Cost Risk Management for a Small to Medium-sized Enterprise in the Cladding Industry

QAQISH, TAMER,AYOUB

Durham University

School of Engineering &

Computing Sciences

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Tamer A. Qaqish

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Abstract

To research the management of risk and cost in the cladding industry, this work has evaluated current practice and deficiencies, concentrating on the lack of integration or standardisation resulting in inaccurate cost estimates, unacceptable risks and loss of profit in cladding manufacture. The research presents an approach for integrating process- and technology-orientated improvements into a knowledge-based model to improve a cladding manufacturing SME's performance. The research also presents a management method for the selection, integration, control and implementation of this approach. Controlling data transfer between systems produces a knowledge-based model, allowing cladding industry designers and estimators to take more accurate decisions, with the objective of reducing risk and improving company profitability. This model, with the addition of external supply chain elements, is a management framework, which can be termed an agile manufacturing system.

The development of this framework has raised the following data certainty questions:

- What is the measured uncertainty of that data?
- How can the industry control and structure high data volumes transferred between systems to produce more accurate cost models?

The answers to these questions were found by applying a structured methodology for the selection, integration and control of technology in the cladding industry, but involving the human factor. In this approach, the principle of entropy was adopted to measure data uncertainty. The structured methodology was made possible by a new categorisation into Innovative, Standard and Semi-Standard cladding projects.

The research applied this structured methodology, combining qualitative and quantitative methods for validating assumptions, to a cladding industry SME case-study. The case-study investigated the validity of real cost and project data and calculated data uncertainty for specific projects, categorised as described, using a risk factor percentage predicted on entropy principles, based on historical data fed back from the SME's ERP system. This risk factor approach was similar to that previously used in the insurance and banking industries. The risk percentage formulae used were based on assumptions extracted from qualitative and quantitative methods applied to the SME, its partner companies and industry specialists. Assumptions about the gross margins for UK metal cladding projects formed part of the risk percentage formulae.

The results of this case-study found that gross margins varied from 5% in standard projects to 40% in the Innovative projects. An entropy scale was proposed as a basis for comparing risk calculation results, with the highest entropy equalling 100%, signifying the highest risk possible. It was found that risk rises in the case-study were from 23% for Standard to 93% for Innovative projects.

This principle of a risk factor percentage was tested in the UK cladding manufacturer SME case-study and its value to the SME was demonstrated.

List of Contents

REFERENCES 165

List of Figures

List of Tables

List of Abbreviations

AMS	Agile Manufacturing System
BOM	Bill of Materials
CAD	Computer Aided Design
CAM	Computer Aided Manufacture
CAE	Computer Aided Engineering
CIM	Computer Integrated Manufacturing
CNC	Computer Numerical Control
CPD	Collaborative Product Design
CRM	Customer Relationship Management
DTI	Department of Trade & Industry - Now Department for Business, Innovation & Skills (BIS)
CWCT	Centre for Window and Cladding Technology
DWG	Drawing format for AutoCAD and associated CAD software
ERP	Enterprise Resource Planning
FBC	Feature-Based Costing
HR	Human Resources
JIT	Just-in-Time
KM	Knowledge Management
KTP	Knowledge Transfer Partnership
KPI	Key Performance Indicator
MRP	Materials Requirements Planning
MRPII	Manufacturing Resource Planning
NN	Neural Networks
PDM	Product Data Management
PLM	Product or Project Lifecycle Management
PSP	Pressed Steel Products Ltd
SME	Small to Medium-Sized Enterprise
TQM	Total Quality Management
UK	United Kingdom
WIP	Work in Progress

List of Software & Technologies

Company	Software	Main Function
Autodesk	AutoCAD	2D Computer Aided Design Software
Autodesk	Inventor	3D Computer Aided Design/Solid Modelling Software
Epicor	Vantage	Business Management Solutions Software
Microsoft	Microsoft .net	Software Framework
Microsoft	Access	Database Software
Microsoft	Excel	Spreadsheet Software
Price Systems LLC	PRICE	Cost Estimation Software
Planit Software	RADAN	Sheet Metal Computer Aided Manufacturing Software
SAP	SAP	Enterprise Resource Planning Software
Dassault Systems	SolidWorks	3D Computer Aided Design/Solid Modelling Software

Statement of Copyright

Declaration

I confirm that no part of the materials offered in this Thesis has previously been submitted by me for a degree in this or any other university and presents entirely my own work, except where appropriately acknowledged citations are given. Where material was generated through joint work, my independent contribution was clearly indicated.

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As ever, the real and deepest thanks are due to the author's parents, who have borne the brunt of the travails over the years and endured the inevitable pressures, doing so in a caring way and loving manner. Their support remains the indispensable foundation of this work.

Dedication

This Thesis is dedicated to the author’s grandparents and aunt (Mr. Ibrahim Qaqish, Mr. Kamal Ayoub, Ms. Jameleh Qaqish, Ms. Wardeh Ayoub and Ms. Mary Ayoub).

1 INTRODUCTION

1.1 General

A changing and competitive manufacturing marketplace in the United Kingdom (UK) has resulted from a decline in UK manufacturing compared to European and Asian manufacturing industries. In contrast, the UK construction sector has experienced rapid growth due to the development of factory–built, pre-fabricated cladding products combined with a high demand for modern aesthetically-pleasing buildings. The complexity and variety of manufacturing processes in the cladding industry has increased to reflect the variety of new building materials and the unique aesthetic requirements of each customer. As a result, construction companies have started to adopt various techniques to improve their control over these processes. Some techniques, including lean manufacturing, kaizen, total quality management systems, supply chain management and business process re-engineering, target management operations process improvement are process-orientated. Other techniques target the technology that automates business and manufacturing processes and are considered technology-orientated [1.1]. This Thesis contributes a methodology for risk mitigation and cost management that adopts a mixed approach involving both process and technology-focused techniques. The aim was to produce a strategic management method that can control costs in a small to medium-sized enterprise (SME) in the UK cladding industry.

It is widely accepted that the ability of a company to compete effectively in an increasingly competitive global market is predominantly influenced by cost, but also the quality of the products and the ability of the producer to bring them onto the market in a timely manner are important [1.2]. In order to control costs and improve the internal activities and processes integrated costing and Agile Manufacturing Systems (AMS) have been developed and successfully introduced by automotive companies such as Nissan and Toyota [1.3].

Decisions regarding product costs are often informed by process-orientated techniques operating on top of advanced information systems. For example Enterprise Resource Planning (ERP) is capable of collecting, analysing and distributing data within a company and even amalgamating the results from different supplier companies [1.4]. On the other hand, technology-orientated techniques are applied to the management and the implementation of technology for design, finance, production and sales of the product throughout its life-cycle [1.2].

A novel method for the implementation and integration of these process- and technology-orientated techniques to allow an SME to improve its response to the highly competitive pressures of the current market is the subject of this Thesis. The research concentrated on the supply chain, cost management, cost estimating and technology integration strategy for an SME in the cladding sector; especially the relationship between the manufacturing, fabrication and design facilities and the architectural demands of modern buildings.

In cladding manufacture the design architect has the overall design role for the building, referred to as “the architect”, the cladding designer has the role of designing the specific cladding components, referred to as “the designer”, the cladding estimator has the role of calculating for the cladding manufacturer the cost of manufacturing those components, and is referred to as “the estimator”.

The cladding of a modern building is a critical and expensive part of the construction process and has a large effect on the aesthetic appearance of the finished product. Many major buildings are not completed on time or budget, due to a lack of understanding of the complex supply chain involved in processing modern building materials and the cladding in particular. The design and procurement of the cladding can make a significant contribution to these delays and yet the cladding is important to the aesthetic impact of the building. This Thesis focuses on methods to allow a cladding manufacturer to produce an aesthetically pleasing product at a reasonable cost but still deliver a good margin to the supplier and meet customer requirements for on-time delivery and reliable quality.

Most previous researchers in this area have concentrated on understanding the cladding supply chain and inter-company processes of the industry to develop standardised methods for controlling and managing the cladding procurement procedure [1.6]. This Thesis instead concentrates on analysing potential discontinuities in the supply chain processes associated with data management and the costing of construction projects, specifically those with a high and aesthetically important cladding content. A particular aspect of the research was to understand the impact on the supply chain of unrealistic cost estimates during the early architectural design phase of a cladding project. In response this Thesis develops an Agile Manufacturing System to cope with rapidly and continuously changing demands on a cladding supplier. It has developed an understanding of the interaction between the information systems of different parties in the supply chain. This allowed the development of an agile system for the design and manufacture of the cladding product able to satisfy this demanding sector of the construction market. The research also identified the features that a prospective technology-focused system must contain. The main aim of the system must be to allow the designer, manufacturer and installer to achieve a cost-effective balance between aesthetics, function and cost of the cladding product in this market.

The methodology developed concentrates on the development of a knowledge-based manufacturing system, based on computer integrated design tools, to allow cladding manufacturers to manage cost and processes associated more effectively. The system will consider the product cost throughout the product life-cycle, where cost should be controlled in the early design stages, through production and finally in during the cladding installation stage. The methodology contributes towards integrating information tools and techniques such as cost management, Product Data Management (PDM), computer aided design (CAD) and computer integrated manufacturing (CIM). Actual data from the industry was collected in order to understand the different qualitative and quantitative methods used. The data was analysed to identify the critical factors that can affect the uncertainty or entropy of the total product data. These methods and the results from the analysis were applied in the form of a case-study, based on PSP Architectural Ltd at Shildon, County Durham, a manufacturer specialising in sheet metal and architectural system fabrication for the cladding industry. It is an SME with less than 70 employees and turnover in 2008 of around £5 million. It is aiming to be a high growth, high value added SME and has a flat management structure. PSP took part in a Knowledge Transfer Partnership (KTP) scheme with Durham University and the author commenced this work as a KTP Associate with PSP in 2002. The author is now Operations Director of PSP and has completed this Thesis as a part-time student at the same time as implementing the ideas in his operational role in the company. Extensive use of PSP case-study material was made in this Thesis.

1.2 The UK Cladding Manufacturing Industry

The cladding sector in the UK is under pressure to deliver better quality innovative products, cope with rapid changes in construction market demand and at the same time make improvements to its processes. The UK construction industry has grown and changed over the past few years accounting for over £100 Bn worth of output in the year 2008-2009 [1.7]. This growth is due to increases in population, building quality, availability of factory-built components for buildings and building design requirements, which affect the quality and the aesthetic impact of building for investors, developers and users. The metal cladding sector is small in comparison with the total construction sector and the total cladding material supplied to the construction market. The three main elements of the cladding industry are:

- Curtain walling;
- Metal composite cladding;
- Rain screen cladding.

The percentage of the rain screen market share in comparison with the curtain walling and metal composite cladding is small. This is due to the highly aesthetic, low volume market that rain screen is targeted at, in comparison with the industrial high volume market for metal composite panel and curtain walling systems. The change in the market in the last 20 years has demanded that cladding manufacturers invest heavily in product development to cope with the market demands. But with the heavy competition in the market the cost of the final product is vital to succeed within the supply chain.

The issues in the UK's cladding manufacturing industry relevant to an SME have been highlighted in a number of reports indicating that the industry should review its business processes to become more efficient and deliver on-time within budget. The studies suggest that the UK cladding sector is inefficient and lacks the capacity to compete effectively in the growing global market [1.6]. Some of the main factors affecting the efficiency of the sector are:

- Lack of integration of information regarding design, manufacturing, installation and rework and the loss of data generated
- Lack of standardisation in technology implementation and integration strategies which allow all parties to share valuable information through the sector

The use of communication and information technologies is creating new opportunities for the cladding sector to exchange information between all the organisations that are working on a construction project. The industry has started to set specifications that allow it to collect, process, store, retrieve and share information between individual parties and members. These specifications can support the planning, control and decision-making within the project organisation [1.6].

It is important to understand and model the cladding sector supply chain from end-to-end and across the complete range of products as a means to improve understanding of current practice and to identifying the processes that need to be considered for development; however, this Thesis has specifically limited its scope to a case-study based on the design and development of rainscreen systems to prove the concept [1.9].

From an architectural perspective, this Thesis demonstrates the different external and internal factors that influence more aesthetic building design. From an organisational perspective, the focus is on the interrelation between factors such as:

- Information system implementation and integration
- Knowledge capture and cost analysis
- Manufacturing performance and improvements

1.3 Aesthetics of Modern Building Design

1.3.1 Building Cladding

Cladding is the generic term for the external envelope or skin of a building which is non-load-bearing. Its function is to keep out the weather but equally to provide the building aesthetic [1.6].

Due to architectural demand, developments in products, methods and regulations, the cladding sector is currently undergoing change in order to respond to today's building needs. Until a few years ago, the majority of buildings were designed with flat and perpendicular claddings and there was a clear distinction between different building elements, such as glazing, pre-fabricated concrete and metal panels systems, as can be seen in Figure 1.1. This allowed the architects to work with specialist manufacturers from each discipline and develop the cladding by integrating the different elements.

Figure 1.1 - Durham University, 1965, building with flat, distinct prefabricated concrete cladding components

Cladding systems appropriate for buildings of a traditional rectangular form do not necessarily lend themselves to more artistic cladding designs. Nowadays claddings may not necessarily be flat or perpendicular, as shown in Figure 1.2. Customers and developers demand buildings of a higher aesthetic standard and require a more integrated approach to design and manufacture the complex architectural component.

Figure 1.2 - Leeds University 2005, showing the impact of aesthetics using curved metal sheet cladding on a building design, this project was manufactured by PSP Architectural Ltd., see Appendix A.

An example of a recent building project, as shown below in Figure 1.3, shows a design with curved cladding, with different colours. In the case of a cladding with more complex shapes, more flexible approaches should be considered for the design and manufacturing of its different elements.

In recent years modular, unitised or pre-fabricated cladding solutions have become more common due to improved off-site production. Pre-fabrication of these products consists of the manufacture of building parts or even complete buildings using various components especially engineered to fit into the building [2.3]. Usually pre-fabricated cladding modules is manufactured and transferred to site in modules to fit the building. Most of the fabrication and pre-installation can be achieved in the factory where modules are produced according to the architect's detailed designs produced by the project contractor.

Figure 1.3 - Durham University, 2009 building, with curved, differently coloured metal cladding

1.3.2 Example of a Modern Architectural Landmark

In December 2004 the Sage Gateshead was opened to the public as a landmark building on Tyneside, forming the heart of an exciting project to redevelop the area's river frontage [1.10]. The £70 million building is a home for live music and is made up of two concert halls and a performance space. The spectacular concourse of the building has river views of the Tyne and is a viewpoint for the Millennium Bridge, the Baltic Centre for Contemporary Art and the Newcastle/Gateshead Quays. The building was designed by Norman Foster and Partners and represents a highly aesthetic modern building using curved cladding and glazing.

Figure 1.4 - The Sage Gateshead, 2004, designed by Norman Foster and Partners

The total steel work used in the building weighs 3858 tonnes. The spectacular curved steel roof, weighing 750 tonnes, is made from 3,000 stainless steel and 250 glass cladding panels. If the roof were laid flat, its 12,000 m^2 area would be big enough to accommodate two football pitches. Most of the structural steel is hidden from view in the foundations and the reinforcing of the walls and floors, see Figure 1.5 & Figure 1.6.

