2 RESEARCH ISSUES

2.1 Introduction

Chapter 2 identifies and reviews the theoretical dimensions of CAPP and directly relevant disciplines and discovers research issues that are worth researching because they are controversial or are gaps that have not been previously answered (Figure 2.1).

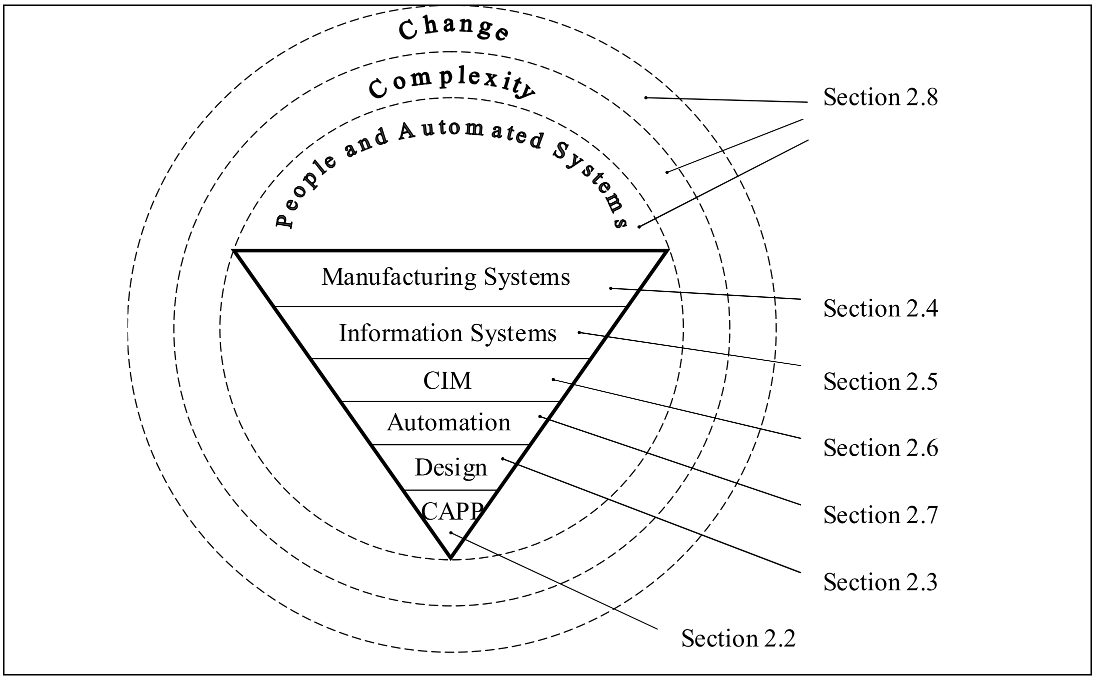

Figure 2.1 Main research problem and directly related disciplines

The chapter starts by defining the manufacturing process planning and CAPP system. Then, because a CAPP system cannot be developed in isolation, a number of related and relevant subjects are briefly surveyed, and finally the chapter will close with conclusions.

The chapter is about the extant literature, so the author's own ideas or opinions have no place in this chapter, except where they are used to structure the treatment of the literature and to create the theoretical framework which aims to show that various decisions are supported by authorities, evidence or logic.

2.2 Process Planning and CAPP Systems

Planning has been considered a multi-perspective problem solving process (Law et al, 2001), concerned with the generation of a set of steps required to reach a specific goal, within given constrains, while optimising some stated criteria (ElMaraghy, 1993). In this context, manufacturing process planning was defined as the transformation of detailed engineering drawing specifications into manufacturing operating instructions (Dorf and Kusiak, 1994) for an overall effective production (Kiritsis, 1995), or a technical activity that establishes the process and resources that transforms the raw material into the desired final part (Rozenfeld and Kerry, 1999) in a cost effective manner (Usher, 2003).

Process planning, documented into planning sheets or route plans (Craw, 1992), required many kinds of human abilities (Ciurana et al., 2003) with a scientific, engineering, and economics background (Kiritsis, 1995) manifested within a company’s limitations factors such as product configuration, available processes and equipment, prevalent culture, organisational structure, and technological systems (Rodd et al. 1992, Twigg 2002). Therefore, in conditions of process planners’ shortage (Zhang, 1994), CAPP, the umbrella term for process planning automated approaches (Hugh, 1994), has evolved and diversified to simplify and improve process planning and to achieve more effective use of manufacturing resources (ElMaraghy, 1993) (Figure 2.2).

As a result, CAPP research, an extremely varied subject area (Kuric and Janec, 1998) that spans over several other scientific and technological domains (Cay and Chassapis, 1997), has generated great interest and quite a lot controversy with its various approaches (Appendix B), implementation techniques, knowledge acquisition and representations (Appendix C), and attempts to identify the data that links design, CAPP, and manufacturing (Appendix D).

