviously, as an engineer, you get far more options if you rapid prototype than conventional machining"

Company B

"The products that I told you about around the year 2000, was predominantly machined out of aluminium. It was one small product; we CNC machined it, prototyped some of the other parts in plastic - small one-off items, but we didn't really begin to embrace proper rapid prototyping on a large scale until around about 2006, when we rapid prototyped hold products"

Company E

"We haven't looked at every means, but we have always looked at conventional methods rather than rapid prototyping"

Company I

"The CAD, I would say, there are examples where it has worked well and there are examples where I think the technology has probably got in the way of achieving that advantage. And it has probably... we've not been particularly clever at our applying 3-D CAD technology. So it has resulted in a delay, whereas if we had been doing it the old way, we probably would have got there faster. Because we haven't exploited the advantage that the 3-D solution has given us, you know - the integrated approach, which is kind of coming now"

6.6.3 Category Nineteen: Selecting a Rapid Prototyping Technique

The codes allocated to the Selecting a Rapid Prototyping Technique category were those related to how the interviewees would select the type of RP technology when a decision is made to deploy within their business, as follows:

Company A

"Had no problem with actually choosing; as an engineer"

Company B

"It is identifying the new technology that is going to be better"

Company D

"We tend to base our decision on the function of a part. So, if that then comes down to the materials that particular process uses"

6.6.4 Category Twenty: Service Provider Locality

The codes allocated to the Service Provider Locality category were those concerning the proximity of the service provider in cases of outsourced RP technology, as follows:

Company A

"We tend to use those because they are local to us; they are 30 miles up the road as you know"

Company D

"We could go nationwide or even we did at one time think of looking to the Far East for prototypes, because the cost is slightly less. But there is a benefit to being able to discuss your requirements with your supplier and face to face is very useful if there is any problem"

6.6.5 Category Twenty-One: Available Funds

The codes allocated to the Available Funds category were those pointing out obtainable funds issues when the decision is made to deploy RP technology within their SMEs, as follows:

Company A

"You have got to justify it properly first"

Company B
"Wouldn't fund without a lot of cross benefit analysis"

Company C
"I think a lot of it is down to finance. We have invested heavily ourselves, particularly in the early days it was quite hard I have to say. But now, obviously, we are paying dividends because we have got the opportunity, we have got the machinery to do what we need to do. So we could of our production dramatically; that is why we moved to much bigger premises"

Company D
"We have always done our expansion from money supply basically"

Company G
"The senior management bought into the idea, so they funded us"

6.6.6 Category Twenty-Two: Criteria for RP Deployment

The codes allocated to the Criteria for Deployment category were those pointing to the elements that concern the interviewees when making a decision to deploy RP technology. These elements were production volumes, customisation, research and development, cost and time, business survival, and quality of RP technology, as follows:

<u>Production Volumes</u>

Company A
"Rapid prototyping is where you have got a retail market or where you have got competitors bringing out products, which you are selling"

Company C
"*Once the volumes were there, we could easily, and still can easily justify rapid prototyping"*

Company E

"We were looking at, a sort of, maybe getting about 5000 impressions from one mould... we felt that rapid prototyping wasn't the way to go. But for smaller quantities I think we would consider it, but obviously, cost is a big issue"

Company H

"We are only manufacturing small quantities. We don't go out looking for large manufacturing batches and I say we are customer driven, so we only tends to make one or two, possibly three products at that time"

Company J

"If we look at a product... I think of a minimum of 1000 units over say a five-year period and maybe over that sort of 10 to 15 year period... three or four thousand. So we always looked at the conventional means"

Customisation

Company D

"Every order that we do and we make 200 every week now - everyone is different to each other"

Company I

"We've come across an area where we've had an operational failure and we've needed to do something fairly quickly and it's focused our attention on delivering a solution quickly"

Company J

"I have not used special purpose parts designed for me, so I haven't had cause to use rapid prototyping"

Research and Development

Company C

"It would be purely an engineering development tool. So we wouldn't be using it for any production parts, but we would be able to react very quickly"

Cost and Time

Company A

"Any enterprise, if they can see it is worth doing the new way, they'll do it on new way"

Company B

"The cost - you can have a rapid prototypes produced with multiple features for a 10th of the cost of a machined item where it has got multiple setups and obviously a machined item may not have the features, the clip features, that you can achieve with rapid prototyping"

Company E

"If you can show people that they will make a product cheaper, or better, then people inevitably must sit up and take notice"

Company D

"The criteria would always be cost and to me it always has to come down to cost, and then appearance, of course. The quality of the product is very important"

Company H

"The key issues for deploying would be to, basically, reduce costs. That would be the key issue. If we could reduce our manufacturing costs, then that would be the key issue to employ some rapid prototyping or anything else"

Company J

"As it is, as we can manufacture it, is not a major problem. But, if there are machines out there that can manufacture what we want quicker, cheaper, faster, better and so on, then we would definitely have a use for that"

Business Survival

Company H

"I think if the business became very quiet all we found that the products were not selling, then maybe we would look into new technologies"

Quality of RP Technology

Company J

"The main issue in rapid prototyping sense is that I don't believe that it can produce the quality of component that we need in order to get a good representation of what we require for testing purposes or, in terms of maybe aesthetics, we got a lot of shows throughout the world with our products"

6.7 Discussion

The first emerging theme, of awareness of the RP technology, revealed that knowledge is an important and vital determinant in the process of implementing any new technology, and RP technology is no exception. The analysis of the interviews has shown that lack of knowledge can hinder the process of deploying RP within the SMEs in all size categories. Figure 6.7 illustrates the level of knowledge of RP technology in each sector, as well as the adopters and non-adopters of RP technology. The size of the bubble denotes the size of the SME and the colour denotes adoption. Also the analysis revealed that the higher the knowledge level is within a company, the more boosted business the design and manufacturing practices. It was found that SMEs that deployed RP technology have, in general, good levels of RP knowledge and good in-house development processes. In contrast, the companies that have low levels of RP knowledge were found to have hardly implemented any in-house development practices. Therefore, it is essential to prompt SMEs to keep up their level of knowledge in order to enhance their in-house manufacturing practices and to help them make appropriate decisions when required.

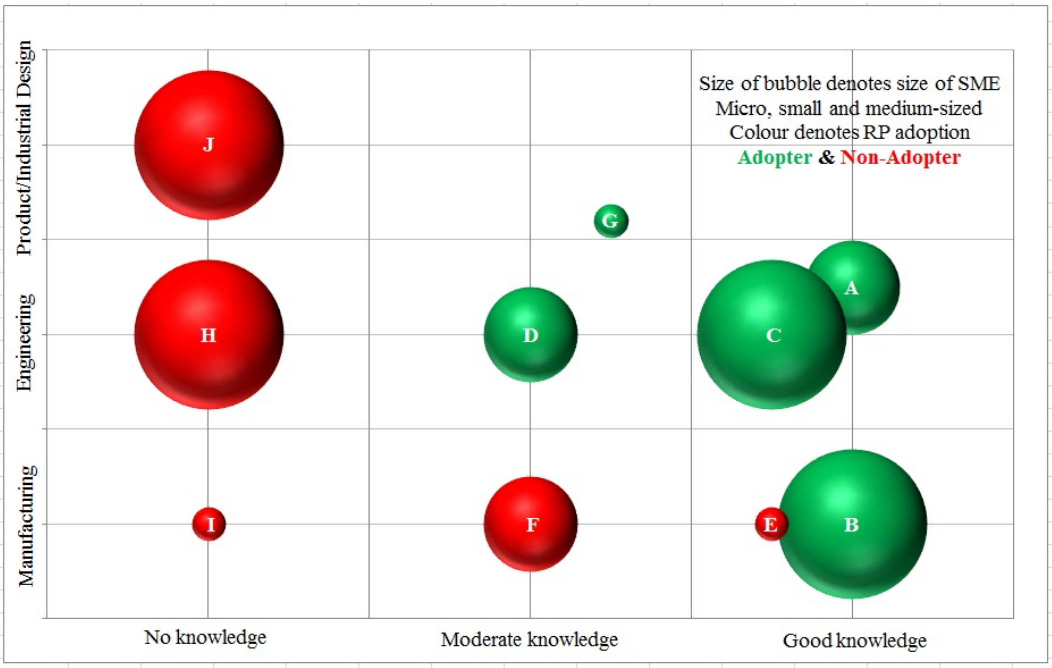

Figure 6.7 Knowledge levels and adoption statuses within the interviewed SMEs

The second theme, of external issues affecting deployment of RP, has revealed that customers have a great impact on the way things are done within a company. An SME that is customer-driven is found to be more proactive when it comes to in-house development and up-to-date knowledge. Therefore, encouraging a space for customer feedback is essential in prompting the companies towards more development engagement. Red tape and government official procedures, whereby regular activities are necessary to keep documents up-to-date and ready so that they may benefit from government initiatives, were found to have a strong negative impact on the companies. Additionally, creativity has to be a key player in stopping the threat from offshore companies, and this can take the form of introducing ideas, reducing cost and time, or any form of competition. For this reason, a culture of habitual internal review within the company is required to identify the need for creative improvements.

The third theme, of internal issues affecting deployment of RP, confirmed that company size is a big barrier in itself, as costs and staff count has a negative effect on the adoption of RP, in terms of cost to buy and staff to run the technology. Also, the decision making level was found to be strongly influenced by the owners' individualities in terms of their experience, knowledge and qualifications. Hence, it is clearly necessary to implement a procedure that can eliminate the negative effect of company size, along with the effect of the decision maker's nature through a strategic regular assessment that maximises the potential to benefit from the available internal resources and external subsidies. Also, the majority of the interviewees have agreed on the proposed combined approach to tackling the identified and prioritised barriers by introducing a process of consistent human development and triggering a culture of in-house research and development.

The fourth theme, of existing scenarios for deployment of RP, has revealed that possible drivers to the enabling of RP technology within the SMEs will again be through knowledge, or trying the technology for a one-off product to gain an insight into what the technology could offer. Also companies which had already deployed RP mentioned that they intended to continue to implement RP processes, and some of the non-adopter companies showed an interest in considering RP in the near future as a result of being involved in this research where they had gathered some knowledge about the potential benefits of RP technology. The analysis also revealed the drivers which could lead them to consider RP technology, namely: rapid development; call for innovation; business demand; potential benefits; needs-based assessment; efficiency and empowerment. Once one or more of these drivers exists, adoption could either be through outsourcing or on-site, based on the driver. Consequently, it is ultimately needed to strategically identify one or more of the mentioned drivers to enable a culture of RP technology within the SMEs.

The fifth theme, of factors influencing deployment of RP, has clarified the elements that help to define the features of the last stage of making the deployment decision - selecting the RP methods. These are: locality of service providers, in the case of out-sourcing, and maintenance in the case of in-house RP; level of customisation, leading to RP only or hybrid with other conventional techniques; and available funding. Thus, an internal self-assessment of the company's strategic status is required to assist with the decision, in tandem with identification of the potential risks and opportunities.

The results thus obtained have substantiated the view that a strategy for deploying RP technology within SMEs can be developed. This has answered the research question and also validated the identified and prioritised barriers from Phase One which were confirmed in Phase Two. SMEs can be RP technology enabled, and/or strategic decision making empowered. This can be achieved through several strategy related factors, which were identified and discussed based on the thematic analysis of qualitative semi-structured interviews conducted with the executive managers of SMEs in the South West of England. These RP technology get-up-and-go factors should be brought together though a strategy that:

- Promotes a self-encouraged state-of-the-art technological culture within SMEs, as a means of maintaining a high level of awareness of the latest new technologies, and in particular RP technology.

- Promotes and enables innovation through in-house design and manufacturing practices.

- Stimulates identification of the specific requirements for RP technology based on the recognised design and/or manufacturing needs through the product life cycle.

- Supports the No-Need for RP deployment situation, when the decision is made based on the strategic analysis of the circumstances within the SME.

- Encourages engagement with customer feedback as a continuing process within the SME, from which the requirements for development are to be generated.

- Motivates tolerance of current national bureaucracy in anticipation of the benefits of governmental support, through a flexible management approach.

- Stimulates a culture of creativity within the SME, as a tool for surviving global competition.

- Upholds sustainable regional development, in order to maximise and strengthen the economy within the SME regional location.

- Encourages reversal of the negative business size effects of cost and staff numbers through an alternative and flexible approach to making the most of the support available to SMEs.

- Persuades strategic routes towards an appropriate strategic decision, which is to be made upon the best available information and with the resources available at the time of making the decision not on other factors such as bad experiences or personal philosophies.

- Motivates a culture of human development within the SME, to overcome the barriers of resistance to change alongside updating the level of knowledge associated with qualifications held.

- Motivates a culture of research and development within the SME, with the aim of controlling the barriers of lack of resources and RP limitations.

- Promotes knowledge management as a means for change within the SME, in order to eliminate the barrier of resistance to change along with the continuing human development.

- Promotes alternative modes of technological deployment within the SMEs, based on the strategic circumstances and the needs of each SME. These could involve outsourcing and onsite adoption routes.

- Promotes empowerment within the SME, as a tool for pushing the boundaries and exploring new horizons for future growth.

- Promotes strategic techniques to perceive the usefulness of RP technology, in order to explore integration methods within SMEs.

- Stimulates ways of integrating and combining the conventional manufacturing methods into collaboration with new technologies, in particular RP technology, to identify customised innovative hybrid manufacturing process integration.

- Promotes risk assessment prior, with and after making the decision to deploy RP technology.

- Promotes a way of identifying the product’s nature with the SME, in terms of levels of standardisation versus customisation.

- Helps to justify the decision to deploy RP technology by exploring new potential markets as a target either for increasing production volume or launching new products or services.

The themes which emerged and their categories, along with the above extracted drive factors are formulated and summarised in the thematic analysis map (Figure 6.8). Colour coding is for illustration purpose only, as each colour identifies a theme with its categories and the resulting actions which are to be implemented in the proposed strategy.

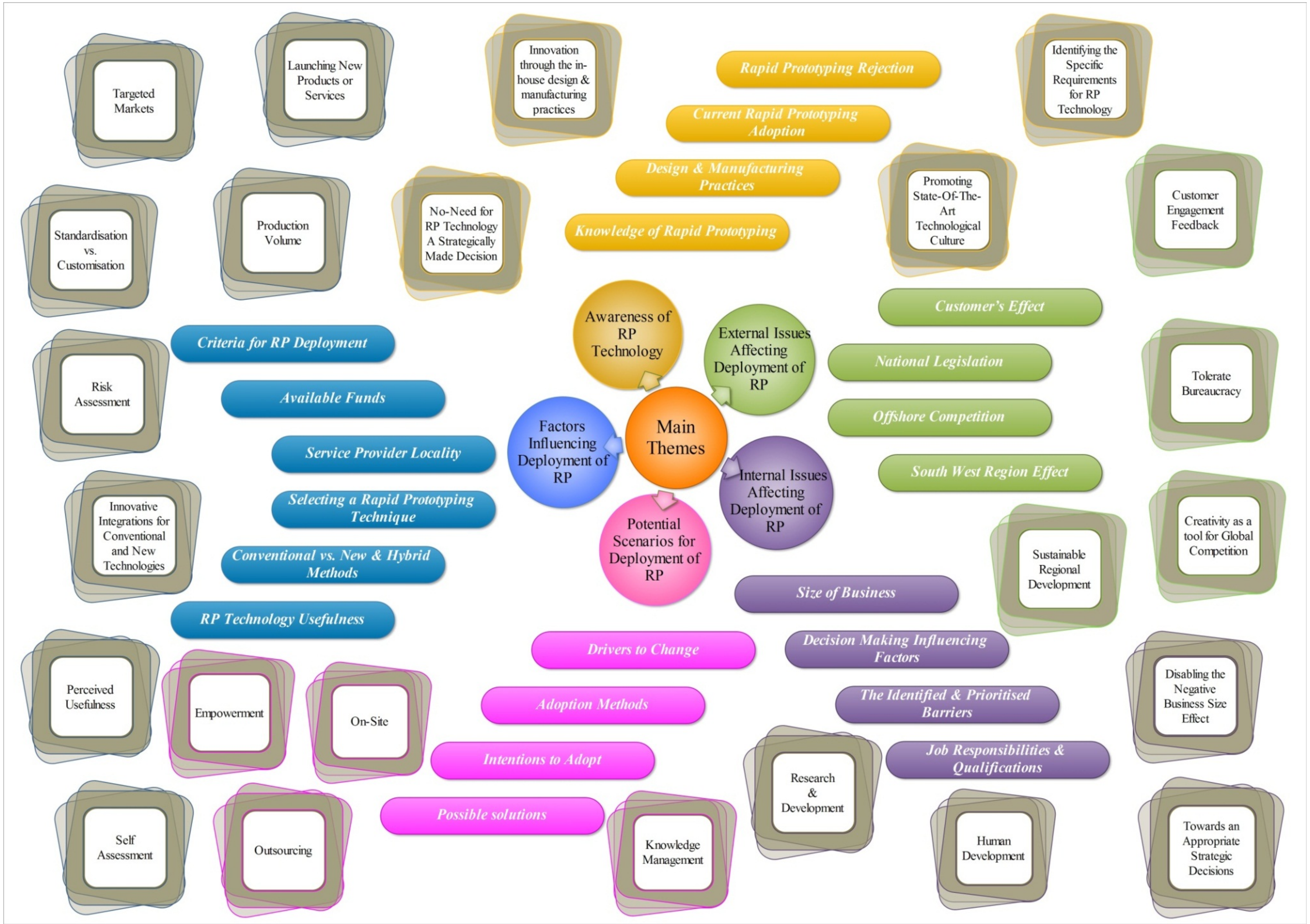

Figure 6.8 Thematic Analysis Map

6.8 Chapter Summary

This chapter presented the process of analysing the qualitative data obtained from the conducted interviews in the second phase of this study. The codes which emerged were grouped into categories for similarity; these categories were then used to identify the main themes, of which there were five. This chapter has also revealed, through the findings of the thematic analysis, the drive factors that are needed so that a strategy can be developed for deploying RP technologies within SMEs. A thematic analysis map was designed and generated to summarise the process. The next chapter presents the developed strategy for deploying RP technology within SMEs.

Chapter 7

Conclusion

7.1 Chapter Overview

This chapter brings together the findings from both the quantitative Phase One and qualitative Phase Two data collection stages, alongside the conclusions obtained from the literature review to answer the research questions of the study. The answer takes the form of a strategy for the deployment of RP technologies in SMEs which deliberately helps them to perform within their business boundaries. The proposed strategy is discussed with regard to its structure, guidance, management and validation. In addition, the chapter emphasises the contributions to both theory and practice made by this research. It concludes by highlighting the limitations of the study and recommending directions for future research. Figure 7.1 shows the chapter structure.