The building was built in two main stages. Firstly the main structure, or base, that represents the concert hall and performance space function, as seen in Figure 1.5 and then the main building cladding, which represents the building aesthetic was added, as shown in Figure 1.6.

Figure 1.5 - Building structure of the main concert hall for the Sage building

Figure 1.6 - Frame of the outer skin of the sage building, on which cladding is mounted surrounding the concert halls

The Sage project demonstrates an extreme of the latest architectural demand for aesthetic buildings with aesthetic cladding, where the mix between the building function and building aesthetic make it a challenge for the cladding contractor and the building has become an important landmark for the North East of England.

In the past building function was the most potent factor affecting building design, nowadays, however, designers are looking to the external cladding aesthetic to be the most important factor [1.11]. The fact that every new landmark building has to look unique has challenged the cladding industry to consider the implementation of AMS and to improve on its lack of integration.

1.4 Research Objectives

The main objectives of the research were:

- To study the consequences of aesthetic design choices of architects of modern buildings on cladding manufacturing SMEs
- To study the cladding sector and identify potential gaps in knowledge and failings in current processes that affect the performance of the industry
- To develop and present different tools and techniques that can be adopted by the cladding sector to integrate internal and external information systems to allow the industry to close these potential gaps
- To develop state-of-the-art methods and techniques suitable for SMEs to allow cladding manufacturers to develop an AMS
- To quantify the results from the applications of these methodologies by collecting industrial data using a structured questionnaire and to use the answers to demonstrate

the factors affecting the implementation of these methods and techniques in an industrial case-study based on the rainscreen system

- To study the uncertainty in the data produced by the cladding manufacturing SMEs when quoting for contracts and then analyse the different factors that can effect data accuracy and therefore cost within the developed AMS

1.5 Structure of the Thesis

Chapter 1 gave an introduction to the Thesis by briefly describing the main characteristics and challenges faces the cladding industry, the main Thesis objectives being identified in section 1.4. The Literature Review of the Thesis is distributed between Chapters 2, 3 and 4.

Chapter 2 presents the data which was gathered about demands placed upon industry by aesthetically complex projects and the cost management data required in the early design. This Chapter also gives a Literature Review of different manufacturing processes and tools utilised by many cladding manufacturing companies. The main gaps in the cladding industry will be identified in this Chapter.

Chapter 3 considers the Literature of different methods and management techniques to control the operational and costing data throughout the manufacturing life-cycle, in order to help SMEs achieve a competitive edge by enabling them to operate an AMS.

Chapter 4 considers the Literature of and introduces a method for analysing the uncertainty of information, which can be used to quantify the certainty of the data flow between company systems. This introduces the new concept of entropy into an information system and gives an example of its use within the cladding sector.

Chapter 5 builds on the preceding two Chapters to show the implementation of a complete AMS utilising the newly identified toolset and novel cost management methods. Again PSP Architectural Ltd (PSP) is used as as the primary source of data. A questionnaire was conducted to gather data regarding the uncertainty and risk associated to a variety of live projects completed by PSP. The success of this approach shows how designers can provide cost information regarding complex product design.

Chapter 6 tests the ideas presented in previous Chapters through a case-study on rainscreen product design at PSP. The company has characteristics that are typical of many small job-shop manufacturing environments and so the case-study indicates the benefits that might be seen in similar environments. The case-study considers all the elements of the AMS that was developed: the interaction, data flow and the interfaces between the business developments elements.

Chapters 7 and 8 evaluate how well the research met the objectives, discuss the conclusions from this work and point to future avenues for extending this Thesis.

Appendices contain the questions and results from the data collected from the following:

- Case-study exemplar cladding projects
- Interviews with Industry Specialists
- Internal questionnaires and results
- External questionnaires and results
- Project risk assessments

2 OVERVIEW OF THE INDUSTRY

2.1 Introduction

This Chapter will concentrate on understanding the supply chain process and inter-company relationships, in order to develop standardised methods for controlling and managing the cladding cost estimation process. Methods will be developed as a result of analysing gaps in the cladding procurement data exchange process.

The following sections will discuss the cladding sector's supply chain phases and the sector's manufacturing processes and technology. The cladding supplier's organisational characteristics and structures and its affect on the building design process will be highlighted.

Finally, this Chapter will suggest how the integration of different systems and tools can be used in the cladding sector to achieve better control over cost data and product aesthetic in the different design stages.

2.2 Cladding Procurement Process

The different stages in the process of developing a high performance cladding system and the analysis of the critical factors which will affect the procurement process will be discussed in the following sections. In addition, the impact of the cost estimation factors related to product functionality and the design aesthetic will be highlighted as part of this Thesis.

2.2.1 Stages in Cladding Procurement

The construction of highly aesthetic buildings is complex and, in most building examples, unique. As the cladding plays a critical part of a modern building, it is important to understand the different stages which make up the total procurement processes. These are shown in Table 2.1 [2.1], which analyses the different stages of the cladding procurement supply chain and also highlights the contribution of the different parties involved in the project at each stage. As construction projects can vary in complexity, the contribution of different parties also varies in each of the presented stages.

Phase	Description	Comment
A	Structural Design	The outline of the location and shape of the cladding will be allocated between the architects and the client. The main structure of the cladding can be recognised.
B	Primary Design	The outline of the cladding will be detailed. The integration of the cladding into the buildings will be determined. The cost of the cladding side will be estimated as a group of components
C	Final Cladding Design	The detailed architectural design of the cladding will be determined, the structural planning is made and the connection to the building frame is detailed. The cost of the cladding is estimated based on each cladding component. The cladding manufacturer design team can be involved with the architects and the contractors in this stage of the project. As all the main specification was determined by this stage a detailed cost estimate can be produced.
D	Specification	The cladding is fully specified. A defined price for the cladding will be made in this stage in addition to delivery and installation timetable. The cladding manufacturer will be involved in this phase.
E	Pricing	In this phase the cladding contractor will be chosen, the bid price was determined in the earlier stages. The cladding contractor will carry out the pricing of the cladding. The cladding pricing will be detailed in this phase, as all the drawing and technical data will be available to the system manufacturers to commence detailed pricing.
F	Planning and Scheduling	In this phase the cladding can be ordered from the cladding manufacturer. Delivery dates will be agreed and added to the main project schedule. The plans and the working drawings of the cladding will be established and sent to the cladding manufacturer. Any changes on the pricing or the technical details will be confirmed from the cladding manufacturer in this stage when a detailed manufacturing design is established.
G	Manufacturing	In this phase the cladding elements, sub-components and overall component are manufactured in series. Both the manufacturing and the installation phases are the most critical phases in the cladding procurement where most of the risk and cost are determined.
H	Installation	The entire component will be installed by the cladding installation contractor.
I	Handover	The project will be completed and handed over from the cladding installation contractor to the main contractor, then to the client.

Table 2.1 - Cladding Procurement Phases

The high profile, aesthetically-demanding projects which require complex design and development and early involvement of all different parties will be discussed in detailed in the following sections. By analysing current gaps in understanding of the manufacturing process and their impact on the product cost and final aesthetic, this Thesis has identified the contribution of the cladding manufacturing companies to the early design stages of a building and also to the process of costing data exchange. Table 2.1 shows that product costing and budgeting in complex and high profile projects starts in the early design phases B-C. It can be seen that the requirement for budgetary accuracy increases with each consecutive phase, to achieve the final budget in phase E. Each stage involves different parties potentially all using different technology based tools such as design software and communication technology, highlighting the lack of a standardised communication between the architects and cladding manufacturer in the early design stage. The relationship between the design requirement and project budget in the cladding procurement supply chain needs to be clearly understood. Depending on project complexity the design requirement is directly linked to the project budget. In modern aesthetic projects, with high design requirements, budget accuracy is vital to project success [2.3]. The relationship between design requirements and project budget also relates to project complexity. Section 2.2.3 will define that complexity in the context of design requirements, manufacturing constraints, after-sales and installation.

The involvement of the cladding manufacturer alongside the main contractor and design architects in the early stages of the project can be vital. This can produce a more accurate estimate of the cladding budget, especially in large complex projects, where the impact of cost is directly linked to the aesthetic design. In non-aesthetically complex buildings, cost is the dominant factor throughout all stages [2.2], [2.3]. Appointment of the main contractor normally occurs at phase E, whilst the cladding contractor and associated manufacturer will be appointed in phases E-F, even if they had been involved previously in the early stages of design.

By interviewing some of the industry specialists (see Appendix B) it was found that the estimating process in the early design stage is seen as a high cost item. The cost usually consists of a highly paid designer spending time analysing drawings and performance criteria, in addition to the administration cost of the sales and estimating department who have to produce the cost estimates. In the case of standard products, architects can use standard price lists as a cost base, but for complex, dimensionally variable and highly aesthetic products, this can be difficult.

In a private communication, Professor Alan Brookes (reproduced in Appendix B) explained the importance of the costing factor that determines the selection of cladding products by architects. He explained that dealing with architects in the early stages of design can be beneficial, as otherwise they usually have little or no understanding of the cladding manufacturing process.

Because they are unaware of the feasibility of new ideas and unable to cost them, architects prefer to use standard systems developed by the cladding system providers and manufacturers.

They usually require a realistic budgetary price in the early design stage in order to make product selection. This highlights the lack of an AMS at the early design stage which can produce budgetary costs for complex product designs and can analyse, with minimum resources, the impact of cost on product functionality and aesthetics. Such a system would need to be applicable to small and medium size cladding companies.

2.2.2 Impact of Aesthetics on the Industry

The previous sections have shown the importance of involving the cladding manufacturers and contractors in the early stages of the product design to allow architects to determine the project budget. In a modern aesthetic building project, the architects aim, especially in Stages A-B, is to satisfy the client's need for a building which meets his functional and cost requirements. The functionality and cost impact is usually considered in Stages B-E. It is important that the architect understands the impact of their aesthetic design on cost and manufacture. Filling this gap can only be achieved by improving communication between architects and cladding manufacturers in the different stages of the cladding procurement supply chain. Nowadays technology can help to achieve this by the import and export of relevant design files between different systems within the cladding manufacturer or between the cladding manufacturer and the architect, who may be in a different country. Large architectural practices such as Norman Foster and Partners are operating through many offices around the world in which design files and information are communicated through a network of suppliers and manufactures. Section 3.3.1 will highlight some examples of the integration capability of such software and how that can be used to develop an effective AMS which will improve the performance of the whole cladding supply chain.

2.2.3 Factors that Affect Cladding Procurement

Cladding manufacturers are usually involved with a variety of types of projects but most projects will follow the same sequence and phases. Decisions related to cost and budgets can vary in each phase according to the complexity and the size of the building design. For example, a standard factory building will not require a large amount of time in phases A-C, since the design of the building is basic, but the planning and installation are required to be efficient, since the time scale for phases G-H is short. On the other hand, a complex building will need more effort in the early stages since the design of the building and its specification is vital to the project success. Figure 2.1 demonstrates a subjective series of complexity decision ratings related to Table 2.1.

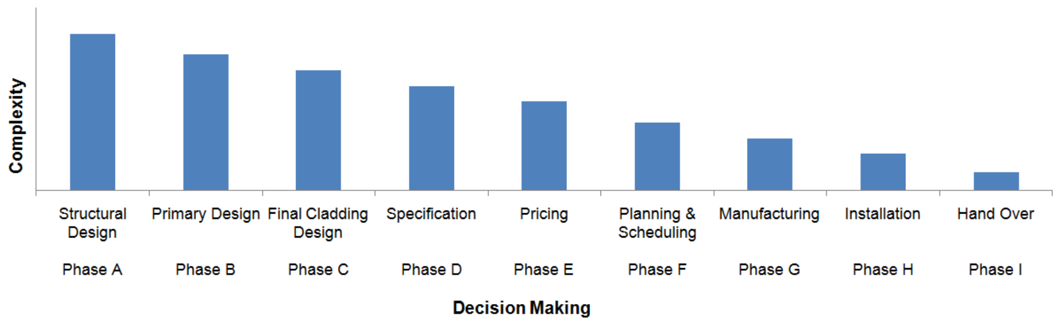


Figure 2.1 - Relationship between project complexity & decision-making process related to cladding cost

There are many other factors that can influence cladding procurement, such as client finance, building functionality, purpose and building location. This Thesis has focused on the factors that can influence the contributions toward the performance of the total supply chain, in the areas of costing and aesthetics.

Interviews with industry specialists and cladding manufactures (see Appendix B and D) brought to light other factors such as Manufacturing Constraints, Parts Complexity and Variety, which are influential in the cladding procurement supply chain, and manufacturing constraints can be divided into two:

- Absolute
- Capability-based

Absolute constraints are limitations which the manufacturer cannot control, usually influenced by external factors. Capability-based constraints can be overcome by investing in new technology, developing new skills within the organisation, training existing employees or adopting new management frameworks that influence the organisation's data management [1.12].

Part Complexity is defined in relation to the design requirements, manufacturing constraints, part variety and data availability. Figure 2.1 shows the complexity scale in relation to decision-making involvement for cladding manufacturers in the procurement supply chain. There is a need for a qualitative approach to identify cladding industry complexity by product categorisation. In the context of the stages presented in Table 2.1; design requirement, manufacturing processes and site installation complexity are directly influenced by the involvement of all the project stakeholders in the early stages of the product design. Complexity can influence cost accuracy and the product aesthetic, which are directly linked to the project budget determined during early stage design. Finally complexity can be defined in the context of Part Variety. The greater projects part variety the higher the complexity will be. Chapter 4 will introduce a checklist to allow cladding SMEs to identify complexity in relation to part variety, manufacturing constraints, technology integration and human resources.

The Interviews also revealed that the most critical factors influencing costing and product aesthetic are directly related to the following:

- Cladding manufacturing company characteristics
- Manufacturing processes and constraints
- Technology and commercial software

These factors were explored in detail to develop a standard computer integrated manufacturing strategy. The purpose of defining a strategy is to foster an environment that allows the designer to take more accurate decisions, in relation to manufacturing constraints, part complexity and aesthetic, which will affect costs.

2.3 Characteristics of Cladding Companies

Cladding companies vary in their characteristics and responses to new technology and management models but they can be characterised by their size, market, products and management structure. Similar to other management and engineering models, the applicability of management frameworks and methods within companies depends on these characteristics [2.5]. As the availability of costing data is essential in all the stages of the product's life-cycle, companies can be differentiated in how they categorise and analyse their data. Some companies may have high labour, material or overhead percentages and choosing the right cost system depends on these factors.

Other research [2.6] has looked at company characteristics from the product development point of view, where product development can be characterised into three main categories according to the cost and design:

- Large scale development 10-20 years, for example, the aerospace industry.
- Mid scale development 1-5 years, for example, automotive and electronic industries.
- Small scale development < than 1 year development, for example the cladding industry.

The applicability of cost management and estimation models depends also on the size, structure and the manufacturing style of companies. Costing data analysis is related to the manufacturing style or systems used in the company. The interaction of costing data in a job shop, make-to-order manufacturing style, is different from a fully automated make-to-stock production line.