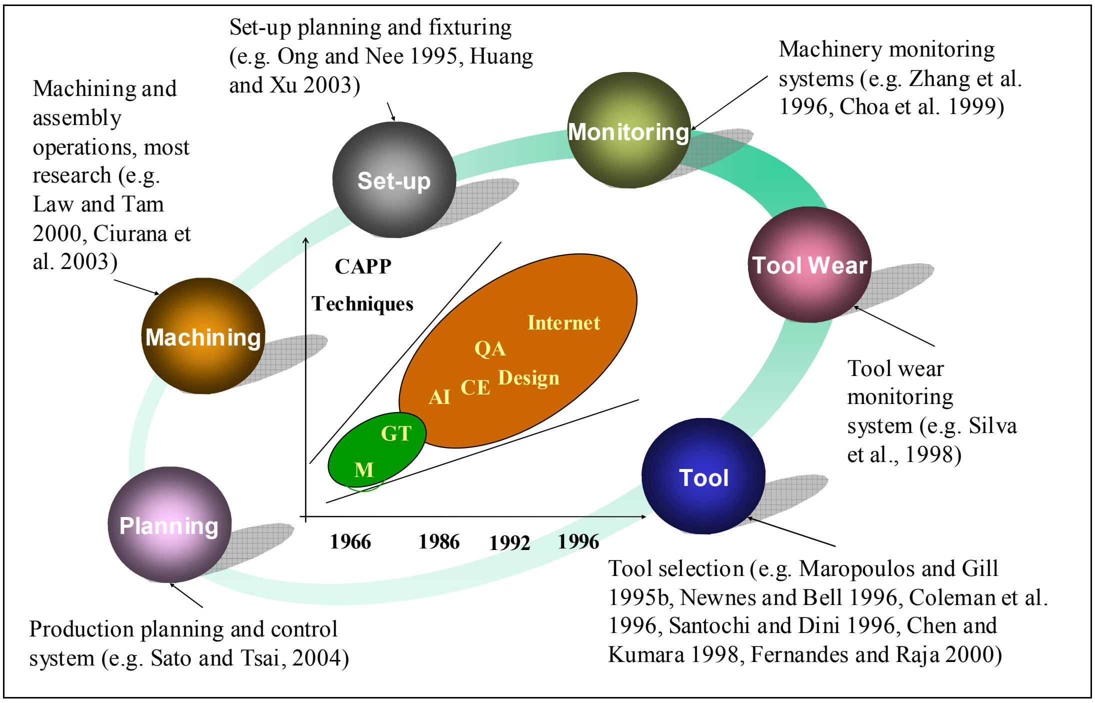

Figure 2.2 CAPP domains and techniques evolution and diversification ("M" Machining, "GT" Group Technology, "QA" Quality Assurance, "CE" Concurrent Engineering)

Also, since a CAPP software system was an artifact created by members of one culture on behalf of members of another culture (van Vliet, 2000), its development and implementation required a good understanding and balance of the actual problems faced by manufacturing organizations and the AI technologies.

This led to the following research question:

How to develop the architecture of a new CAPP software system that takes into consideration the specific application requirements, the enabling technologies, the existing company resources and culture, and also minimises the software development risks and time.

Therefore, to find the answer to this research question, the next sections will identify and review the inherently multidisciplinary directly relevant CAPP disciplines and the myriad ways in which they interact (Price, 1998) (Figure 2.1).

2.3 Engineering Drawing, CAPP System, and Manufacturing Processes

The importance of product design and processes to fabricate the products has been considered undeniable in establishing and maintaining a competitive position for most firms (Meziane 2000, Wang et al. 2002). Therefore, this section attempts to identify the data that links designs, manufacturing, and CAPP systems.

In this context, the evolution of part representation was regarded as a continuous interplay between what we want to achieve and how we want to achieve it (Liang and O'Grady, 1998), and also an attempt to a smooth transition from design to computer aided manufacturing (CAM). Consequently, the part representation evolved from wire modeling, to surface modeling, to solid modeling, and to feature modeling (Appendix E).

Out of these, the features and their role in product design and process planning have generated great interest, heated debate and quite a lot of controversy in recent years (Ciurana et al., 2003). Consequently, the meaning of the term feature has expanded to encompass a physical element of a part with engineering meaning (Rozenfeld and Kerry, 1999) as well as non-geometric job characteristics that can facilitate any form of computer-intelligent decision making (Kunigahalli, 1998). Features were considered the most suitable and promising representation technique for CAPP (Rozenfeld and Kerry 1999, Davies 1997) and possible to link CAD and CAPP (Tseng, 1999). With all these, despite two decades of research, the impact of features technology has been insignificant, and the results have rarely been transferred into industry (Kang et at., 2003). Features were considered still a bottleneck, cumbersome, and problematic process (Kang et at., 2003) because: the extensive geometric calculations and spatial reasoning on the design model led to different descriptions of the product (Martino et al., 1998); they were easy to use for simple parts, but extremely difficult for complex parts (Jain and Kumar, 1998); recognising and extracting even simple features was so complex that the complete realisation of a feature-based CAPP system was difficult to achieve without human intervention (Jang et al., 2003); and a representation nightmare awaits when geometry becomes the vehicle for representing and sharing other forms of engineering knowledge (AAAI, 1997).

At the same time, CAD systems, although recently augmented with tools such as constraint and feature representation, were considered still relying primarily on geometric data of a detailed geometry (Feng and Song, 2000b) that made the automated reasoning highly complex to implement (AAAI, 1997), and made the actual CAD systems inconvenient for most manufacturing applications, including design for manufacturability, cost estimation, and process planning that required a completely different type of information (Abdalla and Knight, 1994).

Consequently, it has been observed that CAPP feature recognition approaches have not been in accordance with CAPP's own requirements (Kang et at., 2003) because, CAD geometry used primitives such as points, lines, and circles, whilst CAPP systems tended to use feature such as faces, cylinders, and grooves (Zhao et al., 2002), consequently making the highly detailed, one by one, feature recognition a waste of time, cost, efficiency (Chang and Chang, 2000), and not necessary in process planning (McMahon et al., 1997). Additionally, most commercial CAD/CAM systems were only available at low level geometric definition which could be saved to create the NC code (Faraj, 2003), but they were not available at a high level of integration where the CAPP system used machining features with relevant technological information ((Zhao et al. 2002, Kang et at. 2003) and crucial for CAD/CAPP integration (Feng et al., 1999).