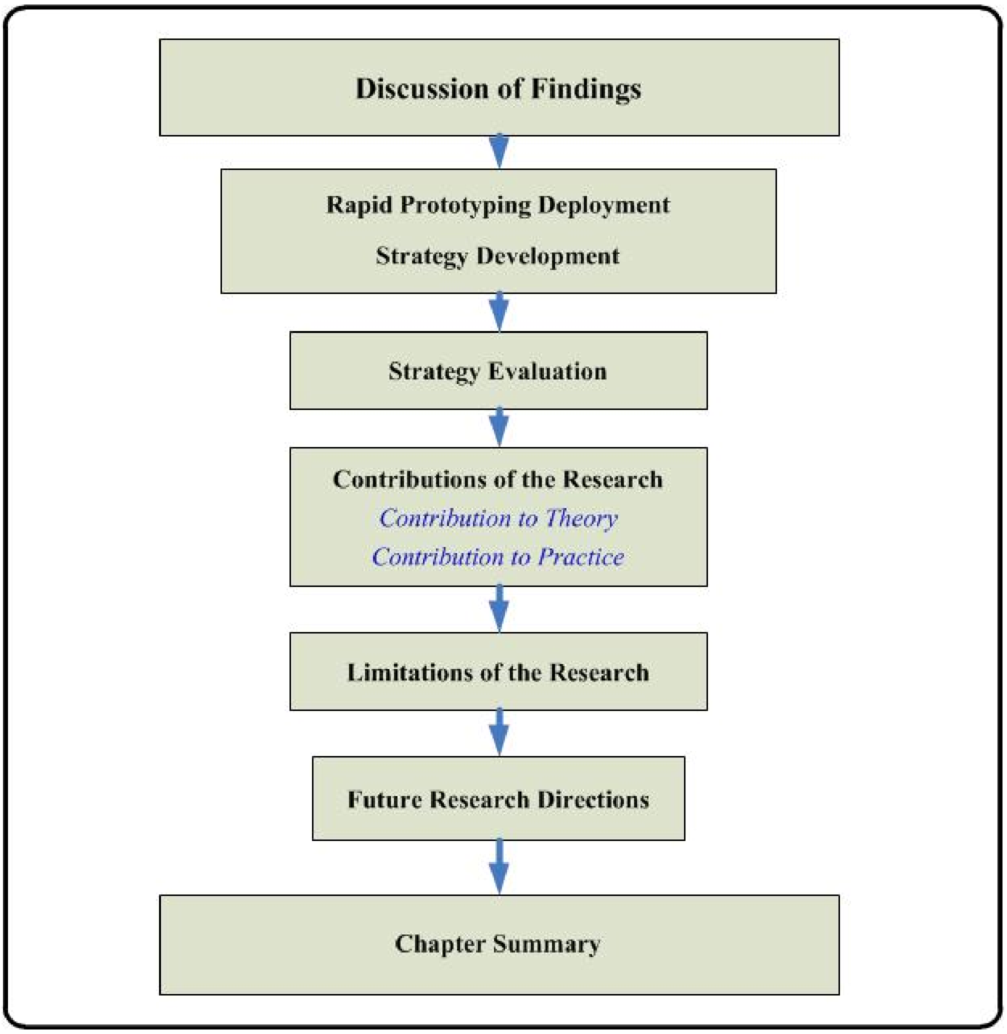

Figure 7.1 Chapter 7 structure

7.2 Discussion of Findings

To look closely at the crucial outcomes obtained by this study, it is essential to go back to the aim and questions underpinning the research. The inclusive motivation of the research was to identify and prioritise the barriers hindering the deployment of RP technology within SMEs, and to determine whether or not a strategy can be developed for that purpose. Constructed upon this comprehensive aim, along with the generic technological barriers identified within Chapter 3, the main question of the research was supported by key sub-questions, as follows. The answers for each are discussed below.

1. What is the level of awareness of SMEs of available new technologies?
2. To what extent is the RP technology recognisable within the SMEs?
3. To what extent are SMEs deploying RP technology, and how?
4. What are the common barriers that hinder the deployment of RP within SMEs, and which comes first?
5. What are the significant factors needed to develop a strategy for the deployment of RP technology within SMEs?

The study revealed that the level of awareness of available new technologies varies between no awareness, limited awareness, good awareness, and high level awareness. This applies to RP technology which is the focus of this study. Also the level of awareness of new technologies, in particular RP technology, cannot be generalised throughout the whole SME sector as this is a result of individual practice. Thus this concern can be tackled by the human development approach. This relates directly to the extent to which RP technology is recognised within the SMEs, and the study has shown that there is already a level of recognition and deployment within some SMEs. However, the study also showed that RP technology was not recognised by the majority of SMEs for a variety of reasons.

These evolved into the potential drivers for maximising the level of recognition within SMEs. In addition to these potential drivers and along with the deployment criteria which were extracted from the existing RP deployment cases, a set of criteria for RP technology deployment were identified and incorporated into the developed strategy. The barriers that hinder the deployment of RP within SMEs were identified in the course of Phase One, and prioritised with suggestions on potential approaches to minimise the effect of these barriers. The identified and prioritised barriers are: resistance to change, lack of professional qualifications, lack of resources, and RP technology limitations. The returned and completed survey questionnaires demonstrated the perceptions of these barriers, which have resulted in the current situation for SMEs; that is, left behind with regard to industrial/manufacturing technological advancement.

These findings were later investigated in depth to understand the actual causes and the possible ways to improve the situation. The suggested approach of tackling both resistance to change and the lack of professional qualifications, through human development, was received positively by all the executive managers who participated in the two phases of the study. It was also clarified by the participants that lack of professional qualifications was not a major issue as they all held high level qualifications, but maintaining an up-to-date knowledge base was an issue which could be tackled effectively through the human development approach. With regard to the lack of resources and RP technology limitations, the participants also supported the suggested research and development approach as a tool for tackling those barriers. Up to this point, these ideas had been theoretically supported as empowerment techniques for eliminating the barriers, but they now needed to be translated into something more practical. Consequently, they were implemented and enabled as a practical tool within the developed strategy.

7.3 Developing the strategy

In order to develop the proposed strategy, the features that characterise the RP technology needed to be incorporated at the very early stages of implementing the strategy. There are unique benefits that can only be achieved by deploying RP, which were recognised from the literature review as well as in the interviewees' words. Wohlers (2012) have reported that "These newer uses of 3D printing could enable unprecedented levels of mass customisation, shrinking and less-costly supply chains, and even the 'democratisation' of manufacturing as consumers and entrepreneurs begin to print their own products". The interviewees stated, based on their own experiences that the customisation levels offered by RP technology could benefit the sectors manufacturing for end-user products more than the sectors manufacturing for business-to-business. This is arguable, because the aircraft industry, for instance, is mostly business-to-business, although the levels of customisation in the manufactured parts are very high, therefore RP technology has shown great potential in this industry.

This makes 'Customisation' the key distinctive component offered by RP technology along with the other known advantages of complexity-free fabrication, multi-material combinations and the shortened supply chains which benefit customers as well as manufacturers. The strategy offers SMEs which are looking to evaluate their need for RP technology and at their capability to deploy it, the Product Process Matrix (PPM) that guides them through the classification of their product's level of customisation.

The developed strategy consists of three key stages, each designed to address some of the identified needs. The three stages are: Pre-Decision Making; Decision Making; and Post-Decision Making. These stages are planned in such a way that an SME can constantly reflect upon the changing needs within the business to ensure that it is not technologically left behind in terms of RP technology. Figure 7.2 shows the Rapid Prototyping Deployment Strategy (RPDS) Flowchart. The strategy also contains a stimulating question which helps the user to determine whether or not his company is ready for RP technology. If the user is not familiar with the term Rapid Prototyping, then the strategy points out that they need to investigate RP. In addition, if the user is familiar with the term RP, but not well versed in it, then the strategy points out that they can use the developed PPM to help recognise the need for RP technology based on the product nature (Figure 7.3). Chua et al. (2010) stated that "The benefits to the company using RP systems are many. One would be the ability to experiment with physical objects of any complexity in a relatively short period of time. It is observed that over the last 35 years, products released in the market place have increased in complexity in shape and form".

Despite, the well-known potential benefits to an SME of adopting RP technology, this strategy is designed to assist managers to make a suitable decision, which may be that for some companies RP is inappropriate. Therefore, the strategy is designed to help SMEs change their way of managing their business towards more objective strategic management rather than the more subjective individual management classically represented by the proprietor. Shankarrao and Shirsath (2013, p.29) defined change management as "an approach of transitioning or shifting teams, organisations, individuals from a present state to a future desired state. It is an organisational process which is aimed to help the stakeholders to accept and embrace changes in a particular business environment".

Correspondingly, the identified barriers, in tandem with the recognised driving factors from the data analysis from both phases, do point out that the concept of change and its management is one of the biggest barriers. Todnem By (2005, p.378) stated that "the successful management of change is a highly required skill. However, the management of organisational change currently tends to be reactive, discontinuous and ad hoc with a reported failure rate of around 70 per cent of all change programmes initiated. This may indicate a basic lack of a valid framework of how to successfully implement and manage organisational change since what is currently available is a wide range of contradictory and confusing theories and approaches, which are mostly lacking empirical evidence and often based on unchallenged hypotheses regarding the nature of contemporary organisational change management".

Therefore, to tackle the barriers and empower the drivers, a strategy that encompasses a tendency to maintain on-going progress in change management to suit the external global trend in business management is needed. Mcadam et al. (2000, p.148) indicated that "there appears to be a strong link between CI (Continuous Improvement) and innovation for SMEs. It can further be contended that companies which have developed a culture of Continuous Improvement have discovered that it can provide a solid foundation on which a culture of effective business innovation can be built. Companies with a proven track record of Continuous Improvement appear not only to be more innovative, but perform better in all the different aspects of innovation as measured".

Hence, classifying the unambiguous needs for RP technology to justify the decision to deploy boosts advanced technological culture within SMEs and enables innovation; just as justifying the No-Need for RP deployment situation is also distinctly acceptable. Besides improving human development, and the R&D that would eliminate the barriers through continuous training, links with the knowledge exchange platforms and engaging customer's feedback to power up potential new developments. Mcadam et al. (2000, p.148) "Businesses have discovered that a culture of Continuous Improvement has helped allow employee creativity and ideas to flourish and grow, with the result that businesses should be able to more readily react to change and respond by doing things differently, or better, across products, processes or procedures".

This culture of Continuous Improvement could be maintained within the SMEs through regular quarterly and annual reviews that would highlight any unpredicted issues that needed to be addressed. According to Communiqué PR - a public relations and strategic communications firm – in a blog post on quarterly reviews, entitled The Value of Quarterly Reviews (Madeline Landis, July 27, 2012): "Experts agree that businesses that invest in quarterly reviews have a greater chance of meeting their goals and succeeding in the marketplace. According to a Harvard Business Review blog post on best practices, titled Four Fatal Flaws of Strategic Planning (Ed Barrows, March 13, 2009) number four on the list is: 'Dodging Strategy Review Meetings'. Enough said".

Also the company self-assessment along with the Pre-decision making evaluation would enable the SMEs to recognise the areas where the distinctive characteristics of RP technology are met. The results from these assessments would inform the following stage of decision making, when it comes to analysing and confirming the opportunities to be gained and detecting the threats to be avoided. Once the decision is made either to deploy or to review again in three months' time, the company will be in an up-to-date position with the RP technology that would make the following reviews much more productive and informative.

Rapid Prototyping Deployment Decision Making Strategy Flowchart

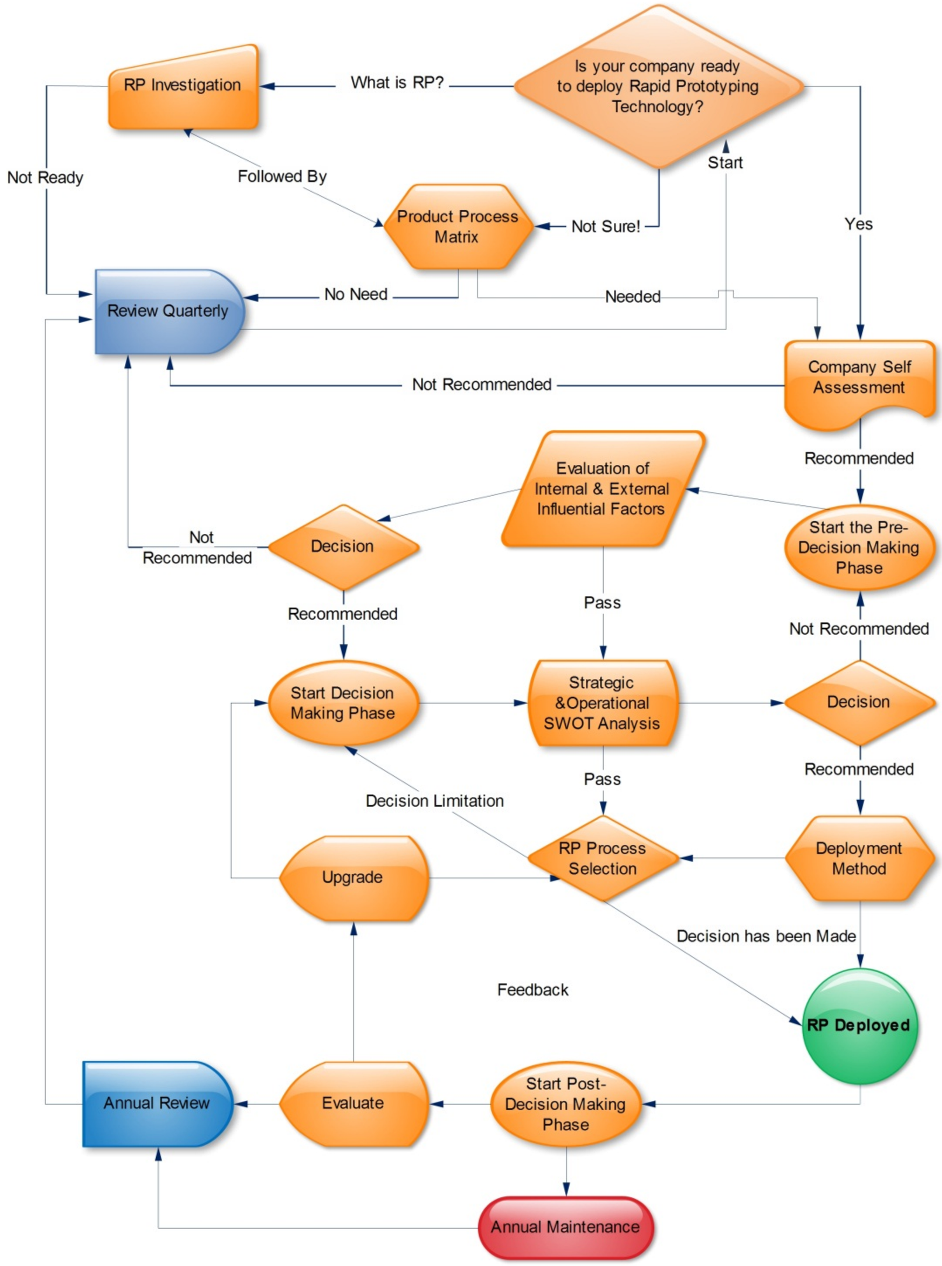

Figure 7.2 Rapid Prototyping Deployment Strategy (RPDS) Flowchart

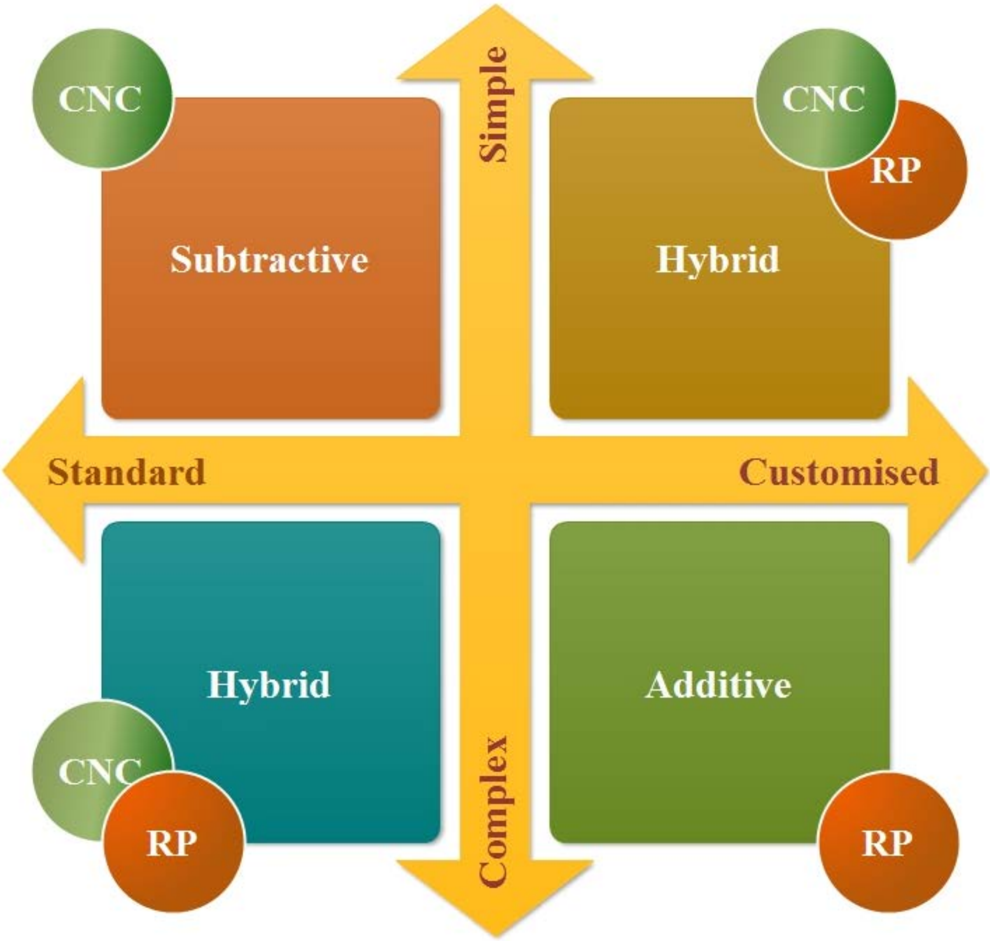

Figure 7.3 Product Process Matrix (PPM)

The PPM helps to identify generally the appropriate processes needed to address the product nature, related to the simplicity, complexity, standardisation, and customisation of the product. This would help the user to initially see where RP might be beneficial to their business. Following application of the PPM to what the company produces, the next step could be to investigate RP to enhance the associated knowledge, to review again after three months, or to go to the next step if a potential to deploy RP is identified. The Company's Strategic Self-Assessment (Figure 7.4) is the gate to the three key stages of the deployment process, where the user is encouraged to self-assess his business position in terms of market position, financial position, design to production status, and the company's position on RP technology.