Companies can be categorised according to their size as large, large/medium and small to medium enterprises. In the UK, the Department for Trade and Industry (DTI) categorises companies according to their size and turnover, where an SME is defined as a company that has less than 250 employees and less than £24 million turnover [2.7]. Finally, some research [2.8] has characterised companies, especially SMEs into four basic types, dependant on the owners' ambitions:

- The lifestyle business
- The survivalist
- The limited growth SME
- The high growth value-added SME

The first of these is where the owner is only interested in taking short term profit without concern for anything else. The survivalist focuses simply on staying in business and the limited growth company has restrictions upon its ability to grow further. Both are typified by having a fairly low turnover, but at the same time having a steady amount of work. Such businesses are competently managed but tend to rely on a single product or a small market. The last category relates to firms that seek out new markets and products [2.8], [2.9].

From the operational perspectives, companies vary in their operational setup and technology. The size of the company and the market it operates in tend to dictate the methods and tools to be applied.

The focus of this Thesis was on the small to medium manufacturing companies with the high growth value added characteristics and with a flat management structure, which are specialized in the fabrication of sheet metal for the cladding and cladding sector. In order to understand the characteristic of these companies, it is vital to study their internal operation and processes, human resources and finally technological and commercial tools used. Sections 2.4 and 2.5 demonstrate the results of analysis taken from gathering data from cladding manufacturers in the UK.

2.4 Overview of Operational Processes in the Industry

The operational process of a cladding manufacturer is mainly sheet metal fabrication, which can be defined as the manipulation of metal to create any type of component to be used in the cladding product. The component could be used in almost any manufactured product including for the medical, computer, electronics, or appliance industries [2.10].

Any product that contains sheet metal components will go through several fabrication processes. These include designing, cutting, forming and finishing. Sheet aluminium, steel, stainless steel, copper, zinc and other metals may be utilised to create the component, which may be a subcomponent for a larger component, or may be the end component itself [2.9], [2.10].

2.4.1 Examples of Manufactured Cladding Products

Building cladding products can be categorised into glass, metal, stone or terracotta systems. As every type of building cladding product is different in relation to the manufacturing, design and construction operation and processes this Thesis has concentrated on the metal cladding products. For the purposes of this Thesis, metal cladding products have been further divided into three sub-categories; standard, Semi-Standard and innovative products. This categorisation will be used as the basis of the methodology that will be adopted in the industry analysis presentation in Chapters 4 and 5.

Three main ranges of the metal cladding products are manufactured by PSP and are considered in the case-study, namely rainscreen systems (which will be the main focus of the analysis), specialist systems and finally standard flashing and guttering systems.

A rainscreen system can be defined as:

> "a layered cladding system typically comprising an outer skin which incorporates air gaps but forms the primary rain barrier, a ventilated air gap that prevents water ingress and an effectively impermeable backing wall" [1.6].

The process of manufacturing the rainscreen is highly dependent on the design process. Rainscreen systems are usually predesigned to be a standard "off the shelf" type system that is tested and approved before marketing the system to the architects or the contractors. The system then can be customised within the pre-agreed tolerance to suit the different type of buildings as shown in Figure 1.2 and Figure 1.3. If large amounts of customisation are required it thereby may become a semi-standard innovative product. There are different types of rain screen used in the UK cladding industry. This Thesis has focussed on the metal type of rain screen fabrication, as shown in the example in Figure 2.2.

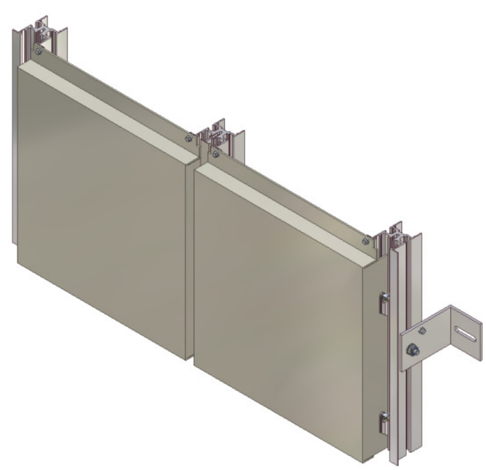


Figure 2.2 - Example of the rainscreen metal cladding system

An example of a specialist cladding product is shown in Figure 2.3. This kind of cladding can be used for both external and internal cladding. The component parts are shaped to meet the aesthetic requirement of the designers.

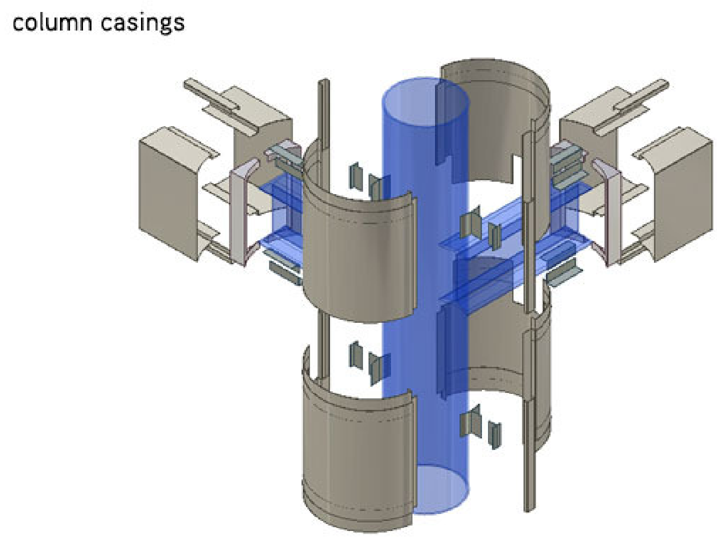


Figure 2.3 - Example of a metal clad column casing design.

This type of product is usually designed to suit each building, so most of the design process will be done according to the architect or the contractor requirements. Some elements can be predefined and standardised, with the help of the available technology in CAD and design software.

The final type of metal cladding that will be discussed is the flashing and guttering system (see Figure 2.4 and Figure 2.5); which is considered a standard, high volume, low complexity product. This type of product is usually pre-designed and, similar to the rainscreen system, the manufacturers can only have limited options to configure the systems to suit the requirements of the building. The key differences between this type of product and the rainscreen system are the cost model, complexity and the level of involvement of the contractor in the design of the product.

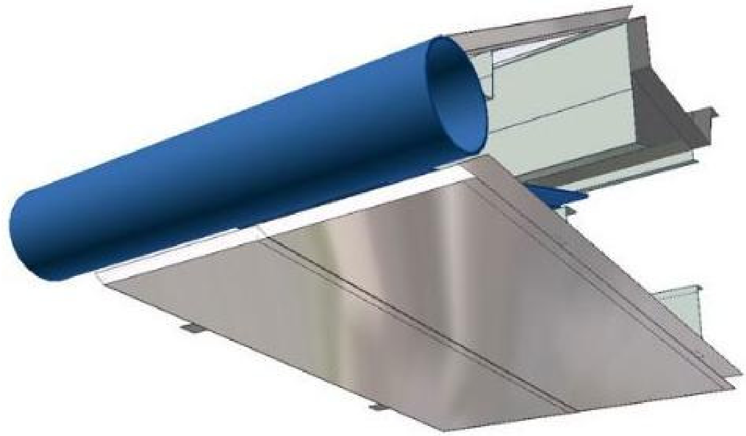


Figure 2.4 - Example of a flashing system

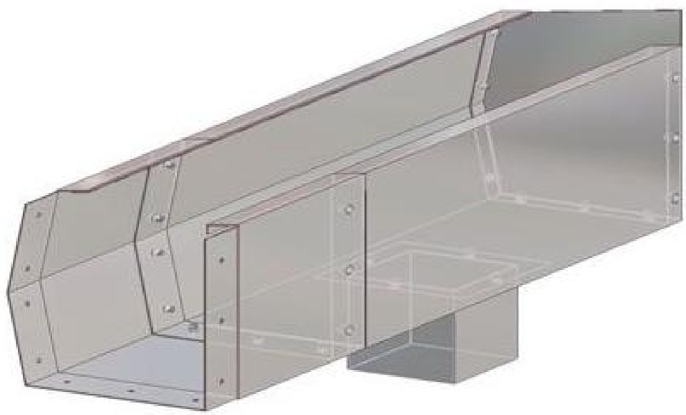


Figure 2.5 - Example of a guttering system

2.4.2 Design and Manufacture Software

Some examples and descriptions of software technologies used by the architects and the cladding manufacturers have been researched and their effectiveness assessed.

2.4.2.1 Design Software

AutoCAD software is the most widely used in sheet metal industries including the cladding industry. Cladding and system design require a combination of functionality and integration in the software. Most modern software was designed to accept the files that are generated from any AutoCAD drawing. AutoCAD is used throughout the whole supply chain in the cladding sector, starting with the architects using AutoCAD Architectural software. AutoCAD for architects enables instantaneous productivity and smooth collaboration within a known software environment. Purpose-built architectural design and drafting tools make for efficient, intuitive creation of a building plan [2.10]. Contractors use standard AutoCAD software to produce building and site drawings, which are then supplied to manufacturers who use them as a basis for their manufacturing designs. Finally manufacturers use solid modelling software such as Autodesk Inventor, which provides a comprehensive set of design tools, for producing, validating and documenting complete digital prototypes. A solid model is a 3D digital prototype that helps the designer to visualise, simulate and analyse how a design will work under real-world conditions before a component is ever built. This helps the manufacturer to get a component to market faster with fewer physical prototypes, enabling more innovative products [2.10].

2.4.2.2 CAD/CAM Sheet Metal Software

One of the most commonly used technologies in the modern sheet metal fabrication is Computer Aided Design / Computer Aided Manufacturing CAD/CAM sheet metal fabrication software, which gives manufacturers the means to transfer design drawings to the manufacturing machines, allowing rapid production essential for sheet metal components and products. Typical production techniques use punching, profiling and combination machine tools to produce components from nested sheets followed by folding on a press-brake. These manufacturing technologies are continually being developed and the software provider has to improve the performance of his product to handle these changes and reduce material waste by providing better optimization tools. The most common software used by cladding manufacturer SMEs in the UK is RADAN, which is capable of extracting data from an AutoCAD file and processing it to produce a CNC program to produce the part [2.12]. Cladding designers using the CAD system for product development can transfer files for a manufacturing concept through to the RADAN software to estimate production cycle times from the product geometry and bill of materials. This can be used as a basis for the cost estimation.

2.4.3 Manufacturing Processes

The sheet metal fabrication processes used by cladding manufacturers involve a number of stages and parameters. The manufacturing process starts with the design of manufactured components from the contractor or architects drawings. This produces a schedule of components based on the cladding general arrangement drawings, including details of their location on the building envelope, dimensions, shape, number and cutting list.

Figure 2.6 - Typical metal cladding factory layout and machinery

The manufacturing technology used during the cladding section fabrication design process was described in Section 2.4.2. This section highlights the unified design and manufacturing systems common place in the industry which include computer-aided design (CAD) and microprocessor-controlled fabrication machinery consisting of manufacturing stations which perform a manufacturing process upon the work piece, as shown in Figure 2.6. Design information can be entered through the CAD system. Usually buildings are pre-designed and developed using CAD by the contractor or the architects. CAD files are then emailed to the design department who produce manufacturing drawings.

The design information is commonly combined with manufacturing process and planning information derived using CAE software, such as RADAN. The design can then be developed into a manufacturing file, used by microprocessor-controlled fabrication machinery, to produce the final component.

Sheet metal processing can involve a number of alternative processes to transform a piece of metal into smaller pieces. The first process is often a cutting process to produce blanks. Shearing is used to cut larger pieces into smaller ones using the shear stress applied by a cutting machine to the sheet material. These small pieces of metal are then moulded or formed. In certain products, punching follows the cutting process. Punching involves stamping designs into the metal with tools and dies. This process is executed by a turret punch machine, available in both hydraulic and electric versions, for processing sheet materials to form 2D shapes from designs loaded from the CAD and microprocessor-control system, see Figure 2.7. The turret punch shown has 360-degree tool rotation for angled cuts and notches and is capable of punching up to 6.4mm mild steel or aluminium and 3mm stainless steel materials. The 2D shapes produced then can be transformed into 3D shapes by going through forming processes, which include CNC bending process and assembly operations. The microprocessor control system transfers the design in the form of a program to the CNC machines in the manufacturing environment [2.10], [2.13].

Figure 2.7 - Turret punch machine, microprocessor-controlled fabrication system to be transferred to the CNC machines in the fabrication manufacturing environment

The material varies in size, thickness and surface properties. Information regarding the material must be defined in the CAD system to enable designers to generate suitable CNC machining programs and produce the production planning sequence. Material information can be loaded directly from the ERP system, which stores all the relevant information regarding the materials and its costs.

There are several forming techniques. Rolling is used to shape flat pieces of metal into cylindrical shapes through the use of roll stands. Bending is defined as the process by which metal can be deformed by deforming the material and changing its shape. In bending and rolling the surface area of the material does not change and bending usually means deformation about one axis [2.13], [2.14]. Bending is a flexible process by which many different shapes can be produced. Standard die sets are used to produce a wide variety of shapes. The material is placed under the die and positioned in place with stops and/or gauges and held in place with hold-downs. The upper part of the press, the ram, with the appropriately shaped die descends and forms the v-shaped bend. Bending is done using press brakes as shown in Figure 2.8 and Figure 2.9.

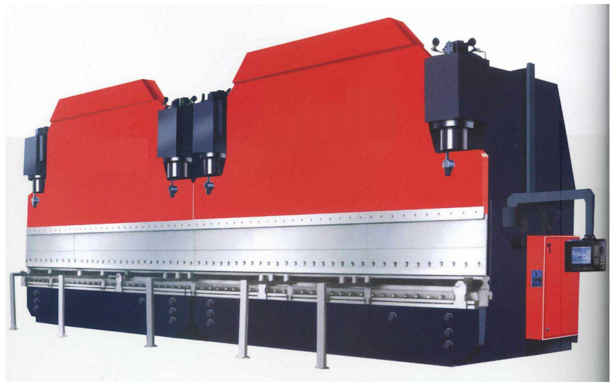


Figure 2.8 - Press brake machine (CNC programmed or manually programmed by press operator)

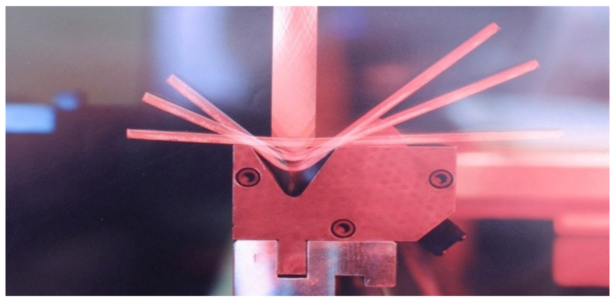


Figure 2.9 - Bending process using the CNC press brake

The press brake normally has a capacity of 20 to 200 tonnes to accommodate sheet metal stock from 1m to 4.5m width. Larger or smaller presses are used for specialized applications. Programmable back gauges and multiple die sets are available currently to improve the efficiency of the process [2.14].