Also, it has been observed that, although the ability of actual CAPP systems to recognize design specification was still weak and a challenging research area (Feng et al. 1999, Feng and Song 2000b), and an experienced human planner used only important features (Chang and Chang, 2000), most academic research attempted to recognize very detailed design information (Feng et al. 1999, Chang and Chang 2000), which did not change the production routes (Maropoulos, 1995).

Furthermore, the engineering drawings were not only represented by geometry elements but also drafting symbols and text that provided the designer with an added flexibility in design (AAAI 1997, Kuric and Janec 1998), and also yielded enough input to determine many of the characteristics of the manufacturing process (Feng et al., 1999, Feng and Song, 2000a). In addition, the tolerance and surface finish data were considered not real attributes of CAD geometric model, but simply text representations on the drawing the same as technical notes (Kang et at., 2003), that made the actual CAD/CAM packages unable to interpret, analyse, calculate, or make decisions about the tolerance and surface finish information stored in them (Kumar and Roman, 1997).

Moreover, there was no accepted mathematically consistent way of representing tolerances (AAAI, 1997), which on the working piece were almost always dependent on the detailed knowledge of the machine operator (Whybrew and Britton, 1997) or established local practice (Esawi and Ashby, 1998). Besides, it has been established a direct relationship between the size tolerances and surface finish (Figure 2.3) that led to a simple methodology for tolerance transfer into surface roughness specifications (Kumar and Roman, 1997), and to the belief that at some time in the next 5 to 15 years, size tolerances and surface finish will be unified (Voelcker, 1997).

Hence, by simplifying the representation of the goals, the constraints, and the variables (Chung and Peng, 2004), the surface finish specifications could be used for the determination of process selection and operation sequencing (Kumar and Roman, 1997), considered the most critical activities of the process planning (Wong and Siu, 1995), and so build a direct link between the design, process planning and inspection models (Xu and Hinduja, 1997).

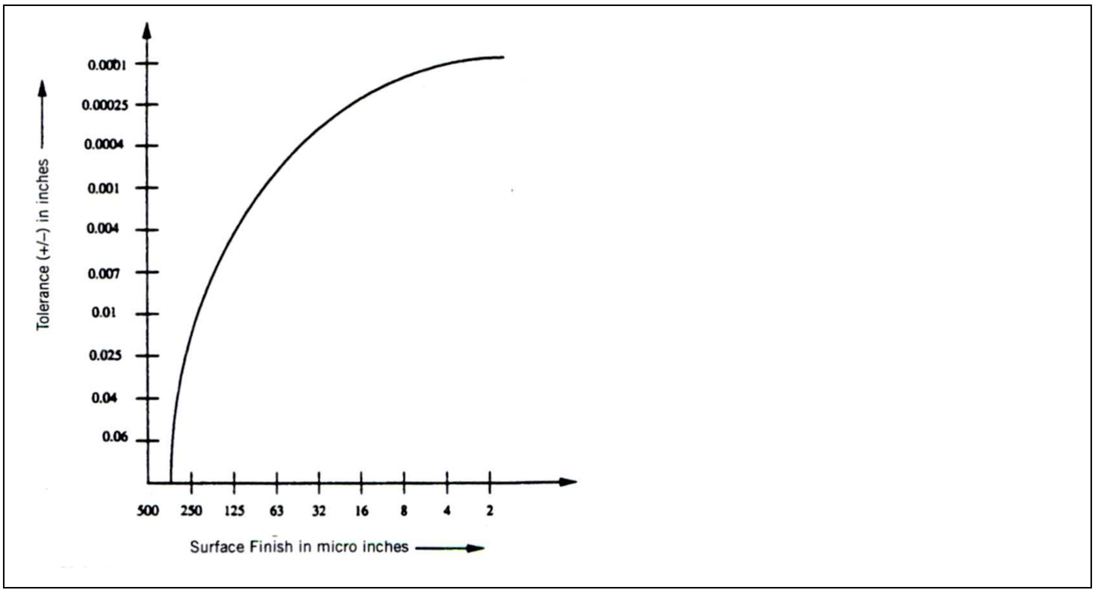

Figure 2.3 Tolerance and surface finish relationship (Kumar and Roman, 1997)

Consequently, there has been research that has suggested creating new CAD and CAPP models that should use critical design and manufacturing objects with information meaningful for CAPP system (OMG 1996, Davies 1997, Chep and Tricarico 1999, Chang and Chang 2000, Zhao et al. 2002, Yuen et al. 2003), consider their relationships ((Naish 1996, McMahon et al. 1997), and so, transform the actual CAPP systems almost completely isolated from the design (Cay and Chassapis 1997, Khoshnevis et al. 1999), and achieve integration (Abdalla and Knight 1994, Kang et at. 2003).

In conclusion to this section, the main reasons for the shortcoming in CAD/CAPP communication have been the methods used in design for product representation and the lack of accepted design and manufacturing standards. These shortcomings have affected CAPP development, which also has been hampered by the decades of research which attempted to recognise process planning data from a detailed engineering design.