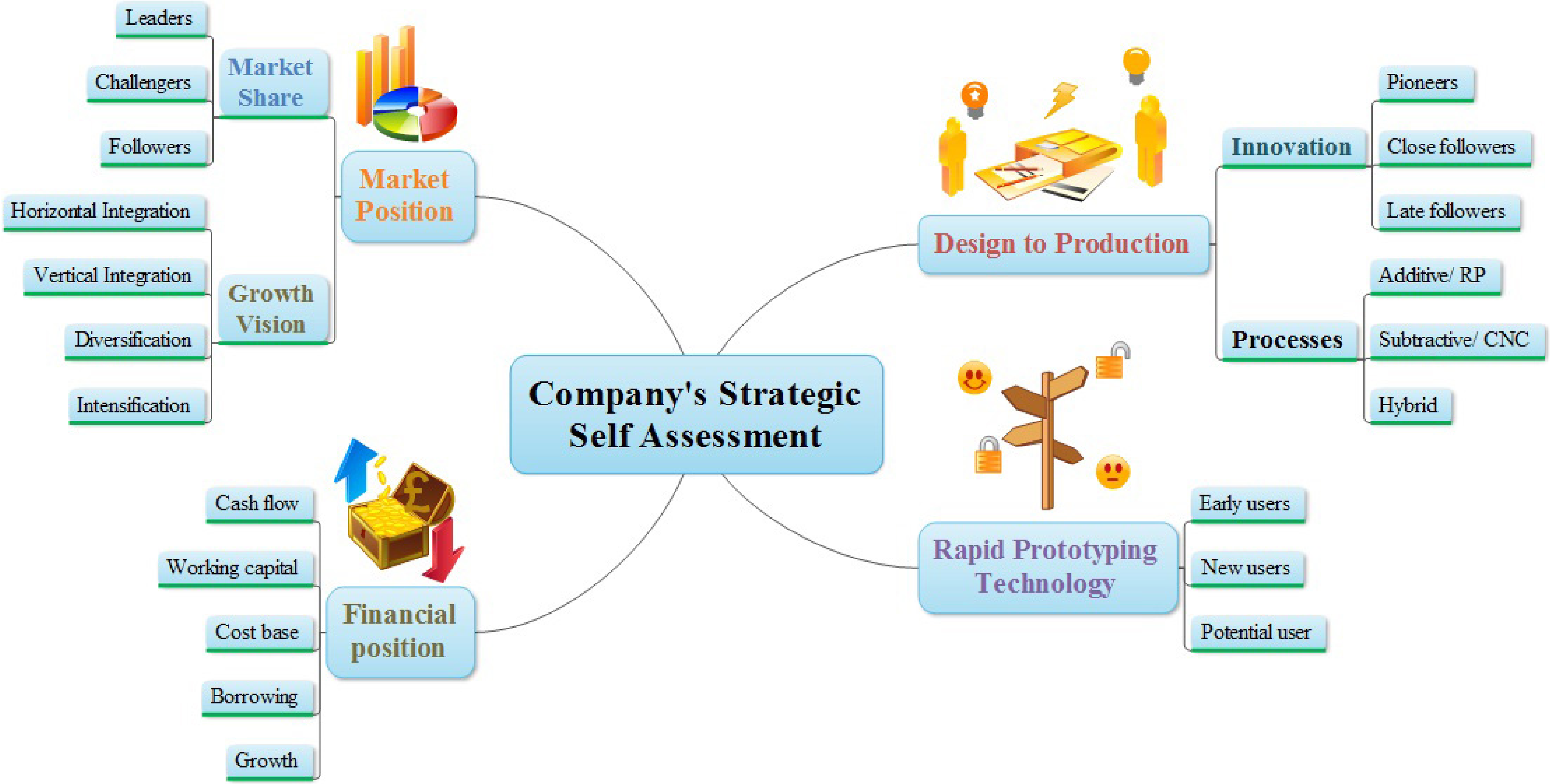

Figure 7.4 The Company's Strategic Self-Assessment

This would provide vital and significant information to help the user decide, on the basis of strategically substantiated information, whether to go on or re-assess the company in three-months' time to avoid dragging the business into unforeseen difficulties. This strategic assessment was designed to address the acknowledged deployment issues, which emerged from the analysis of the data collected. If the Company's Strategic Self-Assessment suggests that they go ahead with the RP technology deployment process, the user is then directed to the Pre-Decision Making stage where internal and external influential deployment factors are investigated and assessed.

7.4 Pre-Decision Making Stage

This stage involves addressing the external factors that stimulate the deployment process, such as backing up the level of RP awareness through engaging with the available RP technology platforms (universities, service providers and regional development agencies); the apparent call for development through the customer's feedback; and ways in which innovations can be used as a tool for global competitiveness. The Pre-decision making stage also involves addressing the internal factors that impact the deployment process, such as: the need for RP technology requirement analysis which is achieved by identifying the product requirements (production volumes, manufacturing processes, and product nature); and the foreseen tangible benefits of deploying RP technology on the product characteristics. These product characteristic benefits can be grouped into relative advantages: compatibility; and trainability of the RP technology. Figure 7.5 shows the Pre-decision making stage model. This stage also involves a risk assessment task, where particularly important internal factors should be evaluated in order to strategically inform the decision whether or not to deploy RP technology.

This includes any culture resistance within the business, project timing, resource constraints, service provider locality, complexity of the operations and the required training. The results and information obtained through the Pre-decision making stage, together with the grades from the company's strategic self-assessment, would adequately inform the SME executive manager in a strategic approach to decide whether to continue with the deployment process, or to review and re-assess the business again in three-month' time. In the case of making the decision to go ahead and deploy RP technology, the assessment will have identified an adequate strategic position, substantiated the needs for RP technology, and maximised the anticipated tangible benefits. Then the strategy directs the user to start the decision making stage and leads them through the RP deployment process.

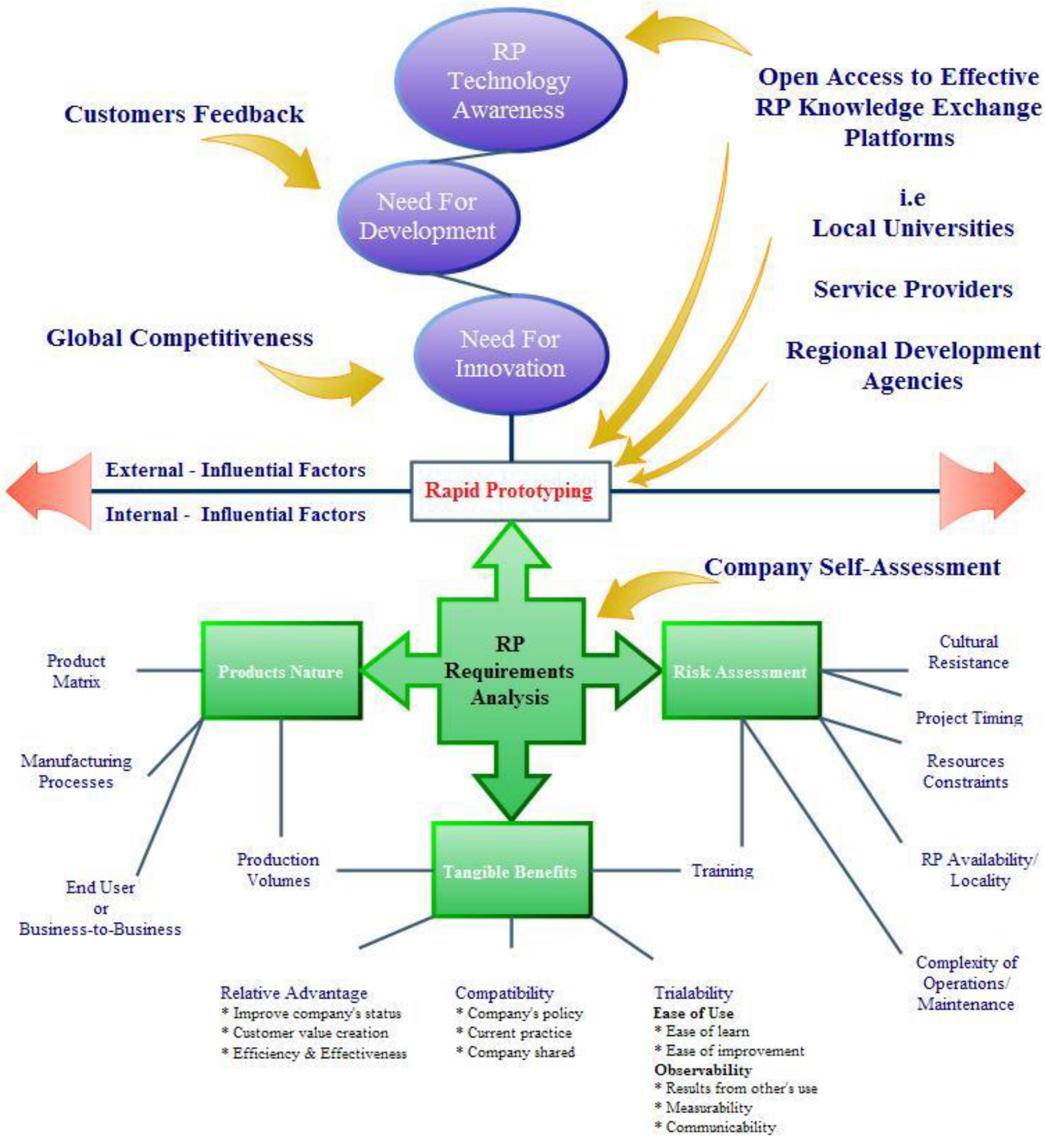

Figure 7.5 Pre-Decision Making Stage

7.5 Decision Making Stage

This stage is designed to act as the last confirmation phase, as it involves a strategic and operational Strength, Weakness, Opportunities, Threats (SWOT) Matrix (Figure 7.6), and the selection of the RP technique. Helms and Nixon (2010, p 218) stated that "SWOT analysis is primarily used to aid an organization plan future strategies". This will allow the executive managers to identify the apparent expected priorities, as well as identifying any possible high risk of deploying the RP technology within the business.

If this final confirmation phase resulted in potential strength and visible opportunities, at that point the final decision to deploy RP technology is made. The decision which then follows is which RP technique and deployment method (on-site or/and outsourcing) should be used. These two final decisions are not modelled within the strategy for two reasons. First, the strategy is mainly concerned with guiding the RP technology deployment decision, and secondly, service seller and providers have more up-to-date, enhanced models to help them select the appropriate RP technique and deployment methods with offers based on the latest market place. Therefore it was decided not to include an RP techniques selection and/or deployment methods model. Once the RP technique is selected and the deployment method chosen, that is when the actual and practical RP deployment is in place. This will allow for genuine information to feedback, which is guided by the strategy to inform the Post-Decision Making Stage.

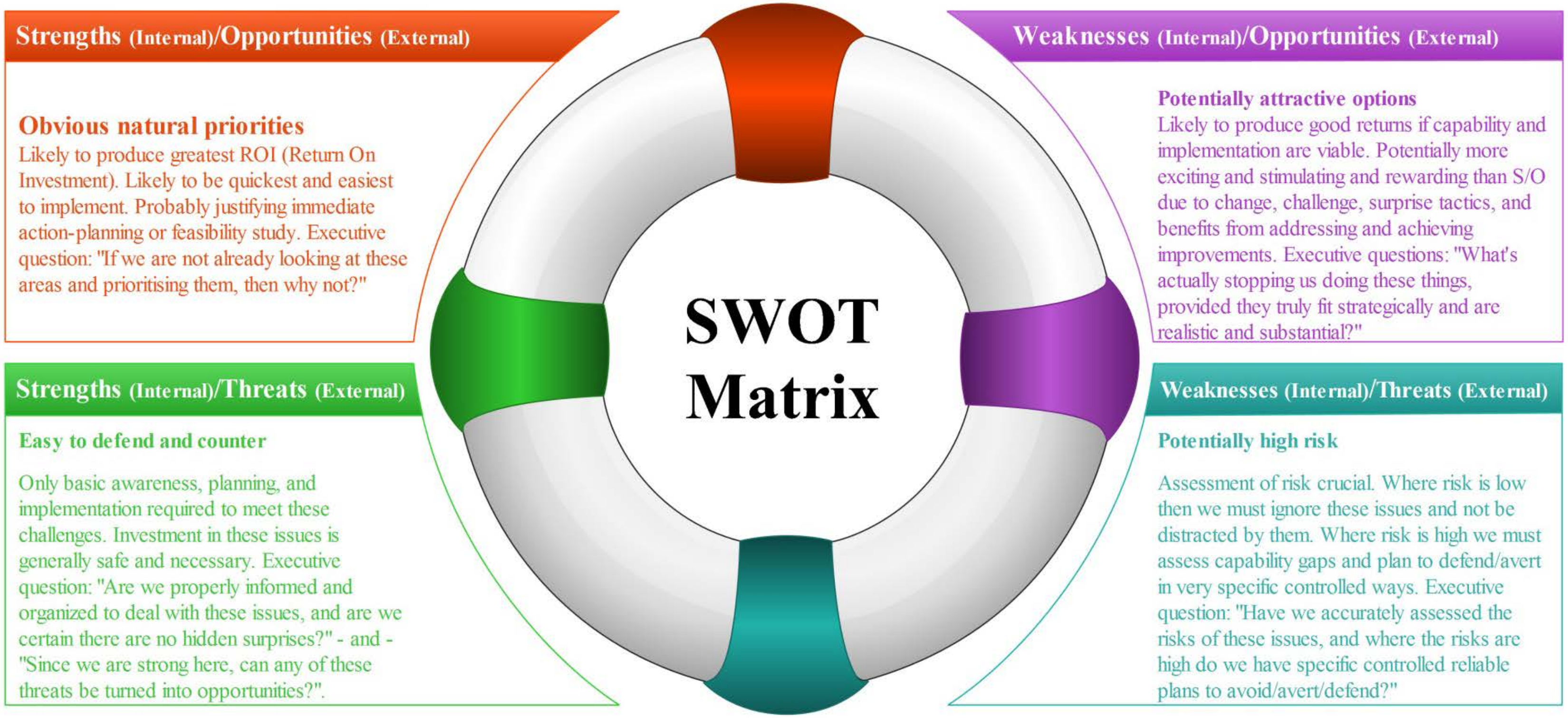

Figure 7.6 Strength, Weakness, Opportunities, Threats (SWOT) Matrix

7.6 Post-Decision Making Stage

This stage is predominantly concerned with two major tasks, RP technology maintenance (in case of on-site deployment method) and upgrading the deployed RP technique as RP technology improvements are very fast. Additionally, the information obtained from this stage would inform the annual review of the RP technology deployment.

7.7 Applying the RPDS

The first step in applying the strategy involves the company in answering the key question of whether or not it is ready to deploy RP technology. The response to this question will lead to one of the following three answers:

A. What is RP technology? This is the case when the company has no knowledge of RP technology.
B. Not sure! This is the case when the company has a general knowledge about RP technology.
C. Yes, ready! This is the case when the company has an adequate knowledge about RP technology.
D. Not ready!

The 'A' route will prompt the company to do some investigation about RP technology. This would result in an initial decision to follow the 'B' route, the 'C' route or the 'D' route. If the company decided to follow the 'B' route, then the next step would be to use the Product Process Matrix. This matrix is designed to help the company identify the initial need for RP technology based on levels of product shape complexity; in tandem with how standard or customised is the product. The outcome from this matrix will lead to the company either following the 'D' route or the 'C' route or proceeding to the next step. Companies following the 'D' route should review and repeat the process again after three months.

Companies following the 'C' route should start the 'company strategic self-assessment' process to evaluate the company's financial and market positions, as well as assessing its technologically up-to-date position. This assessment will inform the decision maker about the available resources that can be used for new investment and identify the need for the RP technology. Based on the assessment conclusion, the decision maker will be ready to either start the Pre-decision making stage, or to review again after three months if the company's position is not sufficiently solid to invest in new technologies.

At the Pre-decision making stage, the company has to raise it awareness of RP technology throughout the available knowledge exchange platforms. This will inform the decision maker about the up-to-date techniques, materials, service providers and any accessible funding that may be beneficial to the company. Also, the company will have to review its customer feedback, as this will help it to recognise the need for development, as well as looking at recent global competitors' products to identify the need for innovation and rank its risks. These are the external factors that would influence the decision with regard to investing in RP technology. The next step in this stage is to consider the internal influential factors: that is, RP requirement analysis to sketch the tangible benefits of such investment, and to consider the associated internal risk levels and review the manufacturing processes within the company to locate where RP technology is a seamless fit. The Pre-decision making stage results in a decision that either RP technology is not recommended at the moment and therefore will be reviewed again in three months' time, or that it is recommended and the company will proceed to the decision making stage.

At the decision making stage, the company will run the SWOT analysis which is a beneficial method for learning the Strengths and Weaknesses of such investment, and for classifying mutually the Opportunities to the company and the Threats the company may face. The results from the SWOT analysis may/may not recommend proceeding with deployment of RP technology, and in the case where it is not recommended the company has to repeat the Pre-decision making again in three months' time along with the company strategic self-assessment. In cases where RP is recommended, the company can start to consider the deployment method. This could be outsourcing if the Pre-decision stage along with the company strategic self-assessment, and/or the type of need for the RP technology does not recommend buying the machines. Otherwise, if the company needs it, and resources allow, then having the machine on-site is the second option if it is justified through the process.

Once the deployment method is confirmed, the selection of the RP processes can be done through the wide range of available online process selection techniques, or though the service providers. At this point the deployment decision has been made, and the post-decision making phase begins. This stage is mainly about the maintenance and evaluation of the deployed RP technique to ensure that it is running perfectly and fit for purpose. The information collected in this stage is of great importance, as it informs the decision maker in the annual review of the performance of the RP deployment, and prompts them either to improve it or possibly to lower any potential risks.

7.8 Strategy Evaluation

To evaluate a strategy, a definition is needed to identify the determined function and to clarify any overlap. For the purpose of this study, the definition by Rumelt (1998) was adopted. It states that "a strategy is a set of objectives, policies, and plans that, taken together, define the scope of the enterprise and its approach to survival and success. Alternatively, we could say that the particular policies, plans, and objectives of a business express its strategy for coping with a complex competitive environment". Just as theory is not known to be absolutely true, and only by practical validation can it be substantiated, strategy cannot be validated unless implemented and tested (Mintzberg 2003). On the other hand, before administrating a strategy it can be tested for critical flows. Rumelt (1998) provided four key testing factors that could arguably be useful when testing a strategy.