The next process in manufacturing is assembly, which can be divided into welding and bonding. Welding is the process of permanently joining two or more metal components, by melting both materials [2.13]. The molten material cools quickly and the two metals are permanently joined. Spot welding and seam welding are two very popular methods used for sheet metal components as shown in Figure 2.10.

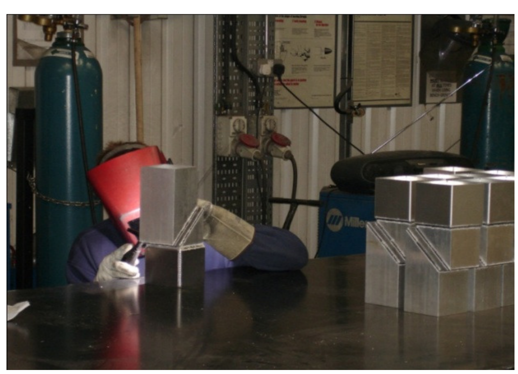


Figure 2.10 - The welding process, which usually requires a skilled operator

On the other hand the bonding process joins two or more parts together by means of intermediate bonding material that holds the two materials together.

After cutting, forming and assembly it must go through a finishing process. In finishing, the sheet metal is polished to eliminate rough spots and the edges are deburred using an abrasive process.

The final process is packaging the product to be shipped to the construction site for installation as shown in Figure 2.11, or if it is a smaller component, is incorporated into a large product before shipping to site. The packaging process should be monitored to ensure that product is packaged to a certain standard to avoid damage during or after delivery. The packaging system is usually linked to the manufacturing system to monitor that parts delivered against the original customer order.

Figure 2.11 - Cladding materials packaged to be shipped to the construction site for installation

2.5 Summary

This Chapter has discussed the cladding product, the supply chain process and inter-company relationships as a basis for developing standardised methods for controlling and managing the cladding operation. The models will be based on understanding the different factors that affect the procurement process of cladding in the supply chain, such as costing and aesthetic impact.

The main factors that have been identified in this Chapter can be summarised to be:

- Cost Factor
- Aesthetic Factor
- Manufacturing Constraints Factor
- Part Complexity and Variety

An important research outcome was the categorisation of cladding product into Standard, Semi Standard and Innovative and the affect of each type on the building design process was highlighted along with factors influencing the methods and tools used. The definition of the product categorisation will be defined in the context of the factors identified above in the next Chapter.

In the early stages of design, designers and cost estimators need to take more accurate design decisions regarding costing and aesthetic. The analysis in this Chapter has identified the gaps in the UK cladding procurement processes, which can be summarised as follows:

- A lack of standard methods for communication between the architect and cladding manufacturer in the early stages of the product design. This was identified in phases A, B and C of Table 2.1.
- A lack of costing control in the cladding design process. This was identified in phase C of Table 2.1.
- A lack of cladding product standardisation that can allow architect to improve the accuracy of cost estimation in the early stages of design. This was identified in phase G of Table 2.1.
- A lack of an AMS that allows cladding manufactures to analyse cost related to the product early design stages. This was identified in all the phases of Table 2.1.

Finally, the main cladding manufacturing processes and technology that is used in today's modern cladding manufacturing companies have been modelled. The stages of the design process within the UK cladding SMEs have been demonstrated using the data collected from PSP.

3 OVERVIEW OF AGILE MANUFACTURING SYSTEM METHODOLOGY

3.1 Introduction

As discussed in earlier Chapters, cost control and reduction is one of the main factors that influence the performance of the cladding industry. Cost can be defined as the sum of money expended in terms of labour, materials, use of equipment and services, to the produce a product or service [1.11]. Cost is not the responsibility of one department within the company; rather it is an integrated function that needs the skilful integration of management, engineering and finance [3.1].

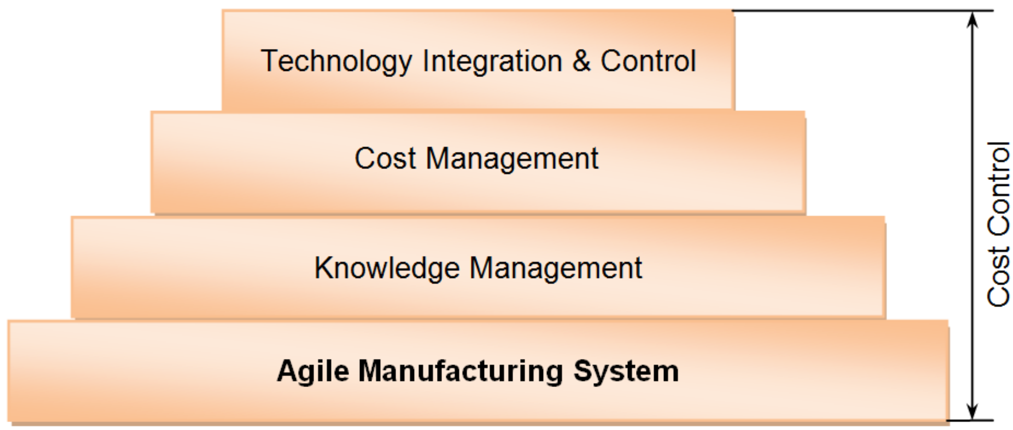


Figure 3.1 - Integrated Cost Control Functionality, leading towards an Agile Manufacturing Framework

Cost may be therefore classified according to various criteria and from different perspectives. The first stage of costing data flow starts in product development where there is a small amount of data available. Reference [3.2] quoted the German Industrial Standard which distinguishes three different types of costing calculations; pre-calculation, intermediate-calculation and post-calculation. Pre-calculation is done in the estimation stage where the product is still being designed. This type of calculation corresponds to stages A-F in Table 2.1 presented in the previous Chapter in which the purpose was to determine a standard cost for the developed or modified product for pricing and manufacturing control. Post-calculations concern the measurement of the cost after the product was realised for financial and cost accounting purposes. This type of calculation represents stages G-I in Table 2.1.

All three costing stages are usually managed by a system, that involves a mix of technical, business and human resource (HR) management techniques, which together are known as cost management.

This Chapter will scrutinise existing process- and technology-oriented initiatives (as defined in Section 1.1) to develop better techniques to control cost in the product design process stages of an agile cladding manufacturer. Techniques and methods presented will be based on bridging the gaps discussed in the previous Chapter in the early stages of communicating design concepts and potential manufacturing scenarios to new customers. This approach can help the designers to take more accurate decisions based on actual knowledge and can increase the potential sales margin and probability of on-budget cladding manufacture.

Figure 3.1 shows a management framework that will lead to an AMS:

- Cost management in SMEs and process focused initiatives
- Enterprise integration technologies for SMEs
- Knowledge management
- Agile manufacturing systems and the cladding supply chain

AMSs can be used in many industries and can focus on different management areas and objectives. In this Thesis the AMS will focus on bridging the gaps identified in Chapter 2. The system can be described in this Thesis as a framework that widely demonstrate the application of different management tools such as cost management, technology integration and knowledge management. Each of these management tools can be applied in-depth individually in the manufacturing environment. This framework will apply certain parts from each tool to develop an overall mechanism that allow cladding manufactures to reduce the gaps between product design and manufacturing and increase the awareness of aesthetic effect and costing on modern buildings. This system will not be demonstrated in the context of in depth processes agility or process re engineering, but as a general management framework that focus on the pre-calculation costing of a cladding product design.

3.2 Cost Management

3.2.1 Introduction

Brinker defined Cost Management as a set of techniques and methods for controlling and improving a company's activities and processes [3.3]. The purpose of any cost management system in the company is to maximise the profit now and for the future [1.12]. Wilson defined cost management as: cost management is not a department or a function in the company; it is a philosophy that inspires the whole company from the top management to the shop floor [1.11]. Cost management is a system in which management of cost related activities can be achieved by collecting and analysing the information for management purposes [3.7]. Finally Rush defined Cost Management as a technique for managing the development process in order to achieve the estimate [3.8].

This Thesis has developed an AMS based on a cost management model that leads to the integration of several management tools: cost estimation, technology management and enterprise integration, data management, operations management and cost estimation as shown in Figure 3.2.

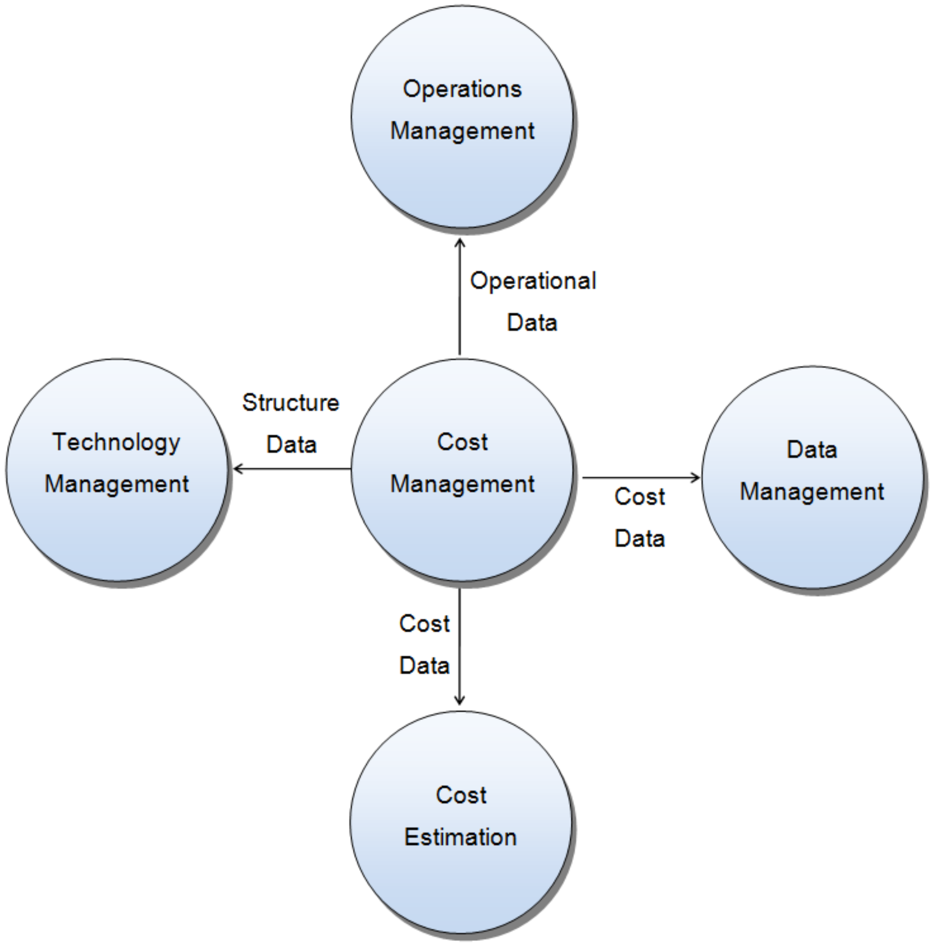


Figure 3.2 - Interaction between technology management, cost estimation, operation management and data management mythologies

The integration between the above tools through the management of the cost, operation and product structure data will be presented as a potential solution for the application of an AMS to an SME in the cladding sector.

3.2.2 Cost Estimation and Modelling

Cost estimation involves making predictions about costs that will be incurred in the future; the accuracy of the estimate being proportional to the span of time between the estimate and the event [3.9]. It is well known, particularly in discrete goods manufacture, that up to 85 percent of the life-cycle cost of a product is established through decisions made during the product development and design stages [3.10]. Hence, cost estimation can help companies with decision-making, cost management and budgeting in product development. Forecasting product cost in the early stages is therefore critical to ensuring that a profit can be made on the items sold. Designers should be aware of product suitability for production, giving a large potential for reducing the product cost in the production stages [3.11]. The main factor in estimating cost during the design development stage is understanding and predicting production cost, because the product selling price is determined by the production cost. So cost estimation is essential to determine if a product will be competitive in the market.

An increasing recognition of cost competition has spurred the development of design for manufacture, design for assembly, design for productivity, design for maintenance and design for costing [1.2]. However, designers can find various obstacles in estimating cost at the design stage, for example, working with the limited amounts of data available at the development stages, changes in technology and processes improvement and inaccuracies of information. Cost can be employed as an evaluation criterion during design in two ways; design *for* costing and design *to* costing [3.12].

Research has shown the need for methods that provide cost information to the designer. While a company must know the total cost of a product, designers are mostly interested in costs which they can control. Cost estimation is typically done by professional estimators who may have little or no design experience and may not be an integral part of the design process. The integration between the design, cost estimation and the manufacturing environment has proven to be vital for the accuracy of costing data throughout the product life-cycle [3.11], [1.2].

The technical framework related to the integration between CAD systems and cost estimation systems in the early design stages, with an integrated manufacturing and supply chain control system will be discussed further in the following Chapters. There are many methods and techniques that have been developed for cost estimation; the following research describes the main three methods that suit the technology that will be implemented in the models.

3.2.3 Traditional Cost Estimation

Traditionally, cost estimates are divided into two types, first sight estimation, which is done early in the cost phase based on the estimator's experience and knowledge; secondly the detailed estimation, which is done in more advanced stages in the design phase based upon a number of historical pieces of data obtained about operation time, labour cost, material cost and overheads [2.1], [3.8]. In detailed estimation the relationship between processes, labour/operation timing and material needs to be stored in a central database. This system must go through several feed-back loops and iterations, in order to review and adjust the costing information stored in the database.

The remainder of this Chapter will concentrate on detailed estimation where all the objectives and product functionality have already been developed and historical costing data is available as this was the approach used by SME considered in this Thesis. Despite product development being the key factor in product costing, design engineers usually start to retrieve accurate information about product cost data only after key design decisions have been made. Product development hands the product description over to the Production Planning Department, which produces the process plan to create more accurate costing data based on production. Iterations of the design will then take place according to the historical data fed back from the production department. The product may have changed during this time before vital cost feed-back is received [1.1]. Short loop iteration of cost information was developed and used in several industries not only in the manufacturing sector, but also in software development [3.13].

3.2.4 Parametric Estimating

"Parametric estimating is the generation and application of equations that describe the relationships between cost schedules and the measurable attributes of a system that must be brought forth, sustained and retired" [3.14]. This type of estimation is used in the early stages of product development; it is shown by a graphical relationship between the physical parameters of a product and cost [3.8]. The application of this technique depends on the analysis of historical data, such as the use of regression analysis techniques. Equations generated from this technique can be used to integrate cost information with the physical parameters of a product; however, this method needs to be rapidly updated with accurate data to feed into the system. This technique is available commercially; one of the most widely used parametric costs estimating commercial software from the 1980's is the Lockheed Martin PRICE system [3.15]. A disadvantage of using this technique it is not recommended for products that utilise new technology, due to product complexity and high cost of implementing and utilising these technologies in SME [1.2].

3.2.5 Feature Based Costing

Feature Based Costing (FBC) uses product features as a basis for costing during the design stages [3.16]. Products can be described by a number of associated features such as holes, flats and surfaces. The growth of CAD/CAM technologies and 3D modelling has influenced the development of feature based costing. Research has investigated the integration between design development, process planning and manufacturing for cost engineering purposes using these techniques [3.16]. FBC indicates the cost of the product by relating the number of features to production and manufacturing, as more product features require the more manufacturing and planning is required.