This led to the:

First hypothesis: **A CAD system that uses common designs and manufacturing objects and preserves most of the actual design representations will enhance CAD/CAPP communication, and lead to the development and implementation of a better CAPP software system.**

2.4 Manufacturing System (MS)

MS has been defined as a large complex system (Wang et al., 2002) consisting of a collection of many issues such as people, equipment, continuous and batch operations with incomplete and/or excessive data (Rodd et al., 1992), and flows of information and a decision-making processes (Scallan, 2003), organized to accomplish the manufacturing operations of a company (Groover, 2001). In this context, the manufacture of discrete parts, mainly machining processes (Wright 2001, DeGarmo et al. 2003), had always generated the need for the development and introduction of new computer-based applications (Maropoulos, 1995).

Also, because MS has been characterised by a deep organisational hierarchy and excessive specialisation (Brandon, 1993) that affected their integration (Lee, 2003), a number of generic models to describe MS have been proposed. But, the high-level, top-down model, such as CIM-OSA (Computer Integrated Manufacturing - Open System Architecture) (Ho et al. 2000, OMG 1996), was difficult to map onto manufacturing resources (Edwards et al., 1998), the bottom-up model failed to accurately reflect the business needs (Edwards et al., 1998), and the new approaches such as bionic, holonic, and fractal manufacturing systems (FrMS) (Figure 2.4) considered as potential candidates for the next generation of manufacturing systems (Shin 1998, Toh and Harding 1999), were difficult to implement (Ryu and Jung 2003).

Therefore, in order to cope with changing circumstances and increase their competitiveness, manufacturing enterprises have applied forms of hard and soft technically demanding tasks (Bullinger et al., 1998) that required the right technology and infrastructure (Ünver and Anlagan, 2002), and a number of manufacturing concepts (Figure 2.5).

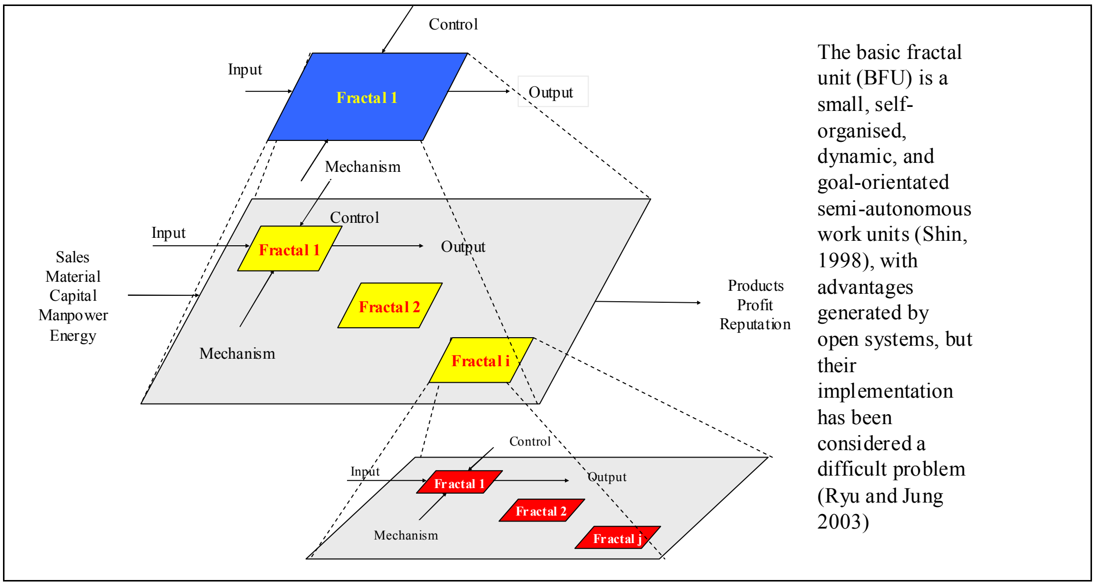

Figure 2.4 Hierarchical structure of the FrMS has been used to represent any level in the company hierarchy (Ryu and Jung 2003) including the human employee (Toh and Harding, 1999).