These factors are consistency, consonance, advantage, and feasibility. Consistency means that a strategy is essentially required not to show commonly inconsistent objectives and procedures. Consonance means that a strategy is essentially required to provide an adaptive response to the external influencing factors and to the changes taking place along with it. Advantage means that a strategy is essentially required to make available procedures for the constructing and sustaining of an economical advantage particularly for the designated development. Feasibility means that a strategy is essentially required not to overload accessible resources or generate avoidable supply difficulties. Mintzberg (2003) indicated that "A strategy that fails to meet one or more of these criteria is strongly suspect. It fails to perform at least one of the key functions that are necessary for the survival of the business". Therefore, an evaluation document for the developed strategy was designed based upon these criteria.

The document consisted of: an executive summary in which the aim and objectives of the study were explained; the developed strategy; guidelines for administrating the strategy; a definition of the term 'strategy' with explanation of the evaluation criteria; and twelve assessment questions. The evaluation document was pilot-tested on the MSc Engineering Project Management postgraduates at Bournemouth University, who were working in different organisations, mostly Engineering/industrial/manufacturing SMEs. The pilot test provided promising results in terms of the critical flows of the strategy, as all of them agreed on the strong possibility that the developed strategy would work in the anticipated way. Then the evaluation document was sent to the participants of Phase Two, for review, evaluation and comment.

7.9 The Evaluation Process Outcomes

The participants, who agreed to be involved in the last phase of this study, received the proposed strategy evaluation form along with an information sheet (see Appendix D). A follow up call was conducted to express the research team's appreciation for their valuable contribution to this study, and to check that they had received the evaluation forms. Nine out of ten participants responded with a response rate of 90%.

The executive managers of the SMEs in the South West of England ranked the strategy (Table 7.1) as follows:

- ✓ 70% agreed that the proposed strategy is internally consistent;
- ✓ 80% agreed that the proposed strategy is externally consonant with its environment;
- ✓ 80% agreed that the proposed strategy is appropriate in view of available resources;
- ✓ 70% agreed that the proposed strategy involves an acceptable degree of risk;
- ✓ 80% agreed that the proposed strategy has an appropriate time horizon;
- ✓ 80% agreed that the proposed strategy is workable;
- ✓ 80% agreed that the proposed strategy is identifiable;
- ✓ 80% agreed that the proposed strategy constitutes a clear stimulus to organisational effort and commitment;
- ✓ 70% agreed that the proposed strategy gives early indications of the responsiveness of markets;
- ✓ 50% disagreed that the proposed strategy relies on weakness;
- ✓ 80% agreed that the proposed strategy exploits major opportunities; and
- ✓ 80% agreed that the proposed strategy avoids, reduces, or mitigates the major threats.

The SMEs' executive managers have welcomed the important RP strategic technological deployment potentially offered by the proposed strategy, and recognised the positive impact the strategy could have on their business. Also they have stated that the strategy is workable, consistent, and appropriate in view of available resources and involves an acceptable degree of risk. This has been encouraging from the knowledge exchange point of view because it can be expected to increase engagements which will implement the strategy in practice.

Table 7.1 The proposed strategy evaluation results

Evaluation Criteria	Strongly Disagree Strongly Agree				
	1	2	3	4	5
The strategy is internally consistent			XX	XXXX XX	X
The strategy is externally consonant with its environment			X	XXXX XXX	X
The strategy is appropriate in view of available resources			X	XXXX XX	XX
The strategy involves an acceptable degree of risk			XX	XXXX X	XX
The strategy has an appropriate time horizon		X		XXXX	XXXX
The strategy is workable			X	XXXX	XXXX
The strategy is identifiable			X	XXXX XX	XX
The strategy constitutes a clear stimulus to organisational effort and commitment			X	XXXX X	XXX
There are early indications of the responsiveness of markets and market segments to the strategy			XX	XXXX XX	X
The strategy relies on weaknesses or does anything to reduce them		XX XXX	XXXX		
The strategy exploits major opportunities			X	XXXX XXX	X
It avoids, reduces, or mitigates the major threats			X	XXXX XXXX	

One of the executive managers enclosed the following comment with his company's response:

> *"We found the information of great value even though it eventually led us to the conclusion the RPT was not for us"*

This shows that the proposed strategy is an objective approach, with the SMEs making the appropriate decision, whether or not that decision results in the deployment of RP technology within their companies.

7.10 Contributions of the Research

7.10.1 Contribution to Theory

The comprehensive literature review highlighted the current studies and schemes relating to the process of deploying RP technology within SMEs and to the broader area of advanced new technologies within SMEs. This was presented in Chapters 2 and 3, which set out the three main existing approaches to tackling general concerns over the adoption of new advanced technologies within SMEs. At the same time as these approaches, new technologies could be deployed within SMEs by implementing a:

1) KTP-based model approach (Ahmad et al. 2009; Azadivar et al. 2000; Bititci and Ates 2009; Cox 2005; Peças and Henriques 2006; Wormald and Evans 2009); or
2) Computer-based model for RP process selection approach (Armillotta 2008; Borille et al. 2010; Byun and Lee 2005; Kerbrat et al. 2010; Munguia 2008; Rao and Padmanabhan 2007); or
3) Internet-based model approach (Lan 2009; Tay et al. 2001)

The three existing model approaches are unsuitable for providing a customised strategic approach to the deployment of RP technology within SMEs (Gibson et al. 2009). This research has contributed to theory by providing not only a more in-depth identification and prioritisation of the effective barriers to deployment of RP technology, but has also developed a customised strategy for informing the practice of such deployment. Additionally, the developed strategy will contribute to the theory/practise of change management within organisations, since the study addresses this essential concern by distinguishing precise behavioural solutions for the individuals in tandem with their organisations.

The addition to change management was needed due to the fact that much of the literature concerned with this subject does not identify any specific and customised knowledge with relation to the deployment of RP technology in

SMEs, and there is a tangle of issues related to the individual. This strategy will help companies, on the level of the individual, to overcome the current resistance to change barrier, by guiding them deliberately throughout the whole process of considering RP technology for deployment within their business.

This should introduce a constructive attitude, which creates a cultural technological change towards not only RP technology but generally with any new potential advanced industrial/manufacturing technology. This change will greatly impact on the individual's performance, knowledge, flexibility, skills and practices within their SMEs, resulting in a new situation of change management within organisations. Moreover, there is a significant impact on research and development, which is reinvigorated by the developed strategy in terms of encouraging innovation within the SMEs. This would also create a culture of new product development within SMEs, resulting in another form of change management in organisations.

It was the process of identification and prioritisation of the barriers to RP deployment within SMEs which led to the development of these impacting factors. Together these factors relate strongly to the upkeep tactics permissible for the duration of the change, providing the chance for individuals to allow change and change management to take place within their businesses. The auxiliary contribution to theory made by this study is the consolidation of RP technology not as a technological adoption process, but as a strategic approach to the maintenance of sustainable SME growth in the light of existing global challenges.

7.10.2 Contribution to Practice

This research contributes to the practice of the deployment of new technologies within SMEs, and in particular the influence for RP technology deployment. This mostly relates to current technological adoption approaches employed within SMEs. Equally, it correspondingly relates to the change management practice currently undertaken within SMEs. This study emphasises the expected effect of administrating the developed strategy on the practice performance within SMEs as a result of a change management yet to happen. The anticipated change will positively impact on the technology deployment methods, and by extension, a change in management will occur as expected. Such opportunity should open new prospects for the industrial/manufacturing SME sector, in terms of economic growth and competitiveness. This research also strengthens and puts forward the view that SMEs can be technologically enabled by those individuals who are in support of change. With the advent of this change, it is hoped that other SMEs will emulate the practices of their peers to achieve similar outcomes.

7.11 Limitations of the Research

Research limitations are inevitable in any study; therefore, it is essential to highlight these limitations when presenting the research outcomes. Also undertaking the research within a course of doctoral scholarship adds further limitations. Appraising the reader of the limitations increases their level of awareness of the boundaries that controlled the study.

Although change management is discussed, this study did not aim to develop that concept, rather, it emphasises that change management will occur spontaneously as a direct result of administering the developed strategy. The processes of transcribing, coding the data, categorising the data and identifying the themes were undertaken by one person – the researcher – as well as the analysis of data collected which was discussed with the supervisory team at the end of each stage. Whilst admitting that this has maximised consistency for the above-explained processes, it has also limited the multiplicity of outlooks to be obtained from a diversity of experts. For that reason, it is recommended that, when employing the same methods for other studies, the processes of coding the data, categorising the data and identifying the themes should possibly involve the participation of a number of diverse and appropriate specialists. This will allow for brainstorming discussions with each other including the researcher and/or the research team, which could provide a different insight for the topic being studied. This study focused on developing a strategy to deploy RP technology within SMEs, and this strategy deliberately aimed to guide the SMEs to make the appropriate decision based on a strategic assessment of the present needs and the available resources in this circumstance. This being the case, it is important to emphasise that no opinion is being expressed with regard to the adoption or otherwise of RP technology. Nevertheless, an appropriate strategic decision, either way, can be supported by employing the developed strategy.

Although a good response rate was achieved in this study when conducting the quantitative Phase One, a representativeness limitation was recognised with regard to the implementation of convenience sampling in the qualitative Phase Two. Consequently, this study does not claim generalisability for the outcomes obtained. However, generalisability could possibly be proven if the developed strategy was practically tested through a KTP or a complete SME self-administration and positively and practically validated. This, regrettably, could not be accomplished within this study due the doctoral nature of the research, which enforced inevitable time and budget limitations, but the study highly recommends executing the developed strategy practically in one of the SMEs of the South West of England. For this reason, the researcher is preparing a proposal for a KTP to be set up between Bournemouth University and one of the SMEs. Another limitation was presented while conducting the qualitative Phase Two, due to the fact that the researcher was experienced in the studied technology and SME sector, which could have introduced biases that may have affected the study findings. However, although a potential bias may have influenced the findings, it also meant that, due to the researcher's knowledge, credibility was guaranteed in this case between the researcher and the participants allowing for more in depth data to emerge.

7.12 Future Research Directions

The data collected by the survey questionnaire presented in Chapter 5 has provided the required information to answer the research question. However, the data could be further analysed to provide additional insights into the field of RP technology implementation. Since Rapid Prototyping Technologies were first introduced, simultaneous forms of infinite product/industrial/manufacturing development processes have also originated. These boundless development profiles are changing the way of doing everything, yes everything! New concepts of designing and manufacturing products have already emerged, and yet more innovative ways will materialise in the near future. This will not have an impact upon the industrial/manufacturing sector, but will impact upon the way we desire and require things. Therefore, this study is to be considered the first in a series exploring the potential drivers which could sustain the industrial/manufacturing SME sector, throughout the current and challenging unstoppable technological acceleration.

Particularly, those new development concepts that associates with RP technology, and links directly to the barriers hindering the RP technology deployment within SMEs. As it is not necessarily that after deploying RP technology within an SME, that resistance to change for instance will be taken for granted as a historical barrier with the associated new concepts. Resistance to change will always be there; it is an element of human nature, but an element whose effect needs to be minimised efficiently, case by case. This will need to be customised strategically for every new RP technology related concept, and in separate studies, which identify the drivers that eliminate the resistance to change factor. The following is a set of proposed directions for study.

- Additive Manufacturing within SMEs: An expandable Deployment of RP Technology
- Customisation: As an SME’s Tool to Curtail Global Competition
- Personal Manufacturing and the Future of Mass Production
- SMEs’ Technological Transformation towards High Value Manufacturing
- Do-It-Yourself concepts from Creative-Recreational to Creative-Manufacturing
- Change Management in Organisations: from Guiding SMEs to Learning from SMEs
- Knowledge Transfer Partnerships and their Impact on Change Management in SMEs
- Additive Manufacturing Medical Applications: A New Mating between Technology and Medicine

7.13 Chapter Summary

The technological advances are snowballing rapidly to the extent that catching up with them in terms of knowledge and strategic considerations is becoming unpredictable. RP technology is in the lead position of these advances, providing new opportunities and introducing new concepts on a daily basis. Simultaneously, SMEs are facing internal and external challenges which are hindering their technological adoption and in particular their adoption of RP technology. An the intensive literature review showed, there is no strategic customised approach to the deployment of RP technology within SMEs. Hence, the concern and focus of this study was to identify the barriers, and develop a strategy for that purpose. This chapter presented the developed strategy for deploying RP technology within SMEs in the South West of England, and discussed both how the developed strategy corresponds to those findings, and the strategy evaluation. The chapter also presented the research limitations and directions for future study.

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Appendix A

Resulting Publications from this Research

VOLUME 12 2012

The International Journal of

Knowledge, Culture, and Change Management: Annual Review

The Barriers that Hinder Rapid Prototyping Deployment within Small and Medium-Sized Enterprises

Which Should Come First?

AHMED R. ROMOUZY ALI, SIAMAK NOROOZI, PHILIP SEWELL, AND TANIA HUMPHRIES-SMITH

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THE INTERNATIONAL JOURNAL OF KNOWLEDGE, CULTURE, AND CHANGE IN ORGANIZATIONS: ANNUAL REVIEW
www.ontheorganization.com

First published in 2013 in Champaign, Illinois, USA
by Common Ground Publishing LLC
www.commongroundpublishing.com

ISSN: 1447-9524

The International Journal of Knowledge, Culture, and Change in Organizations: Annual Review is peer-reviewed, supported by rigorous processes of criterion-referenced article ranking and qualitative commentary, ensuring that only intellectual work of the greatest substance and highest significance is published.

The Barriers that Hinder Rapid Prototyping Deployment within Small and Medium-Sized Enterprises: Which Should Come First?

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Abstract: A radical revolution in manufacturing has started to take place owing to rapid prototyping (RP), which based on completely new additive techniques, produce fully functional parts directly from a three-dimensional computer aided design model without the use of tooling. This offers the potential to change the concept of prototyping, manufacturing, service and distribution, with opportunities for producing highly complex and customised products. Small and medium-sized enterprises (SMEs) are the backbone of the global economy, extensively producing while making a significant and crucial contribution to the global economy. The latest status has boosted the importance of the SMEs in both developed and developing countries due to the increased reliance on international partners. However are these SMEs ready to take on this global challenge? This paper investigates the main barriers of deployment of RP in SMEs. These barriers are prioritised in an attempt to promote a new change management approach to improve the integration of RP technology into SMEs.

Keywords: Rapid Prototyping, Small and Medium Sized Enterprises, Change Management

INTRODUCTION

Small and Medium-sized Enterprises (SMEs) are one of the pillars of industrial development, and the industrialised ones play a particularly important role in the development of different products. Globalisation trends, technological advancements and continuously increasing tough competition in the market place have been changing the rules of business forever (Bititci and Ates 2009). Given the economic importance of industrial SMEs role in the process of product development, these institutions enjoy comparative advantages in production and services that necessitate their presence next to large enterprises. SMEs are boosting their vital role in the market actions of the world with their high rates of employment and intrinsic features, such as flexible production structure, innovation capabilities and devotion to service and networking, each of which are valuable assets in today's economic environment(Selek 2009). In the manufacturing sector, SMEs act as specialist suppliers of components, parts and sub-assemblies to larger companies because the items can be produced at a cheaper price than the large companies could achieve in-house. Lack of product quality supplied by them could adversely affect the competitive ability of the larger organisations (Singh et al. 2008). The definition of SMEs varies from country to country. All over the world, numbers of employees or capital investment or both have been used as basis for defining SMEs (Dangayach and Deshmukh 2005). According to (Verheugen 2005) an enterprise is 'any entity engaged in an economic activity, irrespective of its legal form'. The EU defines such companies as those

Change Management: An International Journal
Volume 12, 2013, http://ontheorganization.com/, ISSN 1447-9524

with fewer than 250 employees (and less than 25 per cent owned by another company), which is thus the standard for UK government's classification (Cox 2005), and which have either an annual turnover not exceeding 50 million euro, or an annual balance sheet total not exceeding 43 million euro (Verheugen 2005).

Between 2002 and 2007, the number of SMEs has increased by over 2 million; the number of large enterprises by only 2000 (Lopriore 2009). SME is known in all manufacturing industries and among academics as the first and best source of career-enhancing manufacturing products and services (Fossum 2010). SMEs cover a wide spectrum of industries and play an important role in both developed and developing economies (Dangayach and Deshmukh 2005). The European Union is home to more than 26 million companies. The number of manufacturing businesses is about 10% of this total, i.e. around 2.5 million, of which 99% are SMEs (Bititci and Ates 2009). SMEs are the backbone of Britain. Napoleon is said to have once remarked that the British are 'a nation of shopkeepers'. He was right in as much as Britain is a nation of small and medium sized enterprises (Rowe 2008). The image of manufacturing is so positive throughout the country that parents encourage their children to enter careers in manufacturing; SME played a key role in clarifying the image (Fossum 2010).

Rapid Prototyping (RP) is a collection of technologies that are driven by computer aided design data to produce physical models and parts through an additive process (Borille et al. 2010). The growth of the RP field has been tremendous over the last one decade. However, RP technology is still not commonly used in many organisations due to various reasons which include difficulty in management, implementation and high cost of machines, processes and materials (Vinodh et al. 2009). As a new technology that uses an additive process, RP has been developed to reduce product development time and cost (Byun and Lee 2005), as well as enhancing quality and flexibility which integrate into custom-fit products. The scope of custom-fit is to create a fully integrated system for the production and supply of high added value products that are personalised and customised both to fit geometrically and functionally the requirements of the user, and are delivered in hours rather than weeks (Direction 2005) "*We're on the verge of a revolution in how things are made*" Says Greg Morris, Morris Technologies (Ogando 2007).

Thus far, research on technological deployment within SMEs has generally spotted the inaccessible barriers that hinder this deployment. This paper deepens the research by prioritising the identified barriers to unlock the adoption of RP technologies in the most appropriate way.

RP Technology Deployment Barriers within SMEs

Management difficulties in SMEs are mainly because many of their industrialists lack high a level of education and professional training and they perform poorly in many areas of production and quality control (Ahmad et al. 2009). An important concern is the management anticipation, if an early guarantee has not been met by reality and therefore the awareness of the potential of RP today can often be clouded by individual understandings of rapid prototyping ten or so years ago (Bourell et al. 2009). The cost of machines, materials, and maintenance is seen as an obstacle to wider adoption of RP technology. The perceived risk and expected returns vary widely from company to company. Cost is only one factor that influences the adoption of an entirely new process or the launching of a new business based on a new process. Time to market is another important one. Some companies are willing to pay a premium if the time savings are significant.