To determine the cost of a feature, this technique needs information about processing times and labour rates and also material quantities and routes of processes. Overhead distribution or estimation, which is also required, is determined by the accounting department; where the gross overhead rate can be distributed to processes or work centres.

Historical data can help to determine the cost of the product and, as in the case of parametric costing, these techniques need accurate, rapid operational data to be available. This approach can be used in the case of the development of new products by comparing new features with similar features of a product that was previously estimated. This data can be copied and adjusted to match the attributes of the new feature.

Some of the limitations of this approach can be observed in the context of complex product assemblies where the cost of all features may be different from the sum of the individual cost of the features. Valid accurate manufacturing data must be available in order to accurately estimate costs using this technique [2.1].

3.2.6 Neural Network Based Cost Estimation

Neural network based costing is based on the use of artificial intelligence [3.16]. It is the next generation of attempts to computerise the human thought processes. Neural networks (NN) use computer programs applied to cost data to learn the effects of a products' attributes and characteristics on costs. This would be achieved by training the costing system with data from past case studies. The NN approximates the functional relationship between attributes and costs during the training. Once trained, the attribute values of a product under development are supplied to the NN, which applies the approximated function obtained from the training data and computes costs from appropriate product input data. NN is a statistical tool but it still needs the experience of an estimator to evaluate the validity of the results of the program and it requires an adequate volume of past costing data for training. This method has not proved reliable when applied to innovative products in the automotive and aerospace industries [3.16]. This technique could be the future of cost estimation and knowledge capture, but during the period of this Thesis this type of technology was still in the research stage.

3.2.7 Cost Accounting

Cost accounting is the system whereby the management accountant ascertains, records, classifies, allots and presents cost data for management decision-making [3.16]. Cost accounting is used for the post-calculation of cost and, as such, is a record of cost information which depends on accurately recorded information on the timing and hourly rates of machine utilisation, performance and labour cost data [1.1].

Cost accounting includes costing elements for materials, labour, energy, transport, capital equipment, machine depreciation, building space, maintenance and services. The collection of this information for management decision-making was a central objective in cost accounting for the last 100 years. Aiding decision-making is, arguably, one of the most important objectives of a cost accounting system. However in 1954, Peter Drucker said [3.18]: "the vocabulary of business and especially for accounting in relation to productivity has become misleading". In order to make their strategic and operational decisions, management needs information regarding the product profitability of products and any cost variances. There are many techniques and methods to collect and present costing data to management in order to enhance the decision-making process [1.12].

3.3 Enterprise Information Systems Integration

3.3.1 System Integration Introduction

This Thesis discusses the interaction of operational costing data between the cost estimation, Enterprise Resource Planning System (ERP) and Computer Aided Design (CAD) systems for the cladding industry. Ou-Yang and Lin [3.27] developed an integrated framework for feature based manufacturing cost estimation at an early design stage. Their system estimated the manufacturing cost of a design according to the shape and the precision of the features. Within the proposed framework only conventional machining processes were taken into consideration.

Sheldon et al. [3.28] proposed a framework for developing an intermediate cost database established between the cost accounting system and the design-for-cost system. This system analysed cost information provided by a cost accounting system to establish the appropriate cost structure. Gieger and Dilts [3.22] developed a conceptual model and working prototype for a new application for blending product design and cost accounting, for automated design-for-cost. The model integrates manufacturing and accounting concepts for feature-based costing and modelling.

Feng et al. [3.29] presented a mathematical model to determine the minimum cost design, based on features wherein the machining time of the component depended on the time for performing operations, the changeover and setup times are converted to a cost. Shehab and Addalla [3.30] developed a knowledge-based model to obtain an appropriate estimation of the manufacturing cost and initial process plan that should be used. Initial process planning includes the selection of machines, machine sequence and machining parameters. This model consists of a theoretical background for a feature-based-costing and CAD systems. The model uses three main databases for feature specification, manufacturing process modelling and resource data storage. The data used to identify each feature were passed to the feature machining time function, which calculated the time required to manufacture a feature according to the data stored in the database.

All the models and technology discussed above show the evolution of integration between Feature Based Costing (FBC) in the design stage, cost accounting and production and operational data. They were developed to suit a specific industry or product development stage. They lacked integration with real time manufacturing systems that update costing data through the life-cycle of the products. Systems that unify process sequences, machining time, wasted time, machine performance, material cost, supply chain costs. In an integrated manner would suit the requirements of SMEs. Companies are looking for an integrated solution and as ERP systems become the standard repository for companies' manufacturing data, the ERP system must be used as the source of the live manufacturing data.

ERP systems have helped companies to estimate basic production and product cost from an existing product design without integration with other cost estimation system, but they lack complex estimation capability. An ERP system could be integrated with an estimation system model to update the manufacturing and operation data in the case of complex product development design. Features are represented in the ERP system through a Bill of Material (BOM) that is pre-built or imported from another source. A BOM is predefined and is equivalent to the process plan in the model by Shehab and Abdalla [3.30]. ERP systems are also integrated with CAD systems through the transfer of text files, which are read by the ERP system. The text file, which contains the features used, is read by the ERP system, which extracts the BOM related to the features created in the CAD system. Shehab and Abdalla's model represents features and relations between the features in association to the feature specification, feature manufacturing processes, machine information and machinability. Analysis of the form features directly associated with certain machining processes has an important effect on generating a BOM or a process plan. In process planning, manufacturing form features are the basis for the selection of the machining processes and the estimation of manufacturing cost. As it was mentioned in Section 3.3.2.2, the ERP system data collection module also collects and stores live manufacturing data, regarding machines, labour and material, which can be used for process planning. The use of live data in the ERP system would provide more accurate feature-based estimates that better reflect real-life data.

3.3.2 Commercial Tools for Cost Estimation

Over the next five years, global manufacturing is expected to invest up to $25Bn in product development solutions [3.19] because within the new global economy, product development processes have been elevated to a leading competitive weapon.

Companies have started to optimise their product development processes in an organised manner in order to achieve more definable, short lead time and cost-effective developed products using Enterprise Information Systems Integration [3.19]. This section will discuss the tools available in such systems for cost estimation and discuss its constraints.

3.3.2.1 Cost Estimation and Industry Constraints

Research based on the software development industry shows that three quarters of the companies using cost estimation software missed their estimates, with 63% over running and

14% under running [3.20]. The reasons behind these are the complexity of the cost estimation application and the need for its integration into existing systems with which it needs to operate. It was found that estimating accuracy depends on the control mechanisms used to manage the project, as much as the procedures used to estimate the cost. Estimating accuracy also depends upon the user understanding and acceptance of the system [3.20].

Another factor influencing and limiting the use of cost estimation applications in commercial costing software such as PRICE is that they are expensive. Estimating applications are only utilised by large companies, for example Lockheed Martin, BAE Systems and Rolls Royce. The estimated cost of the implementation of cost estimation software at a single location can be over £100k, which would be prohibitive for an SME.

SMEs continue to use manual spreadsheet-based costing systems [3.21]. Cost estimation software can include a knowledge-based element where the experience of engineers and designers can be transferred into equations and rules making use of stored historical data and from the knowledge database. However, most cost estimation software available uses parametric estimating [3.21], [3.22], the cost information fed to the cost estimation system is processed in standard models created by the software company and the product cost is then calculated using these models. The accuracy of costing information in an SME using manual spreadsheet and database costing systems can be as accurate as the commercial software if control mechanisms are used to manage the project, dependent upon the procedures used to manage the design. The integration of the cost estimation software with the production and design commercial tools is also important for the accuracy of data [3.22].

3.3.2.2 ERP (Enterprise Resource Planning) Systems

Enterprise Resource Planning (ERP) is a generic term for integrated systems for corporate planning that supersede concepts such as Materials Requirement Panning (MRP) from the 1970s and, later Manufacturing Resource Planning (MRP II) in the 1980s [3.5].

Cost estimation systems have been embodied into ERP software systems, providing a seamless integration of processes across functional boundaries. These have resulted in improved workflow, standardisation of processes and business practices, improved order management, accurate accounting and costing information and supply chain management [3.5].

An ERP system can be the backbone of an SME information system satisfying needs, such as cost estimating, design and product data management applications. As part of the ERP system, the shop floor data capture module provides accurate real time information on the progress of work orders and increases efficiency by collecting data regarding labour time, stock information and Work in Progress (WIP) levels [1.2]. This also collects data concerning the internal status of

processes and elements such as machines, administration, labour and materials cost. This module controls operations and sub-operations using shop floor data and provides an up-to-date summary of information, for use at any time by management.
New ERP developments include Customer Relationship Management (CRM) modules that store information about customers at the appropriate point in the sales cycle. For example, SMEs use CRM to analyse the opportunities to increase revenues, whilst simultaneously enhancing customer loyalty and satisfaction. CRM can also be used to capture information regarding competitors, which can be compared with the company's own data for benchmarking purposes.

The integration of ERP and CRM systems in the proposed business management system would provide an important basic data storage structure and information analysis tools. It also bridges the gap by tying in plant floor information with business management information, such as product costing and pricing by comparing the estimated costing and budget data stored in the CRM with the actual production data supplied by the ERP system. This would provide the management with structured feed-back in relation to the profitability of the project, product, or any division within the business.

The previous sections highlighted the importance of costing in highly competitive markets. ERP systems can enhance concurrent engineering concepts, by providing a central integrated database that all the company functions can access and share information through. Centralising costing data can be very useful for ensuring the validity of this data, for product costing purposes, at all stages through the product life-cycle, i.e. from development, through production, to delivery.

The size of the company is the most influential factor in the implementation of the system. A survey in [3.5] shows that the implementation cost of ERP in small to medium companies varies from 3.08-5.53 % of the total annual revenue, breaking down to 35% for the software, 20% for the hardware, 23% for consulting, 10% for training and 10% for the implementation team.

3.3.2.3 PDM (Product Data Management) Systems

Product Data Management PDM is capable of managing all data related to the design process and sharing it with other systems such as Cost Estimation and ERP systems. PDM supports the concurrent engineering concept through the organisation, by allowing the maintenance of full data control, by distributing it automatically to the people who need it [3.24]. In today's manufacturing environment accelerating the product development cycle by using PDM gives a great competitive advantage that singles you out from your competitors [3.22].

Open standard interfaces enable the user to transfer bill of material (BOM) data directly between popular supply chain ERP systems [2.8]. As shown in Figure 3.3 ERP systems can be integrated with any design packages. For example a BOM can be added onto the design package and transferred to the ERP system.

This integration enhances the decision-making process for the management, designers and estimators. This integration should control the uncertainty in the data transferred between systems.

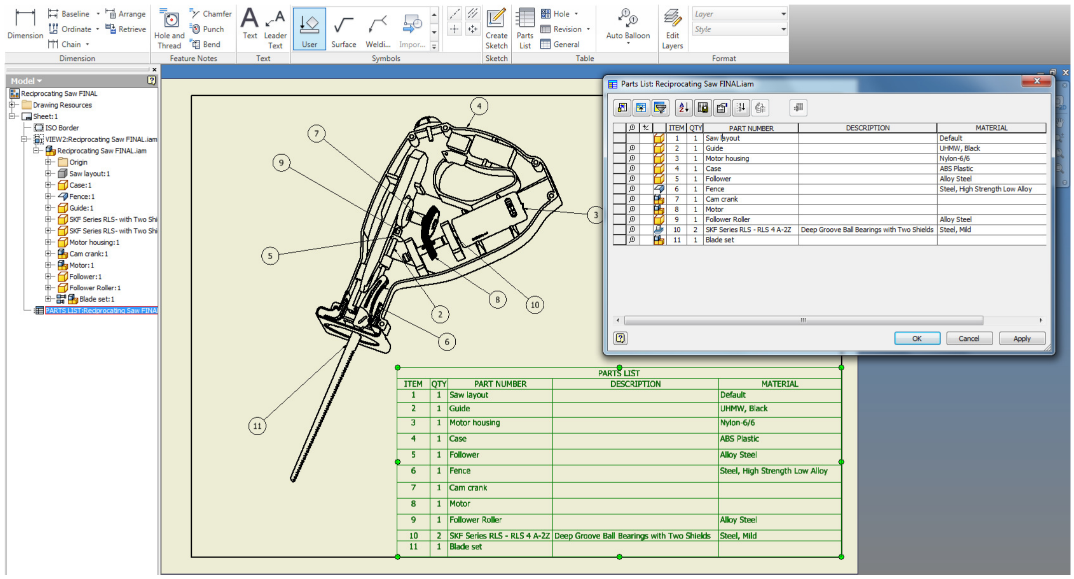


Figure 3.3 - An Example of Integration between a CAD system and ERP system for an electric saw using Autodesk Inventor Software

With rapid changes in the technology these products can provide a two-way integration with ERP system that can feed the system with manufacturing and performance data, to help the designer in taking better decisions regarding the design. A PDM system can import a BOM from the design software and allows the user to edit and change it. As mentioned in previous sections the BOM usually contains the product features along with costs associated with the product [3.24]. The concept is based on the collection of information from the whole product life-cycle in a user friendly way to allow non-engineers to access design data and allow designers to apply concepts such as design to cost and target costing [2.11], [3.25].

As discovered from the interviews conducted in Appendix B, manufacturing companies are usually good at systematically recording component and assembly drawings, but often do not keep comprehensive records of attributes such as size and weight. As a result cost estimators and design engineers have problems accessing costing data related to specific product attributes or linking certain attributes to certain classes of products. PDM can enhance the entry of product data into a database and grouping them in classes. This is invaluable in controlling BOMs for costing and product analysis purposes. Product data can also be organised by product structure. This can enhance the management of manufacturing, costing, financial and maintenance information related to the product and its assemblies.

Limitations in PDM are found to be in the data conversion between the PDM software and other systems and software. The PDM software should also provide a user friendly interface to allow different users with different skills to access a single platform of information [3.24]. SAP, Oracle and People software are examples of PDM systems that can be fully integrated with ERP systems. SAP has extensive integration with PDM for financial information about resources and costs lets users manage project budgets and cost. Research has shown [3.26] that software such as Eigner, which builds on the SAP ERP system backbone, has filled the gap between managing engineering documents and controlling of complex relationships between components and assemblies within the BOM. Integration into ERP systems for data exchange, between BOM, material master and components lists, is supported with a variety of standard adapters and a list of pre-build integrations that is constantly growing [3.1].

As mentioned earlier software such as SAP starts to provide integration solutions that vary from PDM to ERP systems. No software on the market has shown full integration from design to the delivery of the product. Integration in the latest releases of ERP systems can be achieved by a modular solution where customers choose which modules to implement. Manufacturing has changed over the years from mass production to supply chain management. The case-study in Chapter 6 shows that the lack of computer integration between different software have proved to be a weakness in the UK manufacturing SMEs as discussed in presented in Appendix B. The weakness is summarised by the lack of a structured approach linking the technology integration to the human factors and structure and finally the uncertainty of data transferred within the systems. This will be discussed in more depth in the coming Chapters.

Many ERP vendors have begun marketing a new generation of ERP systems, that have been programmed in .net technology allowing more flexibility in integration with other systems such as Microsoft Office, AutoCAD and SolidWorks [3.19]. An example, Epicor has launched their PDM system as a response of the demand of the availability of data processing application and commercial operation which address the integration of ERP with CAD systems. The system allows engineers to utilize the connectivity of both systems to access important information regarding actual operation, material and overhead costs and constraints [1.5].