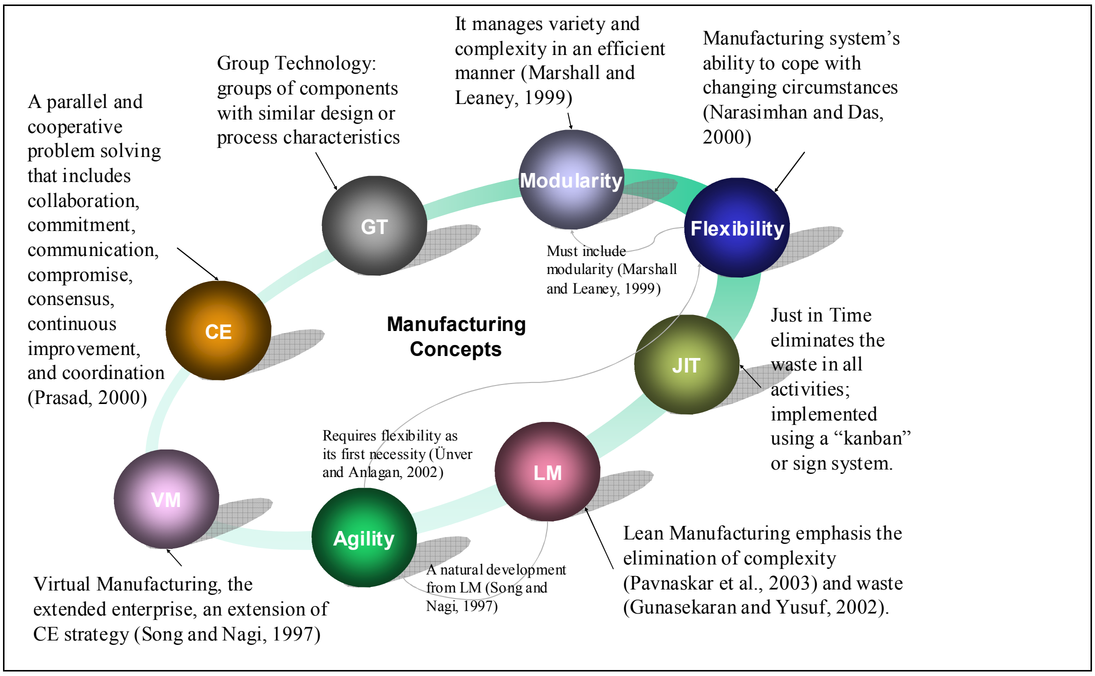

Figure 2.5 Manufacturing concepts

With all these, for example, Concurrent Engineering (CE) was considered a very difficult task due to lack of sub-systems to support cooperative decision making activities and reason about a common product model (Abdalla and Knight 1994, OMG 1996, Han and Requicha 1998), with the link between CAD and CAPP viewed as one of the most difficult tasks (Ahmad et al., 2001)

Consequently, because MS were characterised as an integrated set of sub-systems built around the main functions of the organization and linked according to the material processing (Scallan, 2003), it was suggested that, new research must focus on: the identification of the basic organisational entities and activities that consume company's resources (Walsh et al., 2003); look beyond advanced manufacturing systems to alternative methods of delivering flexibility such as options to make, buy, or out-source solutions (Prasad, 2000); create modular, flexible, configurable processes and working practices (Narasimhan and Das 2000, Joo et al. 2001, Sanchez 2002); adopt a process-based approach (ISO 9001:2000) and build systems around their different levels to keep them efficient and lean (Gingele et al., 2003); adopt heterarchical systems as alternatives to hierarchical company's architecture (Ünver and Anlagan, 2002); and integrate people and technologies into meaningful and highly responsive units (Gupta et al., 1996).

These led to the observation that, over the years, CAPP development was not only hampered by various aspects such as manufacturing enterprise architecture and its characteristics, but also held back by its own non-alignment with the new manufacturing enterprise architectures, concepts, and technologies.

This led to the:

Second hypothesis, Iteration 1[*]: **Better alignment of the architecture of a new CAPP software system with the organizational structure of the engineering company, its characteristics, manufacturing concepts used in practice, and the new technologies, will lead to the development and implementation of a better CAPP software system.**

2.5 Information Systems

The manufacturing enterprise used the information, information systems, and Information Technology (IT) infrastructure to support its business processes. Information, defined as any data or knowledge, acquired or supplied, and necessary for an activity (Pavnaskar et al., 2003), was used by the information systems to interconnect and integrate manufacturing process equipments with other systems (Kusiak, 2000) and support the manufacturing enterprise functions (Wang et al., 2002).

In order to better link the information structures to the operations of the enterprise (Toh and Harding, 1999), the IT infrastructure, defined as a set of IT resources and organisational capabilities, evolved towards being process-centric which is based on what an organisation does (Liu, 2002) (Figure 2.6).

Therefore, the new information systems should be designed to: support and suit business practices (Song and Nagi, 1997); remove irrelevant and redundant information (Yeh and Fisher, 1991); divide complex information and provide only the amount of information needed according to manufacturing processes (Ho et al.,

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[*] Similar with the RUP iterative and risk-driven software development process model, the hypothesis is developed as the literature survey of CAPP's directly relevant disciplines progresses. The process provides a smooth transition between various disciplines because in hypothesis development the reiteration of different aspects occurs, changes had to be incorporated, errors had to be corrected, and the quality for both the development process and the resulting hypothesis had to be assessed.

2000); and have a modular and hybrid structure to reduce application complexity and lower application development (Prasad 2000, HMS 2002).

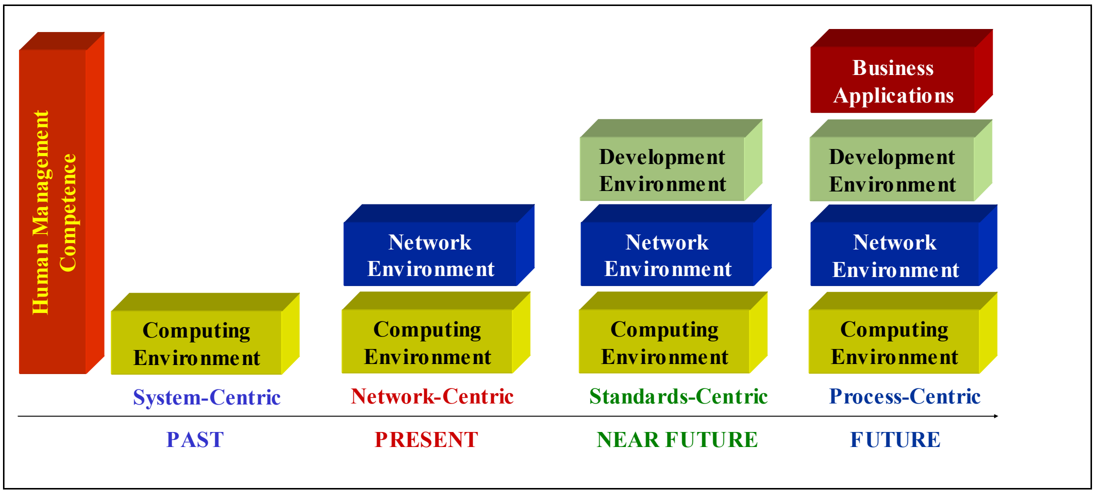

Figure 2.6 IT infrastructure trends (Liu, 2002 - reorganised)

In this context CAPP, with its rich manufacturing data that support business processes, and critically close to the information technology (Luo et al., 1997), was considered a promising way for the integration of design and production, and in general of the whole lifecycle of a product (Song and Nagi, 1997) (Figure 2.7).