A very broad literature search was conducted as the means of collecting initial data. Based on the data collected through this process, a number of conclusions emerged that characterised key common barriers in RP technology deployment for SMEs. Analysis of the data obtained provided a comprehensive perception of the barriers that hinder the deployment of RP technology within SMEs. It was found that barriers which affect the RP adoption are not necessarily technical. Bourell et al. (2009) stated that despite the fact that technical barriers exist, as in most technology areas, the majority of barriers tend to be non-technical and instead are more focused on human-centric issues. Concise listings of the barriers are as follows (Abd Rahman et al. 2010; Ahmad et al. 2009; Borille et al. 2010; Bourell et al. 2009; Lopriore 2009; Thurasamy et al. 2009; Watts 2008):

- Lack of a proper practice.
- Cultural and performance issues.
- Lack of resources.
- Lack of professional qualifications.
- Prioritisation system.
- Decision making level.
- Resistance to change.
- Lack of education.
- RP process limitation.
- Lack of imagination.
- Vested interests that stifle innovation.

The purpose of the research discussed here is to study the common barriers of the RP technology deployment in SMEs. The main aim is to identify in particular and prioritise by significance which one of these barriers is the most effective inhibitor for the RP technology adoption which should be tackled first to reveal the potential change management driver for RP technology deployment within SMEs. A representative sample region was selected on the basis of regional development, where the South West of England (SW) was found to be the most appropriate region for this particular study. Harrison (2010) stated that the south west continues to derive more employment and turnover from SMEs than any other region. The industry data shows variations in dependence on SMEs by industry. In some industries, such as manufacturing, the SW shows a particular dependence on SMEs. Cooling (2011) describes businesses in SW as a lead on innovation, and the most optimistic about job creation in the coming year. In the 2009 SW data, 99.4% of enterprises were classified as small (UK 99.3%)–Figure 1. The majority of these had four or fewer employees (91.6% of SW enterprises, UK 91.2%). Only 0.4% of SW enterprises were classed as medium-sized (UK 0.6%). Only 480 enterprises in the SW were classed as large, making up less than 0.1% of total SW enterprises (UK 0.2%) (Harrison 2010). SMEs in the SW have seen the greatest increase in headcount over the last three years, SMEs in SW have the most confident outlook on growth out of all regions, followed by those in London and Wales (Cooling 2011). The SW has the fifth highest number of enterprises within the regions, but has the third highest number of enterprises per 10,000 adults (1,084), behind London (1,352) and the South East (1,097) (Harrison 2010).

Figure 1: Percentage Share of Small, Medium-sized and Large Enterprises This Figure is Adapted from (Harrison 2010)

Even though shares of SMEs are similar regionally and nationally, as Figure 1 shows the SW's economy is far more dependent on SMEs than the UK average in terms of both employment and turnover (Harrison 2010). This has made the region of SW of England of adequate nature, and its statistical findings with a very high significance. Therefore the probability of generalisation will be genuinely verified.

Methods

Survey Instrument and Sample

This study implemented a quantitative data approach using a self-reported postal structured questionnaire survey with a pre-addressed/pre-stamped return envelope. The intended justification for this approach was based on the prerequisite for many considerations in order to examine the research aim outlined earlier. Using this approach was based on the fact that the surveys strength lies in its ability to study large samples, to look at a large number of variables as well as the effectiveness of the cost involved and the geographical coverage (Axinn and Pearce 2006; Fowler 1998, 2008; Humphries-Smith 2010).

There were two key challenges facing this approach, the first was to find a unified standard definition of the geographical boarders of the SW region. There were few different governmental geographical definitions; consequently the study utilised the definition of SW regional development agency. The second key challenge was to find an information database for the design/industrial/manufacture SMEs in the SW. There were too many databases, none of which were appropriate as they didn't classify and differentiate between for example accountancy SMEs working with industry and a designing/engineering SME working for industry. Therefore, it was agreed to create a new specific database for the design/industrial/manufacture SMEs involved in engineering processes. The data was collected from different sources such as online databases, yellow pages, telephones directories and paid databases. A regional sample of 200 companies was created. While creating the database it was taken into account that it should be random, heterogeneous and representative to guarantee the external validity, so the results can generalised.

The survey consisted of four sections of questions. The first section concluded the company profile. The second section concluded the significance of priorities within the company. The third section concluded the particular investment level within the company. The fourth section of questions investigated the key barriers which the respondents believe to be the main difficulties. In addition to the four sections, the survey included a free text space for other comments to allow the respondents to freely express and address any other related issues. The survey was tested and piloted for significance, clearness and completeness. Due to the nature of SMEs, it was found that the executive managers are the required informants who can appropriately respond to the survey. Choosing the correct informants can rational any possible general means of conflict issues (Miller and Roth 1994; O'regan and Kling 2011; Phillips 1981).

The Respondents

The Rapid Prototyping Deployment Survey (RPDS) 2011 responses involved 21% product/industrial design based SMEs, 30% engineering based SMEs and 49% manufacturing based SMEs. Out of the 55 returned surveys, 50 valid surveys were initially utilised in this study with a 28% response rate which is above the typical response rate for this type of survey. Based on the literature findings, the typical response rate for strategic studies is 10–12% (Carey et al.; Kargar and Parnell 1996; Mckiernan and Morris 1994; O'regan and Kling 2011; Pearce et al. 1987; Raymond and Croteau 2006). Those excluded were considerably incomplete questionnaires. This provided comprehensive ranking for the barriers which hampers the deployment process of RP technologies within SMEs in the SW of England region.

Study Observations

The survey statistical aggregated findings figures show the following:

- 82% designated in-house design practises as significant to their companies while only 60% of them invested in in-house design practises. The company size influenced the in-house design practises, as significance to investment ratio was 5:1 within micro sized (1 to 9 employees), 1:1 within small sized (10 to 49 employees) 5:4 within medium-sized (50–249 employees) enterprises.
- 82% designated in-house research & development as significant to their companies while only 48% of them invested in in-house research & development. The company size influenced the in-house research & development, as significance to investment ratio was 5:1 within micro sized, 1:1 within small sized and 5:3 within medium-sized enterprises.
- 30% designated RP technology processes as significant to their companies when only 24% of them invested in RP technology processes. The company size influenced RP technology processes, as significance to investment ratio was 1:1 within micro sized, small sized and medium-sized enterprises.
- 82% designated computer aided design (CAD) as significant to their companies when only 56% of them invested in CAD. The company size influenced the CAD, as significance to investment ratio was 4:1 within micro sized firms, 5:3 within small sized firms and 4:5 within medium-sized enterprises.
- 60% designated CNC machining as significant to their companies when only 38% of them invested in CNC machining. The company size influenced CNC machining, as significance to investment ratio was 5:1 within micro sized, medium-sized, and identical 1:1 within small sized enterprises.

Also (84% designated innovation processes, 98% designated cost, 94% quality, 96% Time and 84% market share) as significant to their firms. Furthermore the micro sized firms demonstrated very high significance to cost, quality and time than to innovation processes and market share with ratio of 5:3, where small sized firms demonstrated very high significance to quality, fairly high significance to cost and time, significance to innovation processes and very low significance to market share. And finally the medium-sized firms demonstrated very high equal significance to all.

To get an overview on the barriers, Table 1 reports descriptive statistics (25-percentile, 50-percentile/Median and 75-percentile) of the investigated RP technology development barriers on a Likert scale of 1 to 5 to measure the extent to which the executive mangers agrees or disagrees with the existence of each barrier within their companies, where 1=strongly disagree, 2=disagree, 3=neither disagree nor agree, 4=agree, and 5=strongly agree. The results shows lack of resources, lack of professional qualifications, resistance to change and rapid prototyping limitations are the main barriers. As with their 50-percentile/Median and 75-percentile, the executive mangers verified that they either agree or strongly agree with the fact that these barriers are the inhibitor of the RP deployment within their SMEs.

Table 1: Descriptive Statistics

	N	Percentiles		
		25th	50th (Median)	75th
Lack Of a Proper Practice	50	2.00	3.00	3.25
Culture And Performance Issues	50	1.00	3.00	3.00
Lack Of Resources	**50**	**3.00**	**4.00**	**5.00**
Lack Of Professional Qualifications	**50**	**3.00**	**4.00**	**5.00**
Prioritization System	50	2.00	3.00	4.00
Decision Making Level	50	2.00	3.00	3.25
Resistance To Change	**50**	**3.00**	**4.00**	**5.00**
Lack Of Education	50	2.00	3.00	4.00
Rapid Prototyping Limitation	**50**	**2.00**	**4.00**	**5.00**
Lack Of Imagination	50	1.00	2.00	3.00
Vested Interests That Stifle Innovation	50	1.00	2.00	3.25

Table 2 summarises data for the overall statistical findings of the study with rows representing barriers individual actual existence, and columns representing SMEs business nature and company size, In addition to a set of related product/industrial development records.

As each row represents one of the barriers against each business column, it is clear to see if the barrier does exist in that business nature and in what company size within that nature as micro, small or medium. Wherever the barrier is confirmed within a SME, there is a dot to indicate its presence in what company size and a tick to indicate its presence in the business nature. Additionally for each barrier, the table rows also show the degree of significance and level of investment for in house design practises; in house research and development; rapid prototyping technology; computer aided design; computer numerical control machining within each type of the SMEs when this barrier is confirmed. As an overall indicator of how the companies perform while this barrier is effectively active. It has been found from the analysis that:

- Resistance to change is effectively confirmed within micro sized product/industrial design based SMEs, micro and medium sized engineering based SMEs and micro sized manufacturing based SMEs.
- Lack of professional qualifications is effectively confirmed within micro sized product/industrial design based SMEs, micro sized engineering based SMEs and micro sized manufacturing based SMEs.
- Lack of resources is effectively confirmed within micro and medium sized engineering based SMEs and micro sized manufacturing based SMEs.
- Rapid prototyping limitations are effectively confirmed within micro and medium sized engineering based SMEs and medium sized manufacturing based SMEs.

This substantiates and prioritises the barriers of resistance to change; lack of professional qualifications; lack of resources; rapid prototyping limitations within SMEs as the most effective barriers.

Also Table 3 shows the strength of association between barriers measured by a correlation test, using Spearman's rho correlation Coefficient (Schmid and Schmidt 2007), where the correlation coefficients range between -1.00 to +1.00. An ideal negative correlation value is represented by -1.00 while an ideal positive correlation value is represented by +1.00. A lack of correlation value is represented by 0.00. For example there is a high degree of positive correlation between the lack of resources and the lack of professional qualifications; a medium degree of positive correlation between resistance to change and the decision making level; a low degree of positive correlation between the rapid prototyping limitations and the lack of a proper practice; and finally probably no correlation between the vested interests that stifle innovation and the prioritisation system.

Table 2: Summary of the Effective Presence of Each Barrier According to Size/Business Nature of Each SMEs

	Product/Industrial Design based SMEs				Engineering based SMEs				Manufacturing based SMEs			
	1 to 9 Micro	10 to 49 Small		50 to 249 Medium	1 to 9 Micro	10 to 49 Small		50 to 249 Medium	1 to 9 Micro	10 to 49 Small		50 to 249 Medium
	NS/NI	S/NI	NS/I	S/I	NS/NI	S/NI	NS/I	S/I	NS/NI	S/NI	NS/I	S/I
Lack Of a Proper Practice		✓										
	•											
	ABD	AB			ABD					E		C
Culture And Performance Issues												
		AB			ABD			E		DE		C
Lack Of Resources						✓				✓		
					•			•	•			
		AB			ABCDE	AE		E	C	ABDE		BCDE
Lack Of Professional Qualifications		✓				✓				✓		
	•				•				•			
	ABD	AB			ABCD	AE		E	C	ABDE		
Prioritization System		✓				✓						
	•				•							
	ABCD	AB			ABD	AE		E		ADE		
Decision Making Level		✓								✓		
	•								•			
	ABD	AB			ABD	A		E		DE		
Resistance To Change		✓				✓				✓		
	•				•			•	•			
	ABCD	AB			ABD		C	E		ABDE		C
Lack Of Education						✓						
					•							
		AB			ABD		C	E		BDE		
Rapid Prototyping Limitations						✓				✓		
					•			•				•
		AB			ABCD	AE	C	E	C	ABD		
Lack Of Imagination												
		AB			ABD					DE		
Vested Interests That Stifle Innovation						✓						
								•				
		AB			ABD		C	E		ABD		

A = Significance of In House Design Practises vs. Investment In House Design Practises
B = Significance of In House Research and Development vs. Investment In House Research and Development
C = Significance of Rapid Prototyping Technology Processes vs. Investment in Rapid Prototyping Technology Processes
D = Significance of Computer Aided Design CAD vs. Investment in Computer Aided Design CAD
E = Significance of CNC machining vs. Investment in CNC machining
NS = No Significance; NI = No Investment; S = Significance; I = Investment
✓ Means that the barrier is represented

			Lack Of a Proper Practice	Culture And Performance Issues	Lack Of Resources	Lack Of Professional Qualifications	Prioritization System	Decision Making Level	Resistance To Change	Lack Of Education	Rapid Prototyping Limitation	Lack Of Imagination	Vested Interests That Stifle Innovation
Spearman's rho	Lack Of a Proper Practice	Correlation Coefficient											
		Sig. (2-tailed)											
		N											
	Culture And Performance Issues	Correlation Coefficient	.460**										
		Sig. (2-tailed)	.001										
		N	50										
	Lack Of Resources	Correlation Coefficient	.405**	.422**									
		Sig. (2-tailed)	.003	.002									
		N	50	50									
	Lack Of Professional Qualifications	Correlation Coefficient	.631**	.428**	.727**								
		Sig. (2-tailed)	.000	.002	.000								
		N	50	50	50								
	Prioritization System	Correlation Coefficient	.407**	.413**	.325*	.548**							
		Sig. (2-tailed)	.003	.003	.021	.000							
		N	50	50	50	50							
	Decision Making Level	Correlation Coefficient	.459**	.460**	.532**	.599**	.552**						
		Sig. (2-tailed)	.001	.001	.000	.000	.000						
		N	50	50	50	50	50						
	Resistance To Change	Correlation Coefficient	.327*	.619**	.260	.287*	.240	.523**					
		Sig. (2-tailed)	.020	.000	.068	.044	.093	.000					
		N	50	50	50	50	50	50					
	Lack Of Education	Correlation Coefficient	.561**	.640**	.477**	.568**	.470**	.682**	.600**				
		Sig. (2-tailed)	.000	.000	.000	.000	.001	.000	.000				
		N	50	50	50	50	50	50	50				
	Rapid Prototyping Limitation	Correlation Coefficient	.371**	.188	.341*	.356*	.191	.174	.202	.448**			
		Sig. (2-tailed)	.008	.190	.015	.011	.185	.226	.159	.001			
		N	50	50	50	50	50	50	50	50			
	Lack Of Imagination	Correlation Coefficient	.332*	.562**	.383**	.382**	.382**	.546**	.627**	.509**	.148		
		Sig. (2-tailed)	.019	.000	.006	.006	.006	.000	.000	.000	.305		
		N	50	50	50	50	50	50	50	50	50		
	Vested Interests That Stifle Innovation	Correlation Coefficient	.333*	.538**	.336*	.256	.186	.416**	.486**	.624**	.131	.384**	
		Sig. (2-tailed)	.018	.000	.017	.072	.196	.003	.000	.000	.364	.006	
		N	50	50	50	50	50	50	50	50	50	50	

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

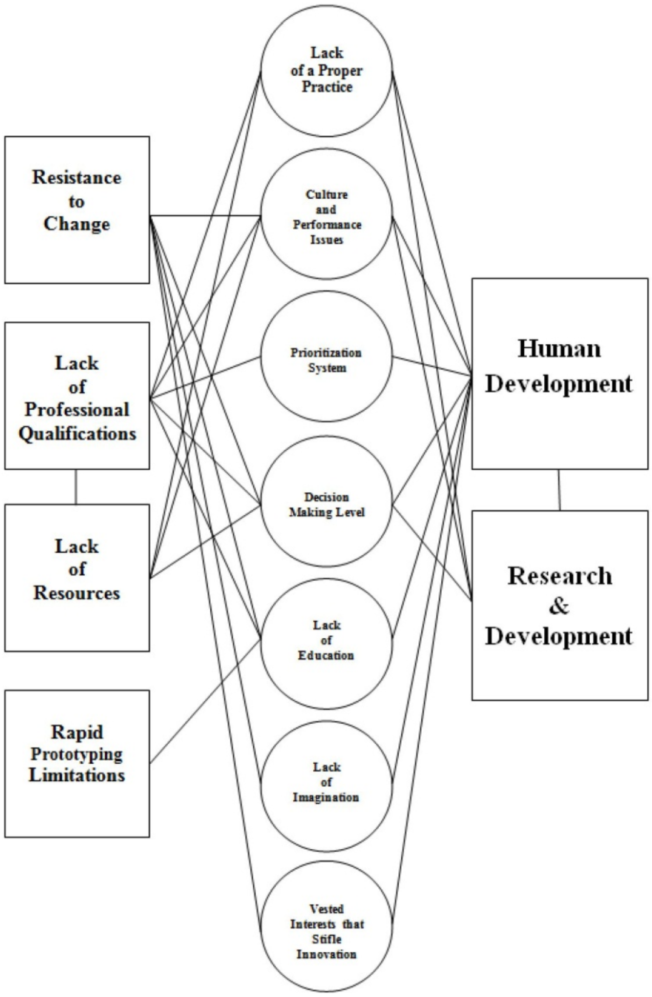

Figure 2: The Association between Barriers, Symbolically as Brain (Biological Neural Network)

Figure 2 demonstrates the association between barriers, simply explained on the general basis of the parallel structure of brains as a functional aspect of biological neural networks. In neural networks there is an inter–connection between the neurons in the different layers of the system; symbolically this study simulates the barriers as layers. Where the main barriers are the input layer, the other barriers are a hidden layer and finally the output layer as the suggested way out to deal with the input barriers. In the output layer incorporation of resistance to change and lack of professional qualifications as process of Human Development, as well as integration of lack of resources and rapid prototyping limitation as an aim for Research and Development to alleviate the process towards the desired change management approach. This approach should build a gradual organisational change, which will engage a strategic as well as technological change as a reflection of the human development on the research and development process.

Conclusion

This paper has focussed and presented a new perception on the barriers that hinder deployment of RP within SMEs. Identifying and investigating various RP technology adoption barriers allowed a new insight for barriers' prioritisation to be recognised. This study has attempted to help SMEs by identifying two key issues:

- What are the effective barriers that hinder SMEs from being "RP technology enabled". SMEs are not able to effectively take on new technologies such RP. This paper has identified the most effective barriers that hinder the adoption of RP within SMEs in SW of England, which also has a high external validity to be transferable to other regions within a similar field.
- Which of the barrier should a SME tackle first to become "RP technology enabled"? This paper introduced findings such as the actual existence of each barrier against the size and nature of the SME, which has been used as practical and effective approach to prioritise each of the barriers.