PDM is a very costly option for SMEs as the implementation process is similar to the parametric estimating software implementation mentioned in the previous sections. During the period of this Thesis PDM technology has changed dramatically which has resulted in a reduction of the cost of the implementation. The following section will discuss the Integration with Microsoft Office as a recommended tool to extract data from the ERP system and link it with the CAD system.

3.3.2.4 Integration of ERP with Microsoft Office Applications

As Microsoft products are widely used in most of today's businesses this Thesis will focus on utilising the functionality available in Microsoft products as a filter to structure the data extracted from both the ERP and PLM systems. Microsoft Word Text documents or Excel spread sheets that have been created using these applications can be directly imported to the ERP database. Each document can be indexed with file name characteristics and search terms when transferred for the first time. On the other hand the ERP system can also export its data directly to Microsoft Word or Excel by using Microsoft Windows standard rules to structure the data in the required format. Excel based costing techniques have been developed by Durham University in order to implement cost related methods by employing spreadsheet and database functions [3.21]. Based on this work the proposed system focuses on using Excel as a main tool to filter the information extracted from the ERP system. Section 3.2 will discuss in more details how Microsoft Office can be used as a tool to capture knowledge in SMEs.

3.3.2.5 Integration of ERP with Computer Aided Design Applications

The reduction of the product development cycle time and the improvement of design quality was supported in the last two decades through the implementation of various computer aided technologies like 2- and 3-Dimensional CAD, CAE, CAM and CIM. These tools accelerate, automate and integrate various engineering and manufacturing processes and should lead to a common data system such as that shown in Figure 3.4 [3.1]. This demonstrates how the adoption of CIM could happen in the cladding manufacturing industry in the UK. The technologies commonly used in the cladding industry, such as CNC programming design software and 2/3D modelling software, are integrated using a standard Excel spreadsheet with the operational ERP system.

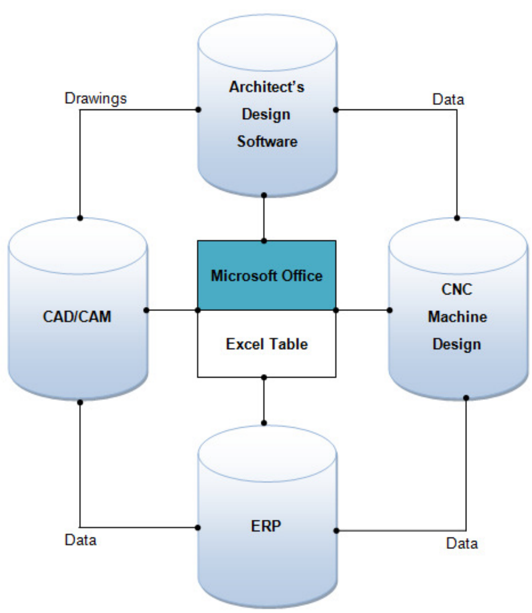


Figure 3.4 - Commercial software integration in the cladding manufacturing SMEs

However, in many companies the result after the introduction of any integration model has often been a heterogeneous, fragmented, multi-system environment, especially in product definition. Browne states that, within the engineering supply chain, manufacturers and suppliers need to work as design partners, however their design and manufacturing systems are frequently incompatible [3.4]. This introduces significant time and cost penalties as their partners attempt to share design information. Moreover, the large amount of data generated by the various CAD tools was often not centrally organised and was therefore inaccessible to other parts of the business. As a consequence, additional new product development costs were introduced as existing designed components and data, which could have reduced the development time, were not (re)used [3.1].

The main aim of ERP developments was to allow the ERP application to communicate with other systems, such as Microsoft Office products and design software. The framework of the new development was based on web technology, allowing systems to communicate with both internal and external systems through the web [3.5]. This development of ERP systems has also encouraged further research into the use of the tools to implement cost related methods with Microsoft spreadsheet and database components. This methodology benefits from a growing library of pre constructed cost engineering data on spreadsheet and database platforms [3.6].

The current state of affairs in the cladding industry can be summarised as a limited integration of software capabilities currently available and this Thesis should develop models and techniques that help a manufacturing SME to overcome this issue. This integration needs to be based on integrating the manufacturing capabilities of the cladding manufacturer and the design capability of architects into a single system that is easy to use, update and control, this will be demonstrated in more detail in Section 3.3.1.

Despite all the technological development in the field of system integration, by itself it will not meet all its objectives without considering operational processes, management structure and companies vital data flow using a structured knowledge capture system [1.12].

3.4 Knowledge Capture Management System

Section 3.2 focused on technology-oriented system integration initiatives. This section will demonstrate the process based initiatives by highlighting the importance of the operational data capture and knowledge structure in organisations. Many companies have managed to integrate their systems but have failed to manage the data generated in way that allows them to meet their initial technology investment objectives [3.33].

The arrival of the information society and the move towards the knowledge-based economy highlights the importance of knowledge and the need to manage knowledge resources, including skills and competencies. Knowledge Management (KM) brings a new dimension by focusing on people and enhances their capability by improving communication, information transfer and collaboration [3.33].

Figure 3.5 shows the proposed knowledge capture management system located as a central point between all the different organisational systems: ERP systems, CAD systems, CNC Design systems and architectural design systems.

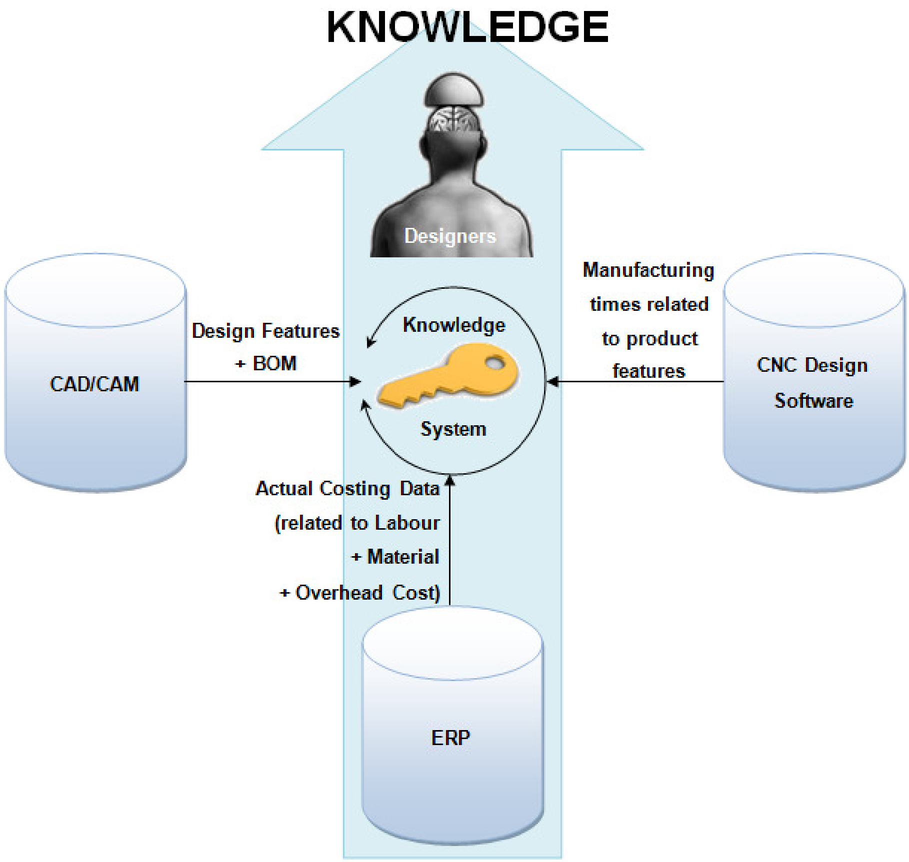


Figure 3.5 - The structure of a centralised knowledge capture management system, based on Microsoft office tools to create an Agile Manufacturing System

The model above demonstrates the flow of the actual data that will be fed into the knowledge capture system. The data flow contains information related to actual costing data generated from the ERP system, BOM and product features generated from the CAD/CAM systems and manufacturing times related to features generated from the CNC design software.

Implementing a knowledge capture management system can be a complex process depending on the approach and methodologies used. As mentioned earlier, it is hypothesised that the implementation must be a mixture between process based initiatives and a technology based initiatives. Research has focused on capturing organisational knowledge by developing complex mathematical techniques such as fuzzy logic [3.6], [3.35]. These techniques are still in the research phase and would require a large amount of resource to implement. SMEs are looking for standard systems that can capture all the relevant data and structure it according to the specified requirements.

Microsoft office tools, such as Excel linked with Access, can be used as most of the market technology available can be linked to most Microsoft Office products. Such implementation does not require a large amount of resource and can be easily managed. Techniques such as process mapping and cost management have to be considered, to map the data required to estimate product costs in the early design stage. Knowledge can be produced based on pre-structured equations and commands built on historical data or human knowledge.

Knowledge can also be captured by qualitative or quantitative methods such as interviews and questionnaires [3.1]. Chapters 4 and 5 will introduce the qualitative and quantitative methods used in this Thesis to capture internal knowledge from the case-study company used to evaluate the uncertainty in the costing system. The integration in the company of technology and systems can lead to a more structured knowledge framework. Research has indicated that the cross-functional activities integrate manufacturing knowledge and contribute to the creation of valuable and rare product categorisation [3.36].

It is important to understand the capabilities of the operational software such as ERP system and the design software such as CAD, SolidWorks and RADAN to import and export data generated from other systems. The control and structure of data imported and exported through a knowledge system will increase the certainty of the costing decision. This also can allow cladding manufactures to structure the product and operational data in a manner that contribute toward products standardisation.

Some philosophy believes that manufacturing and product control is complex, therefore it is difficult to develop a system that will solve the problem of knowledge capture. Technology integration should be limited to supplying data while the decision should be made by human [3.37]. This leads to the importance of understanding the background and responsibilities of the decision-makers. This Thesis focuses on the architect, cladding designer and estimator, the main decision-makers, who will utilise the output from the knowledge system. Architects are a mixture between artist and engineer [2.3], cladding designers are a mixture between engineers and manufacturing operators, with no in-depth background on costing [3.37], and finally cladding estimators are not designers or economists. One of the main aims from this Thesis is to close the gap between the architect and the cladding designers and estimators. Research has demonstrated the importance of adopting a structured framework for controlling and distribution of data between decision-makers to close the gap between design and manufacture [3.38.], which will be demonstrated in this Thesis under the title an Agile Manufacturing Framework.

3.5 An Agile Manufacturing Framework

Sections 3.3 and 3.4 have focused on integration and knowledge capture techniques in order to achieve the main objective of an AMS. The effective implementation of the integration and knowledge capture techniques will form an Agile Manufacturing Framework as shown in Figure 3.1. This section will identify the factors that the AMS implementation process has to consider. Developing an AMS will require a general understanding of the resources and processes structures of the business to which it is applicable. It then has to identify the main business objectives from the system, map the processes and identify the critical data required, select or develop the system, based on the agreed objectives, document all system procedures and train the end users on the system. As the AMS is based on technology integration and knowledge management; some of these factors have been already demonstrated in the previous sections.

For SMEs with limited resources, it is important to study the organisational structure and then identify the need for technology investment to support the design process. Most companies have already implemented production systems such as ERP systems and they have advanced commercial software, as discussed earlier in this Chapter. The main weakness found is that most of these organisations have failed to map the critical operational data throughout the organisational structure. [1.12]

The structure and the manner of mapping this data and extracting it from the system can support the estimation process in the early design stage.
Most design packages can generate a BOM based on component names or features. The component or the feature name must be consistent throughout the systems. Design packages can import the costing data related to the certain features from the production system and change it according to manufacturing rules that can be pre coded in the system.

It is important to develop best practice rules and procedures that control the designing process and the estimation process. The main aim of the system must be to allow the designer, manufacturer and installer to achieve a cost-effective balance between the aesthetics and function of the cladding product in this market. Finally this Chapter has briefly demonstrated that accuracy of data transferred through the AMS, has a large effect on the performance of the AMS. The questions is does the AMS discussed reduce the amount of uncertainty in the costing data? And how can the industry measure these improvements?

3.6 Summary

In demonstrating a mixed approach to technology and process oriented initiatives to meet the fast changing demands of the cladding industry, it was found that, despite all the technological development in the field of system integration, this on its own in the majority of cases will not meet the objectives without considering the operational data structure [1.12].

As a result of the gaps analysis in Chapter 2, the main stages that will lead to the AMS recommended have been discussed in detail. The techniques that have been discussed in this Chapter can be summarised as follows:

- Cost management in SMEs and process focused initiatives. This technique can address the lack of cost control within the design stages.
- Enterprise integration technologies for SMEs, This technique can address standard methods for communication between the cladding manufactures and architects.
- Knowledge management. This technique can address the cladding product standardisation.
- AMSs and the cladding supply chain.

Finally the main objectives from the research are to manage and structure the data flow in the company between the ERP and design software to allow the designer to take more accurate decisions regarding their designs. This next Chapter will answer some of the questions raised in relation to the effectiveness of integration in the cladding industry caused by data uncertainty.

4 DATA UNCERTAINTY, DEFINITIONS & METHODOLOGY

4.1 Introduction to Data Uncertainty & Risk

The previous Chapter has shown that a significant problem for the implementation of an AMS is the collection and analysis of data generated from day-to-day operations, because the accuracy of that data is often questionable, due to the effect of many variables, internal and external to the company.

Previous Chapters surveyed existing research related to the technology management and data integration. This Chapter will describe how data can be collected to support this Thesis to reduce risks in the cladding sector and implement an AMS. It will also discuss the methodology used in this Thesis, clarify the reasons behind it and describe the quality of data used. The methodology outcomes mentioned in the previous Chapters were based on developing an AMS that allows SMEs to improve the cost estimation process especially in the early design stages. Figure 4.1 shows the stages that form the AMS. Figure 4.1 has evolved from Figure 3.1 in the previous Chapter it can be noticed that the risk management of uncertainty control is now part of the methodology forming the research presented in coming Chapters.