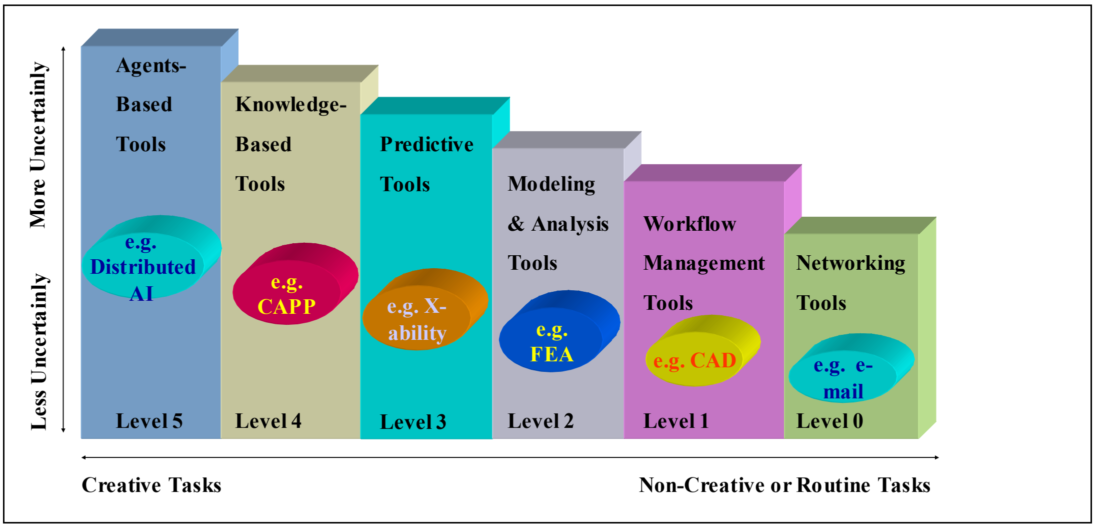

Figure 2.7 Computerised tool classification (Prasad, 2000 - reorganised)

This led to the:

Second hypothesis, Iteration 2: **Better alignment of the architecture of a new modular CAPP software system with the organizational structure of the engineering company, its characteristics, manufacturing concepts used in practice, new technologies, business practices, manufacturing processes, the need for information, and the new trends in IT infrastructure, will lead to the development and implementation of a better CAPP software system.**

2.6 Computer Integrated Manufacturing (CIM)

Manufacturing was considered information and knowledge intensive (Prasad, 2000), therefore, the motivation behind CIM development, described as a comprehensive measure of computerised integration and information sharing (Sun, 2000), or a superimposition of an information system and decision support system over the manufacturing infrastructure, facilities, products, and material flows (Zhang, 2001) in order to coordinate the production activities (Liu et al., 1998) and improve company's operational performance (Love and Barton, 1996).

CIM, that carried the concept of CE to the scale of the whole company (Wright, 2001), has faced important organisational, technical, and social shortcomings. For example, CIM was considered unsuitable for small business server-based applications (Volchkov, 2002); its hierarchical control was too inflexible for small production batches in a dynamically changing environment (Davies, 1997); and not flexible in reconfiguring the shop layout (Ryu and Jung, 2003). As a result of these shortcomings, CIM was merely applied to integration of data, communication, and processes (Prasad, 2000), and a fully computerised integration in the manufacturing system was considered unlikely to be the main model in the near future (Sun, 2000).

Therefore, over the years, the idealistic vision about a fully integrated company was changed to a more moderate view in line with the company's real circumstances and available equipment (Cubonova and Kumicakova 1998, Sun 2000).

Consequently, the new information systems should consider company's real individual condition along with the various enabling technologies (Toh and Harding, 1999); transform CAD from a design tool to a data exchange tool (Prasad, 2000); consider the system architecture a model to simplify the information complexity (Lo and Lin, 1999); handle the knowledge, the communication between different categories of data including CAD and CAPP (Prasad, 2000), and the extended enterprise (Brissaud, 2002); move from a "technology push" situation to a "requirement pull situation", which represents the move from CIM to Intelligent Manufacturing Systems (IMS) (Iung et al., 2001), and so, design information systems to suit business practice (Song and Nagi, 1997).

Finally, although CAPP was still a bottleneck in the whole CIM system (Yan et al., 2001), it was considered an effective, fundamental, and increasingly crucial agent for achieving the desired seamless integration between the various modules in a CIM environment (Davies 1997, Ming et al. 1999, Yan et al. 2001, Kang et at. 2003, Kumara and Rajotia 2003), and a living artifact whose primary concern of how to automate the process plans shifted toward its integration with design, shop floor control, and business functions (ElMaraghy, 1993).