The results of this study have shown that lack of resources, lack of professional qualifications, resistance to change and rapid prototyping limitation are the important barriers. Consequently, the findings of this study suggest the following recommendations as a first step towards an effective strategic and technological change management approach:

- Incorporating and tackling the resistance to change, lack of professional qualifications in the form of human development.
- Integrating and dealing with of lack of resources and rapid prototyping limitation through research and development.

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The focus of the journal is on those intangible drivers which determine not only the livability of organizations for insiders, and their credibility and attraction to outsiders; but also their tangible results in the form of efficiency, effectiveness and productivity. The intangibles of knowledge, culture and change management do not appear on balance sheets, but ultimately do have an enormous impact on "bottom lines". The journal attempts to address dynamics of knowledge, culture and change as they manifest themselves in organizations. The perspectives range from big picture analyses to detailed case studies which speak to the tangible value of organizational intangibles. They traverse a broad terrain, from theory and analysis to practical strategies.

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The International Journal of Knowledge, Culture and Change Management: Annual Review is a peer-reviewed scholarly journal.

ISSN 1447-9524

ISBN 000-0-00000-000-0

Adopting Rapid Prototyping Technology within Small and Medium-Sized Enterprises: The Differences between Reality and Expectation

Ahmed M. Romouzy-Ali, Siamak Noroozi, Philip Sewell, and Tania Humphries-Smith

***Abstract*—The aim of this paper is to study existing adoption of Rapid Prototyping (RP) technology within small- and medium sized enterprises (SMEs) in addition to measuring the need for this technology. This study adopted a mixed method approach involving a postal survey of 200 companies followed by in-depth semi-structure interviews with 10 SMEs generating qualitative data which scrutinised the state on the ground in depth. The barriers to RP adoption were resistance to change, lack of resources, lack of professional qualifications and RP process limitation. Where RP was adopted the executive mangers stated that it is very effective across all of the associated aspects, however due to the barriers low levels of significance in adopting RP were revealed by SMEs not already using it. Consequently, whilst SMEs show negative response towards adopting RP technology, where they do so, they are satisfied with the outcomes. SMEs views about this barriers and the state of adoption generally are explored.**

***Index Terms*—Rapid prototyping technology, Small and Medium Sized enterprises, change management research and development.**

I. Introduction

Human evolution was founded on the basis of forming/shaping knowledge, and actually the narration of humankind civilisation has been boosted by the advancement of forming/shaping expertise[1]. To develop a new product, a prototype of a designed product or mechanism needs to be fabricated before the provision of enormous amounts of investment to new production machinery [2].

Before the 1990s, the industrialised societies had to waste significant time building prototypes of the products and mechanisms to test their performance [3]. The chase for lower operational costs and enhanced manufacturing competence has strained a great number of industrialised firms to adopt advanced manufacturing technology of a variety of processes [4].

Rapid Prototyping (RP) refers to the fabrication of a physical model from computer-Aided Design (CAD) data. RP is a relatively new technology that was first commercialised by 3D Systems in 1987 [5]. What is commonly considered to be the first RP technique, Stereolithography (SLA), was developed by 3D Systems of Valencia, CA, USA. The company was founded in 1986, and since then, a number of different RP techniques have become available. RP potentially offers great benefits in terms of time and cost reduction as well as improved quality of the final product when used during a product development process [6]. RP has also been referred to as solid free-form manufacturing; computer automated manufacturing, and layered manufacturing (LM). RP has obvious use as a vehicle for visualisation. In addition, RP models can be used for testing, such as when an airfoil shape is put into a wind tunnel. RP models can be used to create male models for tooling, such as silicone rubber moulds and investment casts. In some cases, the RP part can be the final part, but typically the RP material is not strong or accurate enough. When the RP material is suitable, highly convoluted shapes (including parts nested within parts) can be produced because of the nature of RP.

This study is mainly focused on the adoption of RP within Small and Medium-sized Enterprises (SMEs). [7] States *"SMEs are crucial in job creation, providing a 10% increase since the start of the current economic crisis and helping to boost recovery in the United Kingdom"*. Statistics shows that there are 4.5 million small businesses in the UK, SMEs account for 99 per cent of all enterprise in the UK, 58.8 per cent of private sector employment and 48.8 per cent of private sector turnover [8]. [9] Describes the categories of SMEs as *"Medium-sized enterprises are defined as enterprises which employ fewer than 250 persons and whose annual turnover total does not exceed 50 million euro or annual balance sheet total does not exceed 43 million euro. Small enterprises are defined as enterprises which employ fewer than 50 persons and whose annual turnover or annual balance sheet total does not exceed 10 million euro. Micro enterprises are defined as enterprises which employ fewer than 10 persons and whose annual turnover or annual balance sheet total does not exceed 2 million euro"* (see fig. 1). Manufacturing has been developing over the years as different needs and technologies arise. The world of business is changing rapidly. The winds of globalisation have pushed SMEs to grapple with the changing needs of their customers. The customer of the twenty-first century, demands products and services that are fast, right, cheap and easy [4]. It is recognised that products launched before their competitors are commonly more profitable and enjoy a larger share of the market [2].

Manuscript received May 14, 2012; revised June 13, 2012.

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Enterprise category	Headcount: Annual Work Unit (AWU)	Annual turnover	or	Annual balance sheet total
Medium-sized	< 250	≤ €50 million (in 1996 € 40 million)	or	≤ €43 million (in 1996 € 27 million)
Small	< 50	≤ €10 million (in 1996 € 7 million)	or	≤ €10 million (in 1996 €5 million)
Micro	< 10	≤ €2 million (previously not defined)	or	≤ €2 million (previously not defined)

Fig. 1. SMEs threshold. source: [9].

In this day and age, stiff competition, technology advancement and the globalisations of markets, most of the companies have been forced to consider and implement a wide variety of innovative management philosophies, approaches, and techniques [10]. The aim of instigating the traditional manufacturing organisations to take on RP technology is to achieve competitiveness [3].

However, the most successful application to benefit from the RP begins with the correct adoption of the process, that makes the process procedure, as well as the right definition of prototype requirements, very important steps [11]. But the adoption must be preceded by confidence and a feasibility study to bring these technologies to manufacturing processes already in use to support the adoption of this decision.

II. Research and Development (R&D) Within SMEs

As global manufacturing industries continue to undergo deep structural changes–which include the relocation not only of production, but also of related knowledge intensive activities such as R&D and other professional services, governments throughout the world are increasingly devoting attention to the support of the national industrial activity [12]. The majority of big enterprises have Research and Development (R&D) departments for bringing innovation projects to the consideration of top management and for facilitating their implementation. Large enterprises view SMEs as satellites that would rotate around them seeking revenue and possible profit [13]. Therefore SMEs must have the knowledge and full awareness of the constructive contribution that this new technology provides, especially when the size of the business is not comparable to the size of business within large companies that have inclusive independent departments for taking such decisions (see fig. 2) [14]. In the present era of globalisation SMEs should possess the ability to get the organisation to innovate quickly and produce an acceptable product and service to capture upcoming business opportunity [4].SMEs, on the other hand, over and over again do not have a proper procedure recognised [15], and R&D culture is absent due to financial constraints [16].

III. The Adoption of RP within SMEs

Despite this significance, more SMEs continue to ignore the adoption of RP technology due to a range of barriers. This moderately -if not extremely- hinders the development as well as the competitiveness of SMEs. However given the industrial and economical significance of SMEs it would seem that RP technology has much to interest the industrial/manufacturing SMEs executive managers. Studies in this field have revealed that SMEs can be rich sources of innovation in relation to new technologies.

This discussion raises a number of relevant questions pertaining to SMEs and RP, which provided the focus for this study:

- Do SMEs adopt RP and if so what are SMEs actual RP adoption strategies?
- Where adopted, how successful is the RP technology perceived to be?
- Where not adopted, what are the barriers hindering the adoption of RP and what are the potential strategies to initiate a change management state to adopt RP?

Based on the UK regional development, the South West of England (SW) was selected as a representative SME sampling region, where the SW was found to be the most appropriate region for this particular study due to its growth and development rates. [7] Describes the SW as *"SMEs in south-west England have the most optimistic outlook on growth out of all regions, followed by those in London and Wales"*.[17] Says *"The South West continues to derive more employment and turnover from SMEs than any other region"*.

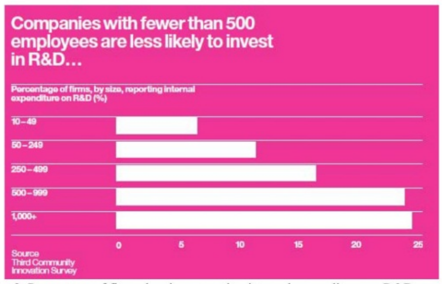

Fig. 2. Percentage of firms, by size, reporting internal expenditure on R&D. source: [14]

IV. Methodology

This study adopted a mixed-method research approach, so as to obtain data of appropriate scope and depth. A large scale postal survey of 200 SMEs in SW was conducted to recognise the adoption of RP technology and identify the barriers hindering the adoption of RP as well as prioritising them. This survey questions regarding RP were incorporated with other survey questions measuring the utilisation of change management culture within SMEs.

This survey was followed by semi-structure in-depth face to face interviews with 10 SMEs executive managers at their business locations; this has provided more in detail exploration of the associated issues. These approach methods are outlined in more detail. The postal survey questions related to the following areas (see Table 1).

This postal self-reported structured survey was designed, piloted, analysed and conducted by the researcher. The survey was sent out with a pre-addressed/*pre-stamped* return envelope. The pilot phase involved random participants of the main sample. A new specific regional database was created for the design/industrial/manufacture SMEs involved in engineering processes. The data was collected from different sources such as online databases, yellow pages, telephones directories and paid databases. While creating the database it was taken into account that it should be random, heterogeneous and representative to guarantee the external validity, so the results can generalised. Out of the 55 returned surveys, 50 valid surveys were initially utilised in this study with a 28% response rate which is above the typical response rate for this type of survey.

Based on the literature findings, the typical response rate for strategic studies is 10-12% [18-23]. Those excluded were considerably incomplete questionnaires.

The second phase of the study was the semi-structure in-depth face to face interviews. The interview covered a range of related areas as follows:-

- The participant's level of education and responsibilities within the SME;
- New technologies adoption, and in particular RP technology within the SME;
- The extent to which he agrees with the first phase results, discussion about the barriers hindering the RP adoption;
- The visible significance of RP technology to the SME;
- The future plans or strategies to adopt RP within the companies

The interviews were aimed to scrutinise in depth the barriers that were identified and prioritised from the first phase of the methodology. The researcher conducted the interviews with the executive managers from 10 SMEs on their location across the SW. A confidentiality agreement was signed with the participants prior to each interview, and the interviews were digitally recorded and afterwards transcribed by the researcher. Using thematic analysis technique to analyse the transcripts, the researcher generated a list of representative codes to themes identified from the transcribed text. The interviews presented several themes all the way through the interpretation of the transcripts, which were revised in the analysis.

TABLE I: THE POSTAL SURVEY QUESTIONS RELATED AREAS

<table>
<tr><td rowspan="2">Company Profile</td><td>Significance of</td><td>Investment in</td><td rowspan="2">RP technology adoption / barriers to adoption within the company</td></tr>
<tr><td colspan="2">In-House Design Practices; In-House R&D; RP Technology; CAD; CNC machining; innovation processes</td></tr>
</table>

V. FINDINGS

A. The Overall Technological Atmosphere

With the aim of understanding of the internal overall technological atmosphere within SMEs, respondents were asked in the postal survey about the related product development issues in terms of significance and investment levels within their companies (see Figure 3). It was clearly seen that in-house design practices, in-house research and development as well as Computer Aided Design (CAD) to be very important with 82 percent suggesting it was very significant and 18 percent suggesting it was less/not significant. RP technology processes was seen to be less/not important with 70 percent suggesting it was less/not significant and 30 percent suggesting it was very significant, however Computer Numerical Control (CNC) was seen to be important with 60 percent suggesting it was very significant and 40 percent suggesting it was less/not significant. Respondents were also asked about the level of investment within their companies in the related issues, they indicated that they had moderate/heavy investments as to 42 percent for in-house design practises; 68 percent for in-house research and development, 48 percent for CAD, 26 percent for CNC and only 10 percent for RP technology processes.

B. Barriers to Adopt RP Technology

The results from the postal survey in relation to the barriers that hinder RP adoption show that 30 percent of the SME companies surveyed had used RP technology process. In the 70 percent of the sample which had never used any RP technology, the most common barriers were resistance to change (44 percent), lack of professional qualifications (36 percent), RP technology limitations (36 percent) and resistance to change (30 percent). While the results are not surprising, it is some of the first collected data to prioritise the barriers that hinder the adoption of RP technology within SMEs. This result suggests that SMEs are more likely to adopt RP on the event of overcoming these only four above mentioned barriers.

A similar more in-depth pattern of data was exposed in the interview findings. The content analysis of the transcribed interviews revealed five main themes:

Human development concerns: Generally the interviewees believed that to sustain a dedicated and stimulated business they need to develop their staff's skills, as these skills are the input in dealing with desired change. Although internal training is regularly implemented to address the development of employees with practical skills, the development of executive level is generally needed to a certain extent. Also most of the companies were facing serious challenges with regards to succession planning and the generation of senior executive managers.

In-House Design Practises

In-House Research and Development

RP Technology Processes

Computer Aided Design (CAD)

Computer Numerical Control (CNC)

Fig. 3 Percentage of significance and level of investment within SMEs.

Strategic concerns: The interviewees viewed resistance to change in a negative way and nearly all agreed that in order to survive they must bring in change within their companies. All expressed a need for technological growth and saw it as input to long-term business survival. The majority were looking to obtain a technological development to improve productivity, effectiveness, competitiveness rather than normal organic growth.

Resources concerns: There was a common awareness of the importance of resources in SMEs, with regard to the financial resources in particular and the capability to deal with the current recession. Arguably that the SME executive needs to combine elements of both financial and management in their responsibility, and of the essential required skills, accountancy was deliberated as without a doubt the most significant. The ability to handle everyday budget concerns to think of the long-term financial flexibility of the company was seen as one of the major challenges.

RP technology awareness: Most of the interviewees perceived RP technology with high level of awareness, as they demonstrated knowledge of the technology. Even though some of them showed a high confident level of knowledge regarding the RP technology, it was found that the executive managers are so reluctant when it comes to decision making level to deploy the RP technology or not. However some of them find outsourcing the RP technology is the right thing to do.

Independent concerns: A range of other matters were found to be independently affecting the SME's liaison with the outside world. Such as global competition from other countries like China, where the labour cost is far cheaper than UK to the extent of which they can't manage. Also knowledge transfer and the challenges associated with it, in addition to the difficulty of sustaining a state-of-the-art link in every relative field. What's more the governmental support which is insufficient plus the escalating trouble of rules and laws.

VI. Discussion

According to these results, the SMEs are functioning in very challenging internal and external surroundings. Human development within SMEs is currently a very high priority, as it will lead to new change management policies to be implemented in their sectors. This will unlock the barriers of resistance to change as well as the lack of professional qualifications as [15] said *'…Most managerial positions at SMEs are acquired based on experience and lack professional qualifications…'*. It is also not surprising that the most frequent barrier is lack of resources, because of which SMEs cannot take on RP technology due to the current internal and external financial constraints. RP is evidently seen as an appropriate process when related to the crucial dynamics on which the SMEs strategically perform *'…Better technology, better tools may help SMEs but we should not miss the real opportunity of creating a new generation of SMEs with a strategic mindset…'* [24].

The way towards a high level of awareness of the need for RP technology against the prioritised barriers is dependent on both prior research linked to SMEs and the provisional strategy to overcome these barriers as '*…The obstacles may be clear, but that doesn't make them easy to address…'* [16]. Despite the high volume of models and frameworks which point to a number of approaches to deploy RP technology, all approaches do not stand up because they are more generic in nature rather than specific in their customisation to this sector. This suggests that any new strategy attempts to help this specific sector of companies to overcome these barriers, should implement the four prioritised barriers as pillars on which the problems will be tackled. One implication of this is the need to boost awareness of the significance of involving the executive managers in any attempts in the forms of either Technology Transfer (TT) or Knowledge Transfer Partnership (KTP). This may be an involvement that will simply lead to establishment of a new RP technological culture with SMEs.

An optimistic unexpected result from this study is the fact that 30 percent of the sample has used RP technology to some extent, either onsite or by outsourcing. This has shown a great variation between reality and expectation, as it was expected from the literature that not only RP is absent but the whole culture of research and development is absent as [15] indicated*'…R&D culture at SMEs is absent due to financial constraints…'*. With approximately one third of the sample having new technological adoption culture within their companies, the chances of more positive change management are more likely to happen rapidly. This underpins the influence associated with the significance of RP technology and its related returns. *"We're on the verge of a revolution in how things are made"* Says Greg Morris, Morris Technologies [25]. Also it expands the relevance of such influence to explicitly cover the SME sector.

The discussed findings help to characterise a leading approach for new opportunities for the RP technology within SMEs. Undoubtedly raising awareness of the importance of human development is a key issue towards an effective decision making about the adoption of RP technology. Moreover there is a need for finding new financial resources alternatives through for example TT or KTP within an SME perspective. Ultimately the reality is not very far from expectation; however there is more work to be done to achieve the envisaged target.

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Siamak Noroozi, Professor. He received his PhD from Sheffield University in 1986 in the area of Finite Element Analysis coupled with Boundary Element Analysis. He currently holds the Chair in Advanced Technology at Bournemouth University. His research interests are Finite Element Analysis, Boundary Element Analysis, biomechanics, condition monitoring, general stress analysis, photoelasticity, alternative numerical analysis, composite technology and aeroelasticity.

Philip Sewell, Dr. He received his BEng degree in mechanical engineering from the University of the West of England in 1999 and a PhD in the field of Prosthetic Design in 2003. He is currently employed as a Senior Academic in Design Simulation at Bournemouth University. His research interests include the design of novel tools for prosthetic fitting, the development of techniques to determine prosthetic interfacial pressure distributions, and experimental and numerical stress analysis.

Tania Humphries-Smith, Dr. She is Associate Dean (Design and Engineering) at Bournemouth University whose teaching areas are Engineering and Product Design. She was in professional practice as a Product Designer before entering Academia. She is also a Member of the Institution of Engineering Designers and Member of Council, as well as a Chartered Engineer. Her research activities are in the areas of both sustainable product design, specifically, the social aspects of sustainable design and design education. She has published papers in design education since 1998.