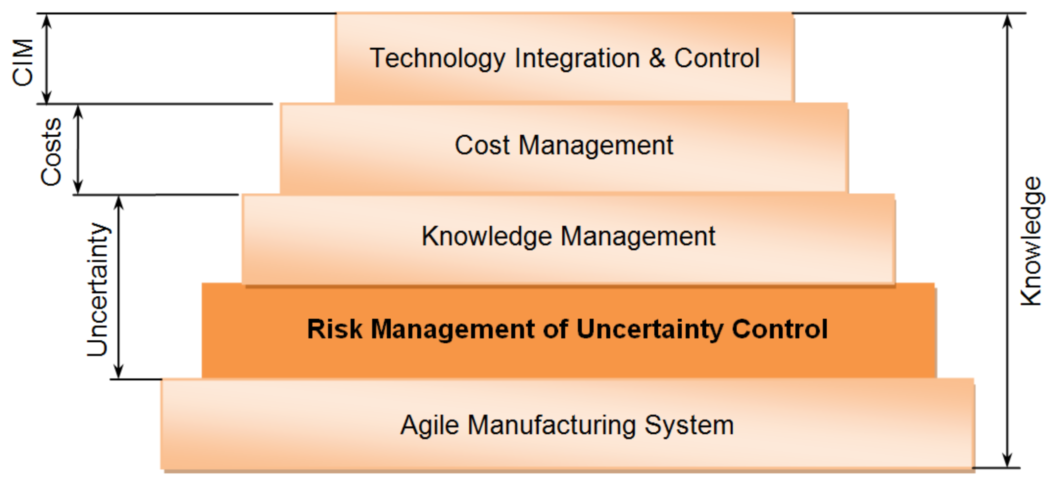


Figure 4.1 - Agile Manufacturing System Parameters

The main aim from any system integration implemented in a cladding SMEs is to establish knowledge to assist designers, managers and estimators to take more accurate decisions about costing, building aesthetic and manufacturing constraints. Figure 4.2 demonstrates the concepts that need to be followed to control and structure the data transferred between systems and allow the cladding manufacturing SMEs to establish a structured output leading to knowledge. The management of cost and uncertainty in addition of the adoption of CIM form an important part of the concept behind Figure 4.1. In gathering the data for this Thesis, it was found that other research on system integration and cost management related to the cladding industry lacked any consideration of risk and uncertainty factors as an integral part of the estimation process.

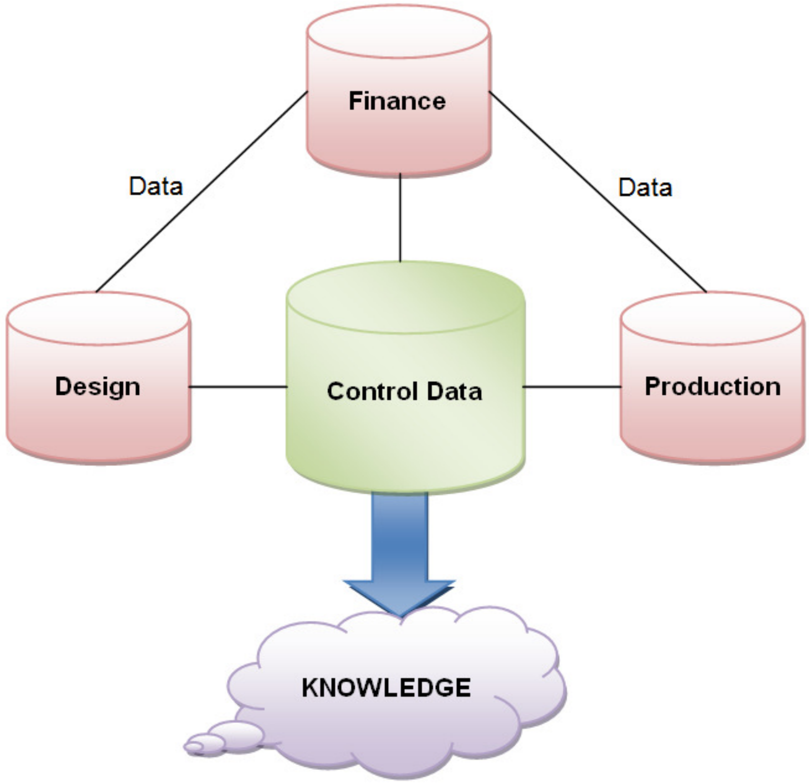


Figure 4.2 - Knowledge Capture – Data Transfer Structure in Cladding SMEs

The main data collection methodology is based on proving the applicability of the models in Figure 4.1 and Figure 4.2 and using the management methodology presented in this Chapter to resolve the arising from earlier Chapters.

Section 4.4 will consider the risk associated with the variability of different types of commercial and operational data. This consideration will involve the analysis of data generated from this Thesis using both quantitative and qualitative methods. The goal of this part of the research will be to:

- Solve the lack of understanding of the cladding industry supply chain and apply a standard project categorisation to cladding industry SMEs
- Solve the lack of structured approach related to risk calculation
- Solve the lack of understanding of risk and its relation to certainty in the cladding industry
- Solve a lack of the adoption of structured approach related to the selection, implementation, control and integration of technologies related to the cladding industry
- Solve the understanding the impact of integration on the risk associated to the cladding projects
- Identify the key factors that impact the project costing estimation process

- Apply the models to identify the importance of involving the cladding manufacturers in the early stages of product and project design
- How to develop tools for designers to utilize historical ERP and design systems data to prepare a more accurate costing for new cladding product designs

Before discussing the how the above goals are to be met, it is important to clarify some of definitions that will be used in this Thesis.

4.2 Definitions

4.2.1 Introduction

This section defines the terms to be used in the research which will be subject to verification by the data analysis. Some terms defined here were verified by earlier research, which is appropriately acknowledged.

4.2.2 General Terms

Gross Margin: Defined as a percentage equal to the Gross Income divided by the Net Sales. Gross Margin is a good indication of how profitable a company is at the most fundamental level. Companies with higher gross margins will have more money left over to spend on other business operations, such as marketing research and development [4.1].

Opportunity: The possibility of realizing a favourable outcome and the impact this outcome has on the involved party. Opportunity is positive risk and can be identified and managed in a similar way to risk [4.2].

Uncertainty: The gap between the information required to estimate an outcome and the information already possessed by the decision-maker [4.2].

Risk: The possibility of suffering loss or harm and the impact that loss has on the involved party. Risk can be characterised in terms of its Severity where:

Severity = Likelihood of Occurrence x Magnitude of the Impact [4.2]

Risk can be assessed in three main components:

- Strategy
- Impact
- Probability

These three components can be defined within the following framework:

Risk Strategy:

- Accept: No action to avoid, transfer or mitigate.

- Mitigate: Lessen the impact
- Transfer: Insurance, outsource complex parts
- Avoid: Change plan or process

Risk Impact:

- Insignificant: Negligible; Critical systems unavailable for less than one hour
- Minor: Inconvenient; Critical systems unavailable for several hours
- Moderate: Client dissatisfaction; Critical systems unavailable for less than 1 day
- Major: Major loss of revenue; Critical systems unavailable for 1 day or series of prolonged outages
- Catastrophic: Loss of revenue sufficient to endanger the business; Critical systems unavailable for protracted period

Risk Probability:

- Rare: 1 in 100000
- Unlikely: 1 in 1000
- Possible: 1 in 100
- Likely: 1 in 10
- Almost certain: 1 in 2

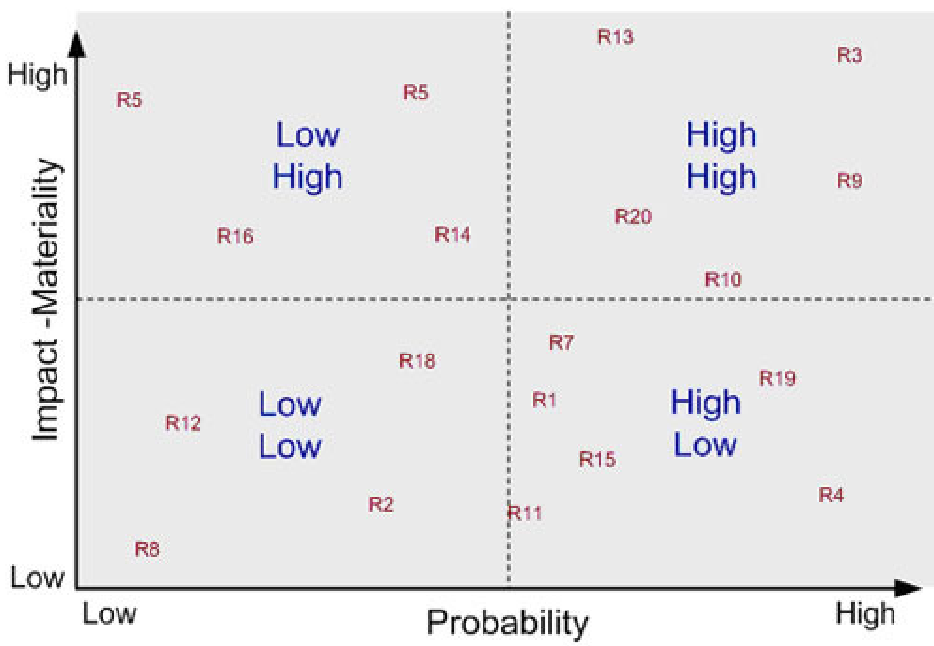


Figure 4.3 – Example of a Risk Assessment tool that can be used to measure the impact against the Likelihood / probability [4.5]

Figure 4.3 shows a tool that can be used to measure the relationship between risk impact and probability. When the probability and impact are high, risk will be high. In the cladding industry risk is directly linked to the project external variables and the gross margin depends upon it. Therefore in this Thesis risk will be defined in the context of the impact of different project types on gross margin, as part of the management strategy summarised under the AMS.

Risk Analysis: The process of identifying and quantifying risk factors by estimating likelihood and magnitude of impacts [4.2].

Risk Management: The identification, assessment and prioritization of risks, defined as the effect of uncertainty on objectives, whether positive or negative [4.2]

Risk Factor - Unquantified: An event or issue that may cause harm to the project from the organisations view point. Risk factors can be stated in the form:

> "X may happen during the execution of this project, which may impact Y", or
>
> "If X occurs, then an impact to Y will be realized."

For example: "If the lay-down area is not optimized then productivity will be low"
or "segmental liners may not be available prior to construction thus delaying project" [4.2].

Risk Factor - Quantified: Defined as the probability of error in production due to unexpected factors. In this case it can be considered as the chance of an increase in estimated cost or decrease in estimated Gross Margin. This Thesis has identified the unexpected factors in the cladding industry related to human, technology, machine accuracy and knowledge factors [4.2].

Different risk factor calculations will be used as part of the project data demonstrated in Chapter 5 below are their definitions:

Predicted Gross Margin Probability Factor

The Predicted Gross Margin Probability Factor based on the Internal Questionnaire results, referred to as the Predicted Risk Factor 1, the equation for which can be expressed as:

Risk Factor 1 = (100 - Certainty of Final Quote) - (Planned Gross Margin for a standard product)

This normalises the Risk Factor to the standard product Gross Margin.

Actual Gross Margin Probability Factor

The Actual Gross Margin Probability Factor based on the results of the Internal Questionnaire, referred to as Actual Risk Factor 1, the equation for which can be expressed as:

Risk Factor 1 = (100 - Certainty of Final Quote) - (Actual Gross Margin for a standard product)

Risk Assessment Weighted Factor

The Risk Assessment Weighted Factor based on an Internal Questionnaire score and a Risk Assessment for each cladding project in Appendixes C & F. This factor will be referred to in this Thesis as Quantified Risk Factor 2. This score depends upon the impact of certainty using scale from 0-5 of the activity being queried in that Internal Questionnaire within the company.

Margin Difference Indicator Risk Factor 3

This Margin Difference Indicator is based on the results of the project as installed. It will be referred to in this Thesis as Risk Factor 3. The equation for this Risk Factor can be expressed as:

Risk Factor 3 = - (1- Final Cost/Initial quote) - Planned Margin

4.2.3 Types of Projects

The following definitions can be used to classify for different types of cladding projects, permitting a more accurate determination of risk.

Standard Projects

Standard Projects have a low complexity and are based on Standard Products that have clear parameters and manufacturing operation costing structure**.**

Semi-Standard Projects

Studying the results from the Industry specialist interview with Dr. Stephen Ledbetter, it was identified that Semi-Standard projects can be divided into two main groups, mass- and complexity-based.

Mass-based

Mass-based projects use pre-designed products that can be changed within pre-designed parameters to suit a building shape. Usually the aesthetic impact on these kinds of projects comes from the use of a large volume or mass of standard cladding components rather than from design a new individual cladding component.

Complexity-based

Complexity-based projects are based on new individual cladding components that require development in the early design stages. Usually the design process introduces a complex geometry into an existing standard product.

Innovative Projects

Projects that are based on completely new cladding components that will need to be developed to suit the project architect or contractor requirements on a particular project. Usually these kinds of projects will require in depth product development and design between the different project parties.

As discussed in Chapter 2 project categorisation has been defined in relation to complexity and in an SME a project could be defined using the following checklist:

- Can the project cost calculated from a standard price list?
- What is the parts variety in the project?
- Can a mass of standard parts achieve the project aesthetic?
- Have the project features been manufactured before?
- Does the company have the capability to manufacture the parts to produce the project features?
- Does the manufacturer need to produce detailed manufacturing drawings to achieve the specific project requirements?
- Who will be responsible to produce the detailed manufacturing drawings for the project?

Products with a standard price list that can be calculated using fixed prices based on manufactured features will categorised as Standard or Semi-Standard Mass.

When a mass of standard products can achieve the aesthetic the project is usually categorised as a Semi-Standard Mass-based project. Projects with high part variety are categorised as Semi-Standard Complexity-based projects. Projects that contain parts with new features, not manufactured before, are considered Innovative. For Standard and Semi-Standard Mass products the drawings are usually done by the contractor, based on standard parameters pre-issued by the cladding manufacturer. For Semi-Standard Complex and Innovative projects all the detailed drawings are usually done by the cladding manufacturer, based on the architect's specification and initial design.

4.3 Introduction of Risk Management to the Industry

Risk is an important part of our daily life and the more control that can be introduced into a process the less risk there will be in its execution. The principles introduced in the insurance, banking and aerospace industries to control risk have been adapted and applied here to the cladding supply chain [4.4] using the risk factor principle to predict the risk percentage of a construction project, involving cladding .

Risk management is important for the insurance industry, who take over risk from customers. Insurers consider every available quantifiable factor to develop high and low insurance risk profiles. The level of risk determines the insurance premium. Generally, insurance policies involving factors with greater risk of claims carry higher premiums[4.4]. For example, many factors affect the premium paid for a car insurance. Each is statistically-based on a risk for a specific population, which the insurer has assessed the customer to be in. The higher the risk associated with a customer, the more he or she is likely to pay for cover. Some of the these risk factors are elaborated on below, but there are others, including driver's gender, miles driven per year, purpose for using the vehicle, for example commuting to work, using for work, leisure only and so on. With such information, insurers can evaluate insurance policy risk to a high accuracy. To this end, insurers collect detailed information on the policy holder and the insured objects. Statistical methods, based on data mining, can be used to analyze or to determine insurance policy risk levels and this is the basis of much of the current industry for on-line auto insurance.

Classification models can categorise predicted cases as "risky" or "safe" and these can be supported by neural networks [4.4]. Intuitive classification is appealing because it is simple and can be made using terms that anyone can understand without professional interpretation. However, there are serious dangers in applying intuitive classification to insurance risk management. The problem lies with the fact that insurance claims are low likelihood events, say less than 10%. Developing predictive models with skewed data is difficult, especially with decision tree classification. Decision trees develop predictive models through segmenting populations into smaller groups repeatedly. It uses the dominant or most frequent value of each segment as the predicted segment value. Dominant values are the values represented by over 50% of the population. Insurance customers are already well screened, so it is possible that no segments may contain risky customers in excess of 50%. Even if they do exist, they may only be slightly over 50%. Segments with 49% of customers having a claim history will be predicted as not "risky", although they are a very high risk group. This type of model will have very low accuracy in accurately predicting customers as "risky". Much worse is that, as a consequence, more non-risky customers may end up being classified "risky" [4.4].