This led to the:

Third hypothesis, Iteration 1: **Simplifying information complexity and the inclusion of CAD, CAPP, and other categories of data in the communication part of CIM will lead to the development and implementation of a better CAPP software system.**

2.7 Automation

Automation, defined as the technology concerned with the application of mechanical, electrical, and computer-based systems, aimed to reduce the amount of manual and clerical effort in production (Groover, 2001). Also, situations in which manual labour was usually preferred over automation include customised products with short life cycle, and tasks too technological to automate. Therefore, it was considered essential to understand the fundamental philosophies of the improvement journey (Hollingum, 1999), and apply a number of automation principles and strategies to find ways to avoid, or at least to mitigate, the spiralling complexity, and therefore making humans and automata real partners with shared goals and a mutual understanding of each other's capabilities and limitations (Wildberger, 2000). In this context, the Understand, Simplify, Automate (USA) principle was considered so general that nearly any automation project could apply it (Groover, 2001) because, understanding the details of the existing process may in fact reveal that simplifying the process is sufficient and automation is not necessary.

Finally, in manufacturing automation, which must not be associated only with the individual production machines, wider issues should be considered such as product design, CAPP, production control, and education and training. Therefore, the long implementation time required to build the knowledge base of a CAPP systems could be avoided by considering a lower degree of CAPP automation in the early stages (Rozenfeld and Kerry, 1999), and increase the level of its automation by following the organisational improvements in the company.

This led to the:

Third hypothesis, iteration 2 (final): **Simplifying information complexity, use of automation principles and strategies, and the inclusion of CAD, CAPP, and other categories of data in the communication part of CIM will lead to the development and implementation of a better CAPP software system.**

2.8 People and Automated Systems, Complexity, and Change

Human-automation interaction has entailed a great deal of new important research (Shafto and Hoffman, 2002). Automated production machinery and systems have improved productivity and increased manufacturing accuracy, but many times the anticipated increase in flexibility and adaptability did not materialise (ElMaraghy, 1993). Consequently, direct relationships have been noticed among requirements of the new manufacturing paradigms (Figure 2.8), computerised automation systems, and people which should use these systems.

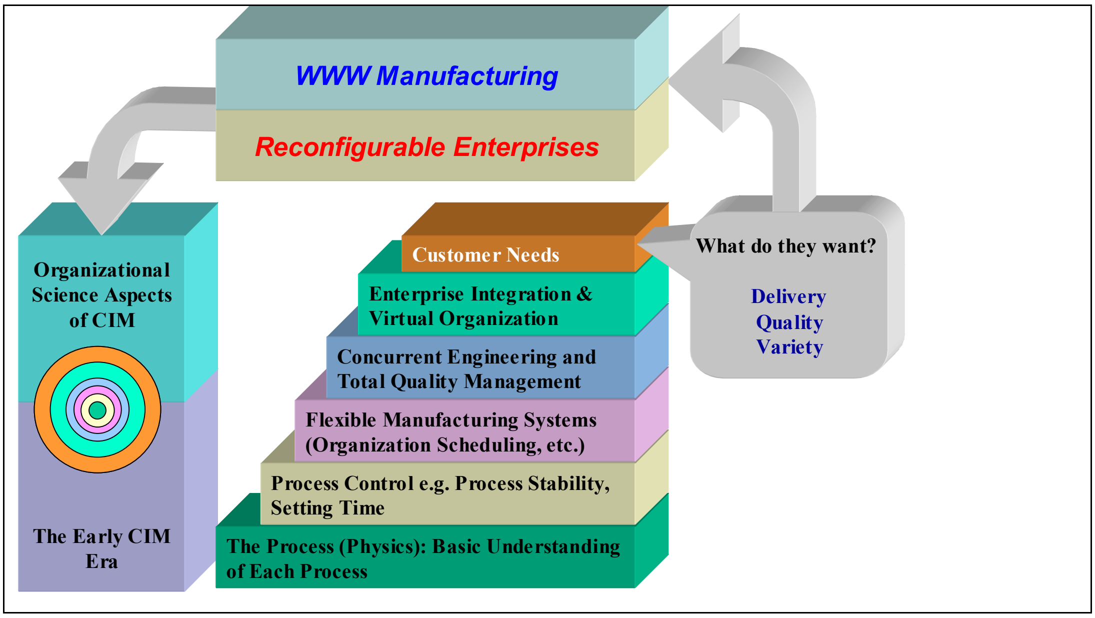

Figure 2.8 Major paradigms in manufacturing and their accumulated list of system characteristics that built upon each other, challenged the limits of traditional engineering approaches, and drew the attention to the need for new approaches

For example, people, the economy's most important asset (Shin, 1998), usually and fundamentally used only a few simple tools to create, understand, or manage complex systems in real life (Budd, 2001). With all these, because the actual professional fields were considered complex and no one can learn about them rapidly (Budd, 2001), the people pursued system features and performance and, in this way, pushed the technology envelope and stretched the limits of their own understanding (Sha, 2001). Sometimes, even when there was no solution to the problem as formally stated (Freuder and Wallace, 2000), people attempted to develop complex systems, usually a consequence of unnecessary requirements (Szyperski et al., 2002), due to the belief that complex systems require complex control systems to manage them (Morley, 1998).