Appendix B
The Survey Information Sheet and Questionnaire

Bournemouth University

School of Design, Engineering & Computing

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Postgraduate Researcher, PhD
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arali@bournemouth.ac.uk

Dear participant,

This survey is part of a PhD research plan that is scrutinizing the extent to which Rapid Prototyping; (RP) is being deployed directly by Small and Medium Enterprises, (SMEs). This includes a broad range of additive manufacturing technologies used for making physical models, prototypes, and custom production parts e.g. SLA, SLS, FDM. For the purpose of this exploration, Computer Numerical Control machining, (CNC) is not being considered as a rapid prototyping technique. It will take approximately 10 minutes to complete the questionnaire.

Your participation in this study is completely voluntary and anonymous. There are no foreseeable risks associated with this research. However, if you feel uncomfortable answering any questions, you can withdraw from the survey at any point. It is very important for this research to gain knowledge about your opinions, experiences and future plans. Your responses will present invaluable information that will help to plan and prioritise future progress of this research.

Your information will be coded and will remain confidential. If you have questions at any time about the survey or the procedures, you may contact the researcher at the above contacts details.

Thank you very much for your participation in this survey, the researcher truly appreciates the time you freely give to share your opinions and experiences. In return, the researcher commit to use the data gained to generate a strategy to appropriately deploy RP within SMEs that is optimised and customised towards High Value Manufacturing (HVM) practises.

Your help is very much appreciated!

Kind regards,

Ahmed Romouzy Ali

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Bournemouth University

Rapid Prototyping Deployment Survey (RPDS)

Confidentiality Agreement

This questionnaire survey is part of a PhD research methodology carried out on a regional scale (South West of England) involving SMEs interested in the Manufacturing/Industry. The overall objective is to identify the extent to which Rapid Prototyping; (RP) is being deployed within SMEs.

All hard copies will be treated as confidential information and stored securely, preventing access by anybody other than the researcher for maximum security and protection of the data. However, it is the researcher and Bournemouth University that will be the administrator and the owner of the data. Researcher will shred (or give to the Bournemouth University for shredding) all hard copies that contain confidential information, and delete all electronic lists when no longer need them for the research/task.
Considering the potential sensitivity of the data related to individuals and companies taking part in the survey, the researcher and the participant of this agreement have agreed on the following:

- Neither the researcher nor the participant has an interest to identify individuals taking part in the survey.
- The researcher will not provide information to anyone that could disclose the identity of individuals taking part. Where necessary to meet this obligation, anonymised statistics of the survey will only be provided to the participants on a group level.

Signed by: Participant:

--- ---

Ahmed Romouzy Ali
BSc (Hons), MSc
Postgraduate Researcher, PhD
Design Simulation Research Centre (DSRC)
School of Design, Engineering & Computing (DEC)
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Date:

Date:

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Rapid Prototyping Deployment Survey (RPDS)

Thank you for volunteering for RPDS! Volunteers are valued and individual responses/documents will be kept confidential and secure, and will not share survey results with any third party.
This survey will take approximately five minutes to complete. Thanks for your time!

Please tick or write a response as appropriate. Your assistance with this research is highly appreciated.

A. Company description

1. Home region of your company (Choose one):

- ☐ Bournemouth, Dorset and Poole
- ☐ Cornwall & the Isles of Scilly
- ☐ Devon, Plymouth and Torbay
- ☐ Gloucestershire
- ☐ Somerset
- ☐ Swindon and Wiltshire
- ☐ West of England

Others (please specify) ____

2. Areas of business (Choose the main one):

- ☐ Product Design
- ☐ Engineering Design
- ☐ Industrial Design

Others (please specify) ____

3. Major products of your company (Mention at least one)

____

____

____

4. Number of employees (Choose one):

- ☐ 1 to 9
- ☐ 10 to 49
- ☐ 50 to 249

B. Significance of Priorities to your company

5. Please indicate the degree of significance to your company in terms of

	Not Significant 1	2	3	4	Most Significant 5
a) In-House Design Practises					
b) In-House R&D					
c) RP Technology processes					
d) Computer Aided Design CAD					
e) CNC machining					
f) innovation processes					
g) Cost					
h) Quality					
i) Timing					
j) Market share					

C. Investment of your company

6. Please indicate the degree of investment of your company in terms of

	No investment 1	2	3	4	Heavy investment 5
a) In-House Design Practises					
b) In-House R&D					
c) RP Technology processes					
d) Computer Aided Design CAD					
e) CNC machining					

D. RP technology deployment in your company

7. Please indicate the extent to which you agree or disagree with the following statements to describe better the existent barriers to appropriately deploy RP technology

	Totally disagree 1	2	3	4	Totally agree 5
a) Lack of a proper practice					
b) Cultural and performance issues					
c) Lack of resources					
d) Lack of professional qualifications					
e) Prioritization system					
f) Decision making level					
g) Resistance to change					
h) Lack of education					
i) RP process limitation					

j) Lack of imagination ☐ ☐ ☐ ☐ ☐
k) Vested interests that stifle innovation

Key for responses

- 1 – Strongly disagree, 2 – Disagree, 3 – Neither disagree nor agree, 4 – Agree, 5 – Strongly agree
- 1 – Totally disagree, 2 – Disagree, 3 – Neither disagree nor agree, 4 – Agree, 5 – Totally agree
- 1 – No activities, 2 – Least activities, 3 – Some activities, 4 – Moderate activities, 5 – Many activities
- 1 – Not important, 2 – Least important, 3 – Important, 4 – Very important, 5 – Most important
- 1 – No investment, 2 – Slight investment, 3 – No idea, 4 – Moderate investment, 5 – Heavy investment
- 1 – Not aware, 2 – Least aware, 3 – Don't exist, 4 – Some awareness, 5 – Fully aware
- 1 – Not used at all, 2 – Least used, 3 – Don't know, 4 – Slightly used, 5 – Very much used
- 1 – No weightage, 2 – Least weightage, 3 – Don't know, 4 – Some weightage, 5 – Full weightage
- 1 – No emphasis, 2 – Least emphasis, 3 – No idea, 4 – Moderate emphasis, 5 – Full emphasis
- 1 – Very low , 2 – Low, 3 – Moderate, 4 – High, 5 – Very High

☐ Please select this box if you would like to be informed as to the progress and results of this research.

☐ Please select this box if you are happy to be involved in a one hour interview with the researcher.

Please fill in the following information if you have already selected any of the above boxes.

Name: ___________________________

Job Title: _________________________

Email: ___________________________

THANK YOU FOR YOUR COLLABORATION!!

Appendix C
The Interviews Information Sheet
and Questions

Bournemouth University

School of Design, Engineering & Computing

Information Sheet and Consent Form

Thank you for accepting to be participated in my research scrutinizing the deployment of Rapid Prototyping Technology within SMEs interested in the Manufacturing/Industry on a regional scale (South West of England), which is being conducted as part of my PhD research with Bournemouth University.

The aim of this research is to provide additional understanding of the concerns faced by SMEs which, as a part of the industrial/Manufacture transform, are required to change past routines or practises. It is wished that your participation in this research will benefit you personally, and that the research will inform those within SMEs accountable for execution of transform.

I would like your permission to record your interview on digital audio recorder. In addition, I would like your permission to transcribe your recorded interview, in whole or part. As a participant in this research, you are assured confidentiality. This research will be reported within my PhD thesis, and parts of it will be reported in journals and at conferences. Within the entire research process, neither individuals nor enterprises will be identified, and the information presented about participants will not allow for identification.

Thank you very much indeed for your participation

Ahmed Romouzy Ali

By signing below, you are indicating that you:

- Have read and understand the information provided above about this research
- Have had any questions answered to you satisfaction
- Understand that if you have additional questions you can contact the research team
- Understand that you are free to withdraw at any time without comment or penalty
- Understand that you can contact the research team if you have any questions about the research, or the research ethics on 01202 961691 or (nbailey@bournemouth.ac.uk)
- Agree to participate in this research
- Consent to record my interview on digital audio recorder
- Consent to transcribe my interview, in whole or part

Name: -------------------------------------- Signature: ------------------------------ Date: --------------------

Please feel free to request of copy of this consent form once signed, for your future reference

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Questions:-

For the record, can you tell me about yourself and your job function?

This research analyse how industrial/manufacturer SMEs take on new technologies, and in particular, how they adopt/reject Rapid Prototyping technology. You might have/not have really thought about it too much, but in the current global industrial/manufacture transform, I want to focus particularly on telling me about your position from this transform.

Rationale:

An opening question aimed to trigger discussion on new technologies, and in particular, Rapid Prototyping technology and to provide insights on how the new technologies, and in particular, Rapid Prototyping technology are perceived by the participant (i.e. effectiveness/ significance).

Tell me about the old technological methods/techniques of doing things in your company.

Rationale:

To discover the technological industrial/manufacture culture of the company, in order to find if this company had/has any development in its history.

Tell me about the new technological methods/techniques of doing things in your company.

Rationale:

To discover what kind of technological industrial/manufacture development the company has implemented recently.

The first phase of the data collection revealed that the most effective barriers that hold back the adoption of new technologies and in particular Rapid Prototyping technology are in order

Resistance to change; Lack of professional qualifications; Lack of resources; Rapid Prototyping limitations

To what extent you agree with these results?

Rationale:

To find out the extent to which this results does express for the situation on the ground.

If these four barriers are summed up into two major issues

Human Development; Research & Development

How do you think these two issues can be solved?

Rationale:

To discover what kind of solutions does the participant would adopt if offered in future.

What are your future technological adoption intentions, if any?

Rationale:

To discover whether non-technological adopters are considering future technological adoptions and reasons for that and also whether basic technology adopters are considering more forms of new technological adoptions and why.

(Probe questions, if needed)

- Explain for me what you came across throughout the technological transform from old methods/techniques to the new methods/techniques?
- What assisted the technological development of the transform?
- What held back the technological development of the transform?

Rationale:

To discover the factors/obstacles that affects the technological development of the transform.

- What part if any, do you think your level of knowledge and experience engaged in recreation of your company technological transform process?
- What part if any, do you think your individual manner or character engaged in recreation of your company technological transform process?
- What part if any, do you think the industrial/ manufacturing rules and practices engaged in recreation of your company technological transform process?
- What part if any, do you think the age and size of your company engaged in recreation of your company technological transform process?
- What part if any, do you think the turnover/profit of your company engaged in recreation of your company technological transform process?
- What part if any, do you think the owner(s)/mangers engaged in recreation of your company technological transform process?

Rationale:

To discover whether there is a relationship between the above factors and the technological transform process to determine whether there is a link between any of them.

Did the adoption of new technologies, in particular Rapid Prototyping Technology has paid off or will pay off financially/strategically? I.e. were you able to expand your market, increase sales, locate new customers, enhance customer services, etc? What valuation criteria do you apply to weigh up whether the adoption of new technologies, in particular Rapid Prototyping Technology has achieved its goals?

Rationale:

To understand the actual reasons behind technology adoption within SMEs, i.e. has the adoption decision been a result of competitive pressure, customer demand or only towards a technological presence, or has it been a result of a strategic planning to improve the products and capture likely profits.

We have discussed many things that could have an impact on the transform of your company to meet the current challenges on the global industrial/manufacturing circumstances. Just to finish our discussion, could you give me a quick summing up of what you see as the key issues, in order of priority that you believe assisted adoption of new technologies and in particular Rapid prototyping? That you believe held back adoption of new technologies and in particular Rapid prototyping?

Rationale:

To sum up, conclude the interview while confirming and ordering the participant's thoughts.

Will you be happy to participate in last phase of this study to review and validate the outcome strategy of this research?

Appendix D
The Proposed Strategy Information Sheet
and Evaluation Form

Bournemouth University

School of Design, Engineering & Computing

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Dear Mr

On behalf of my PhD research team at The Design Simulation Research Centre, Bournemouth University. We thank you for your valuable participation in my doctorial research study concerning deploying Rapid Prototyping Technology (RPT) within Small and Medium-Sized Enterprises (SMEs) in the South West (SW) of England. In this research the barriers hindering the deployment of RPT were identified and prioritised, and more influential deployment drives were also recognised.

This has resulted in developing a new strategy to deploy RPT within SMEs in SW of England, and that simply couldn't have been achieved without your very much appreciated input. You kindly also welcomed being involved in the strategy's final evaluation phase. Therefore, the developed strategy is enclosed for you to review, and to kindly please complete an evaluation form and post it back to us via the enclosed pre-paid self-addressed envelope.

Thank you again for taking the time to be a part of this research. If you have any comments or concerns, please feel free to contact me. We value your expertise and appreciate your continued support to this research.

Sincerely,

Ahmed Romouzy Ali

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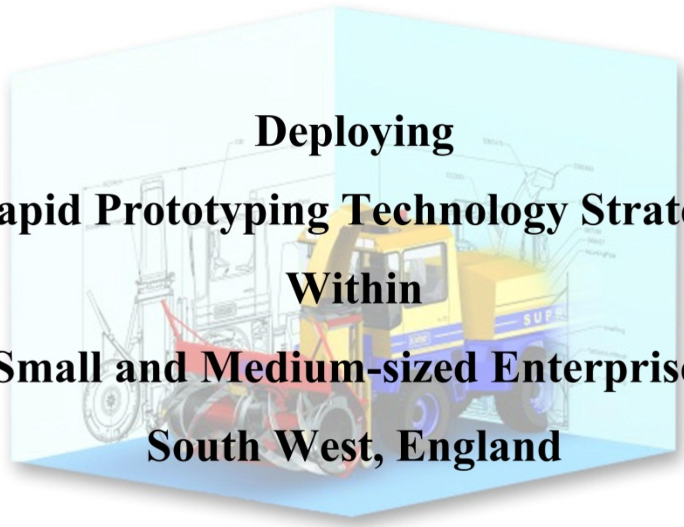
Bournemouth University



Deploying Rapid Prototyping Technology Strategy Within Small and Medium-sized Enterprises South West, England

RAPID PROTOTYPING

Photo adapted from http://www.ien.com/article/solid-edge-v17/294

CONTENTS LIST

1 EXECUTIVE SUMMARY

This document is a Strategy pursuing a comprehensive approach for Deploying Rapid Prototyping Technology (DRPT) within Small and Medium Enterprises (SMEs) in the industrial/manufacturing/engineering sectors in the South West England. This strategy seeks to realise significant product developments and promote sustainable competent, effective and RP technology-led industrial/manufacturing processes that deliver competitive products.

Through DRPT strategy the SMEs executive managers should be able to strengthen their businesses by developing and boosting new RP technology-led products, and/or making the decision to use/not to use RP technology for strategic reasons. To achieve the maximum impact, DRPT strategy has a particular focus on the whole deployment process not only the selection of the RP technology. This focus has a three major phases represented in the pre-decision making stage, decision making stage and post-decision making stage. DRPT strategy aims to make the most of the invested resources to ensure SMEs maintain a high level of adeptness and competency. This strategy was designed by a PhD researcher from the Design Simulation Research Centre at Bournemouth University based on the data collected from SMEs' executive managers in SW England.

The purpose of the DRPT strategy is to provide an explicit plan and a conceptual framework to deploy RP without going into too much detail about the course of actions as this may vary from company to another and can easily be identified once the strategy put into practice. The DRPT strategy is not a static strategy; it will develop and progress as the needs of the business change corresponding to the product improvements in the business's roadmap and maturity in the RP technology. In this strategy document the research encapsulate the key influencing factors affecting the deployment of RP technology.

The research considered their impact based on the conducted industrial discussion but it also recognises the outcomes of the previous research done and published in the same context. To that extent the strategy was needed to remain flexible in its approach and to prioritise the business needs. The conceptual framework implemented within the strategy will progressively develop the use of RP technology in the industrial companies to improve the efficiency of the manufacturing processes and usefulness of the resources using RP technology such as for prototyping, product analysis/testing and additive manufacturing. The original procedures of prototyping, testing and manufacturing and other methods will be reassessed, improved, sustained and maintained to keep a consistent rapid implementation of the new RP processes. Investing in the staff training and development is essential to grant competent personnel in order to achieve the most outstanding end results from the RP industrial deployment.

The study revealed that the level of awareness of available new technologies varies between no awareness; limited awareness; good awareness to high level of awareness. This applies to RP technology which is the focus of this study, and also the level of awareness of new technologies in particular RP technology cannot be generalised throughout the whole SMEs sector as this is a result of the individual's practises. Thus this concern can be tackled upon over the human development approach. This relates directly to the extent to which RP technology is recognised within the SMEs, where the study has shown that was already recognised and deployed with some SMEs.

But on the other hand, the study also showed that RP technology was not recognised by the majority of the SMEs owing to different causes. This evolved to be the potential drives for maximising the level of recognition within the SMEs. In addition to these potential drives and along together with the deploying criteria which were extracted from the existing RP deployment cases, a criteria factors for RP technology deployment was identified all through the developed strategy. The barriers that hinder the deployment of RP within SMEs were identified in the course of Phase One, and prioritised with suggestion of potential approaches to minimise the effect of these barriers. The identified and prioritised barriers are resistance to change; lack of professional qualifications; lack of resources; and RP technology limitation.

The returned and completed survey questionnaires showed a status of perception for those barriers, which resulted in the current situation of SMEs, left behind the industrial/manufacturing technological advancement. These findings were later investigated deeply to stand on the actual causes and the possible ways out to improve the situation. The suggested approach to tackle resistance to change along with lack of professional qualifications through continues human development process was received desirably by all the executive managers who participated in the two phase of study. It was also clarified by the participants that lack of professional qualifications is not a major issue as they all holds a high level of qualifications, but keeping an up-to-date knowledge is the issue which can be tackled effectively through the human development approach. With regard to the lack of resources and RP technology limitation, the participants also supported the suggested research and development approach as a tool for tackling those barriers. Up to this point, this was theoretically supported as an empowerment tool for eliminating those barriers, however yet this tool needed to be translated into a practical tool. Consequently, these approaches were implemented and enabled as a practical tool within the developed strategy.

The developed strategy consist of three key stages, each stage is designed to address some of the identified needs. These stages are planned in the way with which, a SME can maintain a continuous RP technological strategic reflection to any change of the needs within the business, to guarantee that the SME is not going to be technologically left behind in terms of RP technology. Figure 1 shows the Rapid Prototyping Deployment Strategy (RPDS) Flowchart.

Moreover, the strategy also contains a stimulating question to guide the user to be acquainted of whether or not his company is ready for RP technology. If the user is not familiar with the term Rapid Prototyping, then the strategy points out to investigate RP. In addition, if the user is familiar with the term RP but not sure, then the strategy points out to use the developed Product Process Matrix (PPM) to help recognise the need for RP technology based on the product nature (Figure 2). The literature review reported that "The benefits to the company using RP systems are many. One would be the ability to experiment with physical objects of any complexity in a relatively short period of time. It is observed that over the last 35 years, products released in the market place have increased in complexity in shape and form".

Bournemouth University
Deploying Rapid Prototyping technology (DRPT) Strategy

Rapid Prototyping Deployment Decision Making Strategy Flowchart

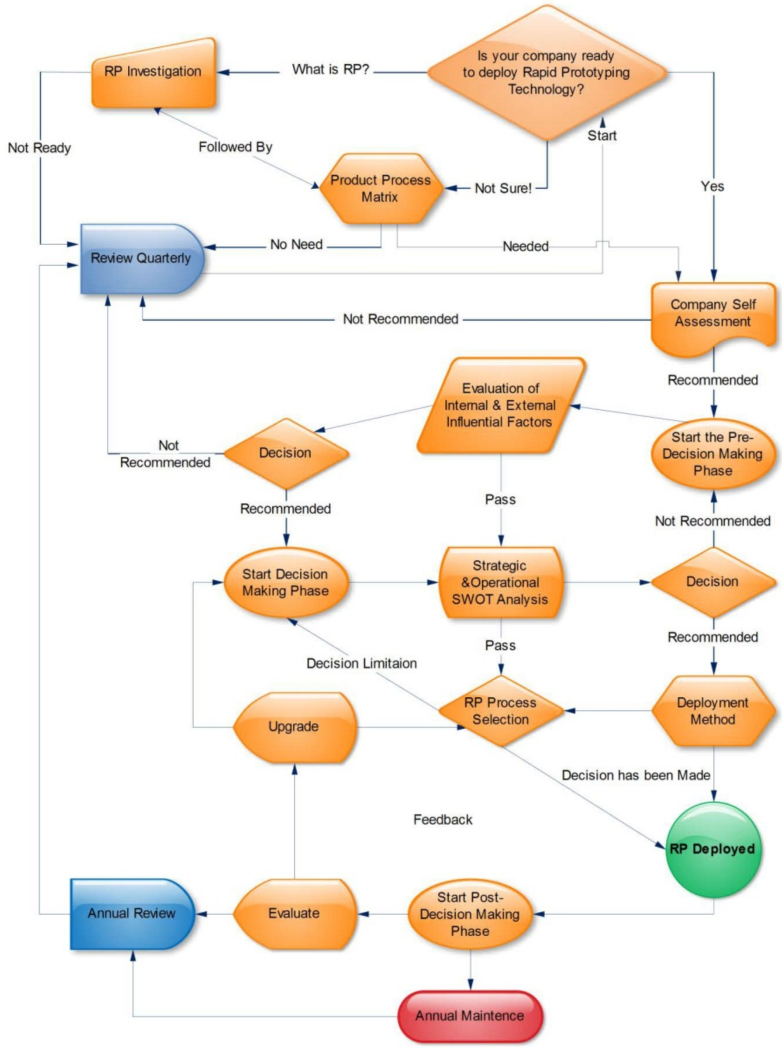


Figure 1

Page | 5

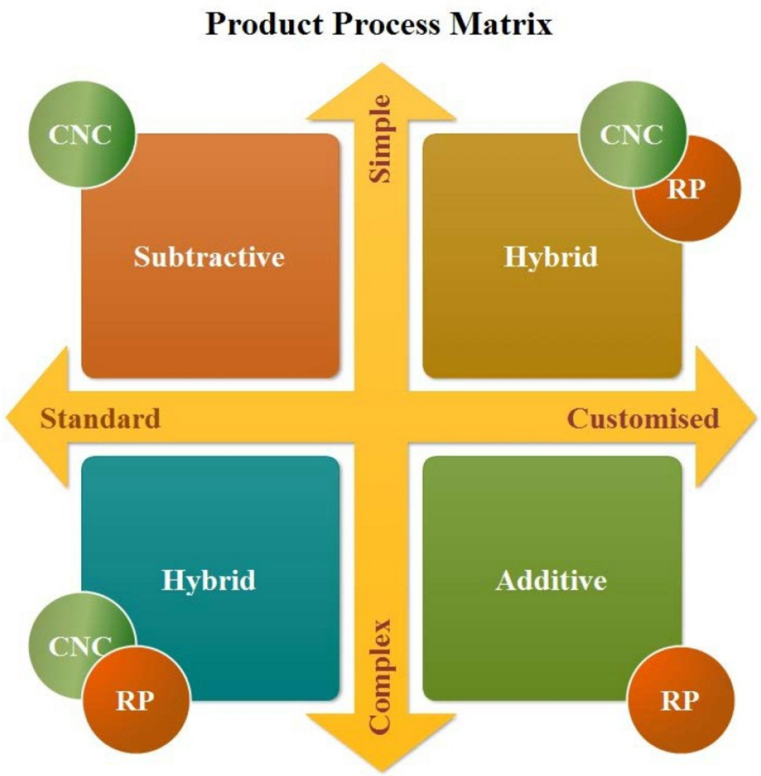


Figure 2

The PPM helps to identify generally the appropriate processes needed to address the product nature, which relate to the simplicity; complexity; standardisation; and customisation of the product. This would help the user to initially see where RP might be beneficial to his business. Following to applying the PPM to what the company produce, the next step could be to investigate RP to enhance the associated knowledge; review again after three month or to go to the next step if a potential to deploy RP was identified. The Company's Strategic Self-Assessment (Figure 3) is the gate to the three key stages of the deployment process, where the user is encouraged to self-assess his business position in terms of market position; financial position; design to production status; and the company's position on RP technology.

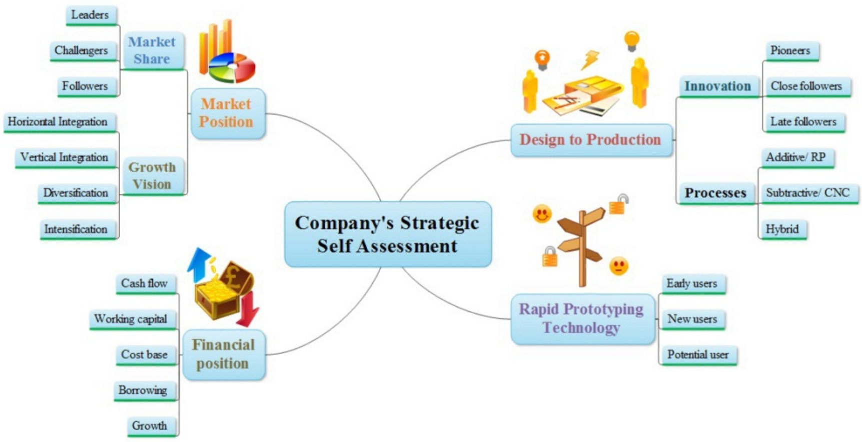

Company's Strategic Self Assessment
Market Position
Market Share
Leaders
Challengers
Followers
Growth Vision
Horizontal Integration
Vertical Integration
Diversification
Intensification
Financial position
Cash flow
Working capital
Cost base
Borrowing
Growth
Design to Production
Innovation
Pioneers
Close followers
Late followers
Processes
Additive/ RP
Subtractive/ CNC
Hybrid
Rapid Prototyping Technology
Early users
New users
Potential user

Figure 3

This would provide vital and significant information, as to help the user deciding on strategically substantiated information whether to go on or re-assess the company in three-month time to avoid dragging the business into unforeseen difficulties. This strategic assessment was designed to address the acknowledged deployment issues, which emerged from the analysis of the data collected. If the Company's Strategic Self-Assessment suggested to go on with the RP technology deployment process, the user then is directed to the Pre-Decision Making stage where internal and external influential deployment factors would be investigated and assessed.

Pre-Decision Making Stage

This stage involves addressing the external factors that stimulus the deployment process, such as backing up the level of RP awareness through engaging with the available RP technology platforms (universities, service providers and regional development agencies); the apparent call for development through the customers feedback; and ways for innovations as a tool for global competitiveness. The pre-decision making stage also involves addressing the internal factors that impact the deployment process, such as the need for RP technology requirement analysis through identifying the product requirement (production volumes, manufacturing processes, and product nature); the foreseen tangible benefits of the deploying RP technology on the product characteristics. These product characteristics benefits can be group into relative advantages; compatibility; and trainability of the RP technology. Figure 4 shows the pre-decision making stage model. This stage also involves a risk assessment task, where particular important internal factors should be evaluated in order to strategically inform making the decision of deploying RP technology. This includes any culture resistance within the business, project timing, resources constraints, service provider locality, complexity of the operations and the required training. The results and information obtained through the pre-decision making stage in tandem with the grades from the company's strategic self-assessment, would adequately inform the SME executive manager in a strategic approach to decide whether to continue with the deployment process, or to review and re-assess the business again in three-month time. In the case of making the decision to go on with deploying RP technology, as the assessment shown adequate strategic position, substantiated the needs for RP technology, and maximised the anticipated tangible benefits. Then the strategy directs the user to start the Decision making stage, where it directs the user through the RP deployment process.

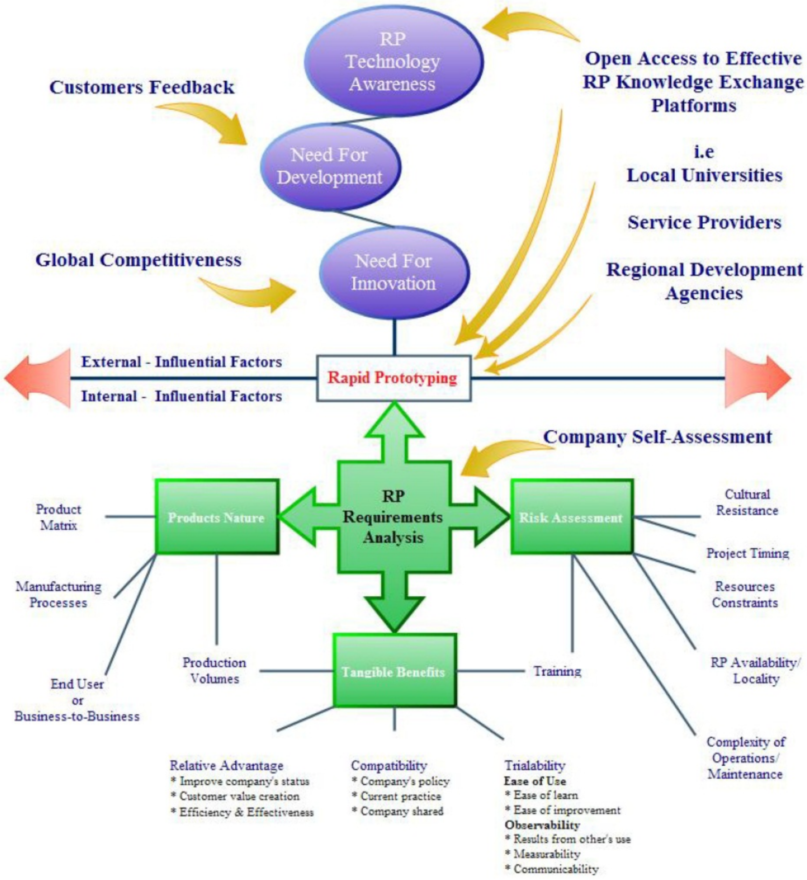


Figure 4

Decision Making Stage

This stage is designed to act as the last confirmation phase, as it involves a strategic and operational Strength, Weakness, Opportunities, Threats (SWOT) Matrix (Figure 5); and the selection of RP technique. This will allow the executive managers to identify the apparent expected priorities, as well as identifying any possible high risk of deploying the RP technology within the business.

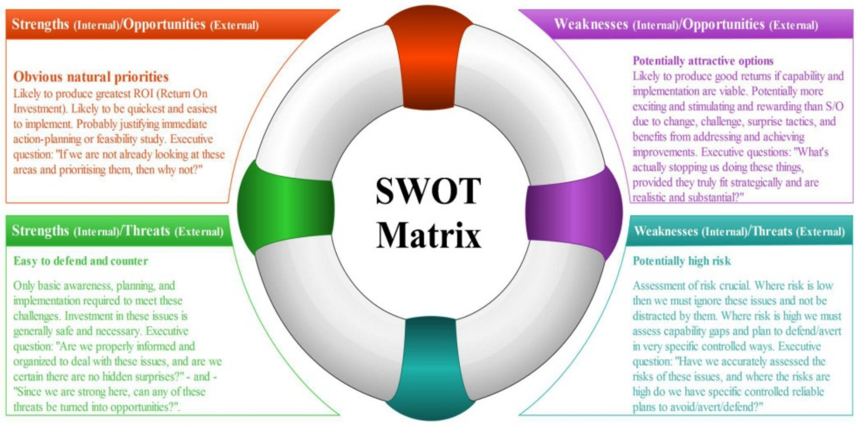

Strengths (Internal)/Opportunities (External)
Obvious natural priorities
Likely to produce greatest ROI (Return On Investment). Likely to be quickest and easiest to implement. Probably justifying immediate action-planning or feasibility study. Executive question: "If we are not already looking at these areas and prioritising them, then why not?"
Weaknesses (Internal)/Opportunities (External)
Potentially attractive options
Likely to produce good returns if capability and implementation are viable. Potentially more exciting and stimulating and rewarding than S/O due to change, challenge, surprise tactics, and benefits from addressing and achieving improvements. Executive questions: "What's actually stopping us doing these things, provided they truly fit strategically and are realistic and substantial?"
SWOT
Matrix
Strengths (Internal)/Threats (External)
Easy to defend and counter
Only basic awareness, planning, and implementation required to meet these challenges. Investment in these issues is generally safe and necessary. Executive question: "Are we properly informed and organized to deal with these issues, and are we certain there are no hidden surprises?" - and - "Since we are strong here, can any of these threats be turned into opportunities?".
Weaknesses (Internal)/Threats (External)
Potentially high risk
Assessment of risk crucial. Where risk is low then we must ignore these issues and not be distracted by them. Where risk is high we must assess capability gaps and plan to defend/avert in very specific controlled ways. Executive question: "Have we accurately assessed the risks of these issues, and where the risks are high do we have specific controlled reliable plans to avoid/avert/defend?"

Figure 5

If this final confirmation phase resulted in potential strength and visible opportunities, at that point the final decision to deploy RP technology is made. Yet the following decision is on which RP technique and the deployment method (on-site or/and outsourcing). These two final decisions are not modelled within the strategy for two reasons. First, the strategy is mainly concerned with guiding the RP technology deployment decision, and secondly the service seller and providers have more updated enhanced models to help select the RP appropriate technique and deploying methods with offers based on the latest of market place. Therefore it was decided not to include a RP techniques selection or/and deploying methods models. Once the RP technique is selected and the deployment method is chosen, the actual and practical RP deployment is in place. This will allow for genuine feedback information, which as per guided by the strategy will inform the Post-Decision Making Stage.

Post-Decision Making Stage

This stage is predominantly concerned with two major tasks, RP technology maintenance (in case of on-site deployment method) and upgrading the deployed RP technique as RP technology improvements are very fast. Additionally, the information obtained from this stage would inform the annual review of the RP technology deployment.

Strategy Evaluation

The term "strategy" has been so widely used for different purposes that it has lost any clearly defined meaning. For our purposes a strategy is a set of objectives, policies, and plans that, taken together, define the scope of the enterprise and its approach to survival and success. Alternatively, we could say that the particular policies, plans, and objectives of a business express its strategy for coping with a complex competitive environment.

One of the fundamental tenets of science is that a theory can never be proven to be absolutely true. A theory can, however, be declared absolutely false if it falls to stand up to testing. Similarly, it is impossible to demonstrate conclusively that a particular business strategy is optimal or even to guarantee that it will work. One can, nevertheless, test it for critical flaws. Of the many tests which could be justifiably applied to a business strategy, most will fit within one of these broad criteria:

• Consistency: The strategy must not present mutually inconsistent goals and policies.

• Consonance: The strategy must represent an adaptive response to the external environment and to the critical changes occurring within it.

• Advantage: The strategy must provide for the creation and/or maintenance of a competitive advantage in the selected area of activity.

• Feasibility: The strategy must neither overtax available resources nor create unsolvable sub problems.

A strategy that fails to meet one or more of these criteria is strongly suspect. It fails to perform at least one of the key functions that are necessary for the survival of the business.

Bournemouth University
Deploying Rapid Prototyping technology (DRPT) Strategy

<u>EVALUATION TOOL</u>

We appreciate your help in evaluating this strategy. Please indicate your rating of the strategy in the categories below by circling the appropriate number, using a scale of 1 Strongly Disagree through 5 strongly Agree with each of the aspects of the evaluation tool.

The strategy is internally consistent… Internal consistency refers to the cumulative impact of various strategies on the organizations.

Strongly Disagree				Strongly Agree
1	**2**	**3**	**4**	**5**

The strategy is externally consonance with its environment… An important test of strategy is whether the chosen strategy in consistent with environment (constituent demands, competition, economy, product / industry life cycle, suppliers, customers) - whether the really make sense with respect to what is going on outside.

Strongly Disagree				Strongly Agree
1	**2**	**3**	**4**	**5**

The strategy is appropriate in view of available resources… Resources are those things that company is or has and that help it to achieve its corporate objectives. Included are money, competence, facilities and other. Without appropriate resources, organization simply cannot make strategic work.

Strongly Disagree **Strongly Agree**

1 2 3 4 5

The strategy involves an acceptable degree of risk… Strategy and resources, taken together, determine the degree of risk which the company is undertaken. Each company must determine the amount of risk it wishes to incur. This is a critical managerial choice. In attempting to assess the degree of risk associated with a particular strategy, management must assess such issues as the total amount of resources a strategy requires, the proportion of the organization's resources that a strategy will consume, and the amount of time that must be committed.

Strongly Disagree **Strongly Agree**

1 2 3 4 5

The strategy has an appropriate time horizon… A significant part of every strategy is the time horizon on which it is based. For example, a new product developed, a plant put on stream, a degree of market penetration, become significant strategic objectives only if accomplished by a certain time. Management must ensure that the time necessary to implement the strategy is consistent. Inconsistency between these two variables can make it impossible to reach goals in a satisfactory way.

Strongly Disagree **Strongly Agree**

1 2 3 4 5

The strategy is workable…

Strongly Disagree **Strongly Agree**

1 2 3 4 5

The strategy is identifiable…

Strongly Disagree						**Strongly Agree**
	1	**2**	**3**	**4**	**5**	

The strategy constitutes a clear stimulus to organizational effort and commitment…

Strongly Disagree						**Strongly Agree**
	1	**2**	**3**	**4**	**5**	

There are early indications of the responsiveness of markets and market segments to the strategy…

Strongly Disagree **Strongly Agree**

1 2 3 4 5

The strategy relies on weakness or does anything to reduce them…

Strongly Disagree **Strongly Agree**

1 2 3 4 5

The strategy exploits major opportunities…

Strongly Disagree Strongly Agree

1 2 3 4 5

It avoids, reduces, or mitigates the major threats. If not, there are adequate contingency plans…

Strongly Disagree Strongly Agree

1 2 3 4 5

Further suggestions:

THANK YOU!