In this context, new concepts suggested to use the wisdom of simplicity in order to control complexity (Morley 1998, Sha 2001, Budd 2001); separate critical requirements from desirable properties (Sha, 2001); find some solution by relaxing some constraints (Freuder and Wallace, 2000); and replace the problem of global optimality in favour of the more realistic goals that decompose the complex problem into smaller more manageable sub-problems (Kochikar and Narendran 1998, Lo and Lin 1999). As co-operation was the philosophy behind agile manufacturing strategy (Song and Nagi, 1997), these sub-systems capable of learning, adapting, optimisation, and reconfiguration (Wang et al., 2002), and developed at every level of the organisation (Kim, 1999), should demonstrate their collective intelligence by following simple rules that could create a new system which is robust, easily computable, adaptable, and probably more intelligent than the sum of its parts (Morley, 1998).

Furthermore, the new carefully crafted computational approaches (Kusiak, 2000) should be based on an understanding of how people learn and use their past experience (Bomba, 1998) and so, determine how people, machines, and information technology can work together beneficially (Shin, 1998) and collectively at various stages of the product development (Shen and Norrie, 1999).

Therefore, to have a realistic approach, the new software solutions should be viewed as vehicles to assist in achieving various manufacturing goals rather than to replace humans (Sreeram and Chawdhry, 1999) which, irrespective of the degree of automation and computerization, should be the focus, and explicitly incorporated as components at the system design stage (Kusiak, 2000).

Finally, with complexity, considered a notion of inherent difficulty of a problem, a solution, or an approach (Szyperski et al., 2002), and with no single formalism, technique, or tool capable of generating useful decisions in a modern enterprise (Kusiak, 2000), unless the human factor is included, the representation of any collaborative systems will be unrealistic and not useful for manufacturing (Shin,

1998). Therefore, the human planner should be considered still irreplaceable (Kryssanov et al., 1998) and a critical component (Shin, 1998).
This led to the:

Second hypothesis, iteration 3 (final): **Decomposing CAPP's complex problems into smaller more manageable sub-problems, keeping human in the systems loop, and better alignment of the architecture of a new modular CAPP software system with the organizational structure of the engineering company, its characteristics, manufacturing concepts used in practice, new technologies, business practices, manufacturing processes, the need for information, and the new trends in the IT infrastructure, will lead to the development and implementation of a better aggregate CAPP software system.**

2.9 Conclusions

The chapter made the attempt for a new contribution in its own rights through novel insights derived from the research literature. Although the focus of this chapter was on the issues of CAPP systems, there have been also considered complex, multifaceted, and cross-disciplinary directly related disciplines worth researching not only to better understand CAPP environment, but also to develop an integrated planning and risk managed methodology capable to deliver a robust solution to a new practical oriented CAPP software system. Also, at this point in the thesis, the reader will have some appreciation for the challenges facing development of a new CAPP software system and comprehend the environments it operates. Finally, based on the theoretical framework and the hypothesis and research question developed throughout the chapter (Figure 2.9), the next chapter will describe the major methodologies used to answer these hypotheses and research questions.

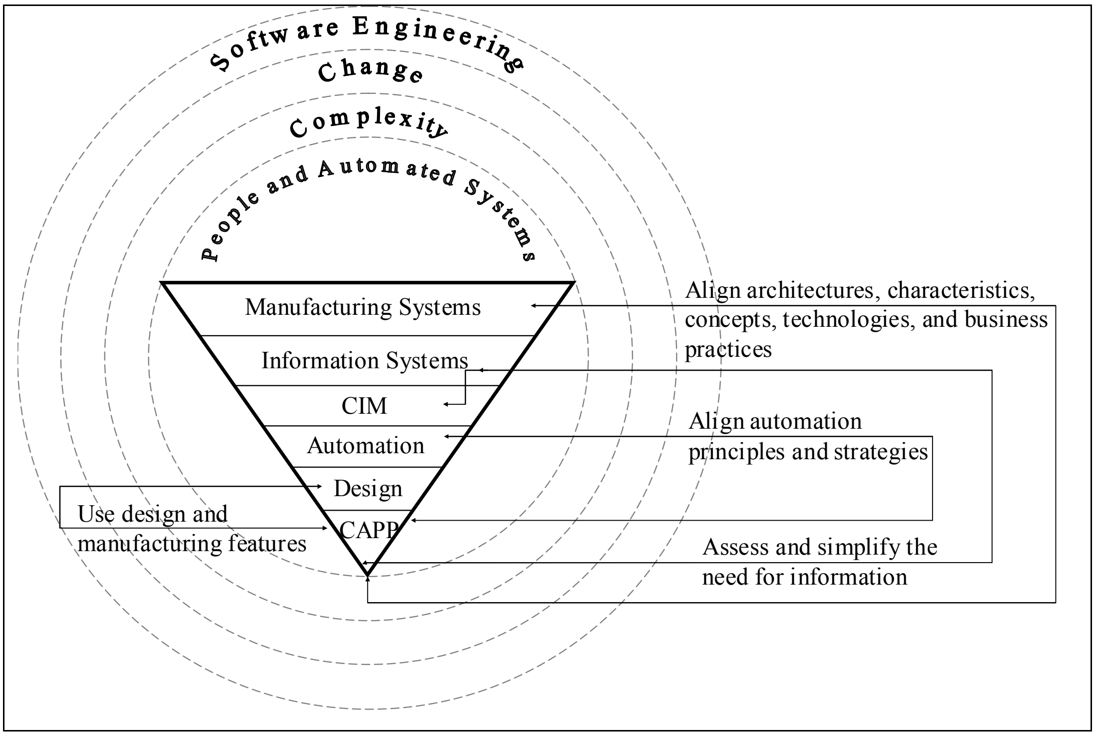

Figure 2.9 Main research problem, relationships, and directions for action