The construction industry is plagued by risk and has frequently suffered poor performance because of the lack of standardisation and lack of risk management, especially in SMEs. There are a number of risk management techniques available to help alleviate these issues, but they are usually based on operational research techniques developed in the 1960s and for the most part have failed to meet the needs of construction industry project managers. In this Thesis, a hierarchical risk breakdown structure is used to develop a formal model for qualitative risk assessment [4.5]. Construction projects have to be executed in a complex environment characterised by uncertainty or risk and failure can be caused by three main factors, time, budget and quality [4.5]. These factors are directly influenced by lack of planning or communication standardisation between project stakeholders [1.6]. Risk management in the construction industry can be used for reducing potential risk impacts on time and cost project parameters [4.6]. Mixed qualitative and quantitative approaches have been proposed to manage that risk. In SMEs with limited resources most risk management methods have failed either due to their complexity or their impracticability of use [4.7].

This Thesis focuses on risk management as part of the management framework proposed in Chapter 3. Risk management is an iterative process, similar to cost management [4.8]. Risk can be identified and analysed by collecting historical data result from the technology integration and knowledge management systems. As a result risk can be reduced or removed by the implementation of preventative actions, which can be monitored from data extracted from the ERP system.

This section has reviewed the literature related to the use of risk management methodologies. This concept, used in both banking and insurance industries, can be achieved in the cladding industry by categorising projects according to their complexity and using Risk Assessment Sheets, containing a mixture of qualitative and quantitative risk assessment measures appropriate to cladding projects.

4.4 Entropy in Information Systems

4.4.1 General

What is the risk in a manufacturing process and how can it be measured? Previous research has explored risk and tried to express it mathematically [4.1] [4.9]. This Thesis will use the novel idea of information entropy to express the risks of gross margin variation associated with different cladding projects, since it is largely the consequences of poor information that cause the risk in the industry. It is important to understand that manufacturing variances can affect cost in early product design stages and the larger the variances, the higher the later risks will be. Adopting the AMS suggested in early Chapters should control some of the variances, resulting in more accurate data at lower risk. The data will be collected using quantitative and qualitative methods described later.

In information theory, entropy is a measure of the uncertainty associated with a random variable which is usually data. The term by itself in this context usually refers to the Shannon entropy, which quantifies, in the sense of an expected value, the information contained in a message, usually in units of bits. Shannon entropy is a measure of the average information content missing when one does not know missing value of the random variable [4.10].

Within thermodynamics, statistical mechanics and information theory entropy is a measure of the number of ways in which a system may be arranged, often taken to be a measure of "disorder", the higher the entropy, the higher the disorder. Increases in entropy correspond to irreversible changes in a system, because some energy must be expended, for example as waste heat, limiting the amount of work a system can do. Thermodynamic entropy is a non-conserved state function that is of importance in physics and chemistry. Historically, the concept of entropy was developed in order to explain why some processes are spontaneous and others are not. Systems tend to progress in a direction of increasing entropy. Entropy therefore measures a system's tendency towards spontaneous change. For isolated systems, entropy never decreases. This fact has several important consequences in science: first, it prohibits "perpetual motion" machines; and second, it suggests an arrow of time [4.10].

There are close parallels between the mathematical expressions for the thermodynamic entropy of a physical system and the Shannon entropy in an information system which lays out the basic elements of communication as follows:

- An information source produces a message
- A transmitter operates on the message to create a signal, which can be sent through a channel
- A channel is the medium over which the signal, carrying the information that composes the message, is sent and a channel can produce disorder or missing information
- A receiver, which transforms the signal back into the message intended for delivery
- A destination, which can be a person or a machine, for whom or which the message is intended [4.3]

One of the means of measuring the quantity of information is Shannon entropy function. As mentioned earlier that the entropy measures the amount of information passed from a transmitter to a receiver, and it can be considered as an index of the uncertainty level of a process or activity.

Mathematically Shannon Entropy can be expressed as a group of events and the probabilities of the events to accrue.

The Entropy E is defined mathematically as follows:

H=$\sum_{i=1}^{n} p_i * \log{(p_i)}$
Where $0 * ln(0) = 0$

The Function H is continuous in p_i, H=0 if there is a maximum certainty, and H achieve is maximum when uncertainty is maximum. The knowledge about a probability of an event to occur reduces H in which reduces the uncertainty. [4.11].

Uncertainty in this context can be measured on the same scale that information entropy was measured by Shannon, in which 1 is high and 0 is low entropy. The higher the entropy, the greater the uncertainty in the information system linked to the risk associated to any project. This method was applied to quantify the risk associated with product development [4.1]. Other research [4.9] collected at least 1000 data values from each example to form a mathematical probability formula for calculating Shannon entropy. Alternatively [4.12] defined system complexity using an entropy function for each product or project based on a complex mathematical model representing multi-assembly or supply chain complexity situations.

4.4.2 Entropy Applications

The entropy concept was used in the automotive and aerospace manufacturing [4.12] by different researchers demonstrating the relationship between complexity and uncertainty. Olvera [4.13] used the entropy concept to assess the uncertainty of supply chain information-sharing among partners. Information is equivalent to the removal of uncertainty and uncertainty and entropy are identical [4.14]. In this context, to manage a manufacturing system well, decision-makers need a reliable picture of process and costing data, with streamlined feed-forward and feed-back of information, coupled to optimal decision-making between project stakeholders [4.15], achieving minimum entropy/maximum certainty. According to Shannon the entropy function is regarded as a quantitative uncertainty measure [4.13] By statistical analysis, a significant negative correlation between system complexity and manufacturing performance was concluded based on results collected from 70 automotive-based assembly lines around the world [4.16]. The more processes and data are controlled the less complexity and risk in the system, leading to lower entropy.[4.17]

Meijer used the entropic impact as a measure of complexity in a manufacturing system [4.18], defined at the organisational structure boundaries where manager data uncertainty occurred. The interaction between human resources and organisation systems, where decision-maker can make choices from options influenced by uncertainty and manufacturing constraints, was considered. Meijer confirmed the argument that structured manufacturing data is required to reduce risk and uncertainty to a certain level. The amount of information needed to reduce uncertainty can be used as a measure of decision-making complexity [4.19]. Complexity of the present state of a system can also be linked to the human and social organisations within the system [4.20]. This supports the argument of Agrawal [1.12] quoted in Chapter 1 regarding the training of operation and cost management workers in the formation of any system to reduce complexity.

4.4.3 Entropy for the Cladding Industry

These references demonstrate the relationship between uncertainty, complexity and entropy in the automotive, electrical and aerospace manufacturing industries. How can entropy be applied in the cladding industry and what will be the relationship between entropy and risk? Due to the limited number of projects from the cladding SME and the lack of data volume available from them it has not been possible to apply the quantitative methods described above. The research will simplify the entropy application to measure the effectiveness of an AMS to a cladding SME. The assumption will be based upon the idea that the more complex the system is the more uncertain, the higher the entropy and the higher the risk. The entropy concept will then be used subjectively to measure gross margin impact quantitatively. In reality that measurement will contain qualitative trends to enhance cost and gross margin decision-making in early cladding project design stages. The qualitative concept behind Shannon's theory will be used to define the variation of Gross margin in the context of cladding industry. Shannon's argument focused on the importance of the transmission of information through a channel of communication to give a clear message. This argument can be applied to most operational systems used by manufacturing companies. The more organised and clear the data transferred between the systems, the more accurate the output from the systems will be. Shannon linked the disorder of a system with its entropy level. The higher the entropy the more disordered the system will be. The lower the entropy the more organised and accurate the transmission of data will be between the systems. The principle adopted in this Thesis is that this concept of information system entropy can be applied to operational data collected through management systems such as PDM, ERP and CAD/CAM/CAE. The more disordered the signals transferred between these systems the more uncertain will be the messages received from those systems. The output of these systems such as cost data and project estimates will depend on the organisation and the structure of the systems used. The more control the system has over the variables produced in any process, the lower the entropy will be and the more accurate the output will be. As the entropy measures a system's tendency towards spontaneous change, the operations data should be controlled so that the level of spontaneous change is low. The lower this control the greater the disorder and the higher the risk of an incorrect decision, especially a decision related to product costing and system project price estimation.

This Chapter also stresses the need in the cladding industry to address gross margins, therefore this Thesis will apply a simple entropy or uncertainty percentage scale common to all the case-study projects Gross Margin Variation Risk as follows:

Entropy	Low 0%	High 100%
Uncertainty	Low 0%	High 100%
Certainty	High 100%	Low 0%

Therefore the certainty of Gross Margin Data will complement the uncertainty, thus the uncertainty = 100- certainty. By looking at the data collected from projects shown Appendix A it was found that the more disorder in the data the higher is the entropy. This data disorder can be related to the uncertainty in the project. On the other hand the lower the entropy, the less the disorder, the lower the uncertainty. Appendix C will also demonstrate the effect of data size on cladding project complexity, which could have been used as a measure of entropy.

This assumption is based on the concept that the more the operations data is structured and integrated within the organisation then the lower the entropy the less the disorder and uncertainty will be in the communication between the transmitter and receiver of the data. Any disorder in the data communicated between two systems can lead to higher number of variables and the higher the entropy and the uncertainty in the output results.

Finally by nature entropy always increases and whenever you have a decrease in entropy caused by the production of ordered systems, as in technological development, there must be an equivalent increase in entropy elsewhere, raising the question whether high entropy is always bad or is zero entropy a possibility? To answer these questions, the whole concept of entropy application needs to be defined in the context of gross margin variation were zero mean that there is 100% certainty and the output of any system is fully predictable. Also the application of entropy in this Thesis is based on the entropy being dependent on the data size and product complexity which is clearly defined in earlier Chapters. The complexity of the mathematical concept of entropy has been used in a simple manner, to form part of manufacturing management strategy that combines both science and social science in the context of cladding industry risk management. In fact a cladding industry management system with zero entropy could only occur if a cladding project were perfectly controlled, which could only arise if it were impracticably simple.

4.5 Research Philosophy and Methodology

In order to apply these ideas of entropy to risk in data within a cladding manufacturing SME it is necessary to define a research philosophy and methods to be applied as follows.

4.5.1 Research Philosophy

In the context of research, a philosophy holds the beliefs about the way data or information should be gathered [4.21]. A scientific philosophy is a set of basic assumptions based on beliefs about the nature of realities and their truth or falsity, not subject to empirical testing [4.22],[4.23]

Inductive or empirical research starts with an observation [4.24], [4.25].Theoretical sampling is the process of establishing the number of cases needed to represent different aspects of reality [4.26], [4.27].

Primary data sources are unpublished to date and gathered by the researcher. Secondary data sources refer to any previously published materials. The sources of evidence can be divided into documentation, archival records, interviews, direct and participant observation by questionnaires and case studies [4.28].

Another methodology issue is the interaction between the researcher and the observed phenomenon [4.29],[4.30].In natural sciences experimental conditions are usually repeatedly reproducible, in time and space and the researcher can make repeated and accurate measurements in an environment where his or her impact is generally negligible [4.27].However in real world business environments variations of variables and their inter-relations cannot be investigated experimentally because the researcher cannot intervene to make accurate measurements [4.31].Research has to be based upon the subjective gathering of data using, for example questionnaires and interviews. Managerial and operational research used in this Thesis must be positioned between natural and social sciences; human interactions are therefore an integral part, but not the main focus, of the research. When studying the managerial real world issues the researcher is often directly involved [4.32], [4.33].As time progresses and experience develops amongst involved participants the experiments cannot be repeated additionally customers and competitors cannot be controlled [4.27].Therefore business context and human relations involve with it are unique. The gathering of data based on human experience has to be quantified to measure any result.

Two methodologies have been used in this Thesis to quantify the uncertainty of data in a cladding manufacturing SME. The first was by conducting different types of interviews to determine risk factors. The second was by applying the risk factors to a case-study model. The research methodology and philosophy of this Thesis was aimed at validating the relationship between this data and the entropy determined by the results of the questionnaires.

Section 4.5.2 will demonstrate the applicability of the methodology for gathering managerial and operational experience through various sources of evidence to this Thesis.

A basic question arising from this Thesis philosophy is: How can this Thesis produce new knowledge? As suggested in Chapter 3, system integration and data uncertainty in the cladding sector is a wide subject that was an issue since the start of architectural use of industrialised materials. However, this Thesis is a first attempt to quantify design and manufacturing process risk in a cladding manufacturing SME and the result of the quantification dose represent a new knowledge contribution.

4.5.2 Research Methods

The commonest classification of research methods is into quantitative and qualitative [4.34].Quantitative research methods originate from natural sciences studying natural phenomena and their interaction using measurable and numerical evidence. A controlled laboratory experiment is considered an ideal method to explore variables and their relations [4.35], [4.36].

Qualitative research is an inquiry process of understanding based on distinct methodological traditions of inquiry that explore a social or human problem. The researcher builds a complex, holistic picture, analyses words, reports detailed views of informants and conducts the study in a natural setting [4.37]. Common qualitative research methods, such as interpretism [4.38], do not provide the same level of control as quantitative experiments, used in positivism.

This Thesis has used the following quantitative and qualitative methods to confirm the applicability of the operational models. The qualitative methods have utilised Interviews with Industry Specialists and Section C-D in the External Questionnaires. The quantitative methods used have been in the form of a Case-study, an Internal Questionnaire, Section A-B of the External Questionnaire, Project Data Sheet and Risk Assessment. Therefore a mixture of quantitative and qualitative methods was used for collecting actual data from the industry through Interviews, Case-study and internal and External Questionnaires, as summarised in Table 4.1.

Stakeholder	*Internal Questionnaire*	*External Questionnaire*	*Case-study*	*Interview with Industry Specialist*
Architects		☑		☑
Cladding Designers	☑	☑	☑	☑
Cladding Estimators	☑	☑	☑	☑
Sub-Contractors		☑		
Main Contractors		☑		☑
Business Owners	☑	☑	☑	☑
Academics		☑		☑

Table 4.1 - Data Capture Methods

4.5.3 Quantitative Methods

In the social sciences, quantitative research contrasts with qualitative research and can be defined as the examination, analysis and interpretation of observations for the purpose of discovering underlying meanings and patterns of relationships, including classifications of types of phenomena and entities, in a manner that does involve mathematical models [4.25].

4.5.3.1 Internal Questionnaires

The Internal Questionnaire is a quantitative method as it uncovers the trends that highlight the certainty level associated with the risk factors, selected as part of this Thesis. The results from the questionnaires will be analysed and quantified to demonstrate how systems integration and linking operational data with architectural design can reduce the entropy or uncertainty, reducing the risk associated with a project. A questionnaire is a list of written questions that can be completed in one of two basic ways.

The Internal Questionnaire, see Appendix C, was applied to the cross- functional teams in the case-study company. The main aim of the Internal Questionnaire was to determine the certainty level using the entropy methodology demonstrated earlier in this Chapter. The collection of answers was based on the sales, design and production department of the case-study company PSP. The different cladding projects which were assessed, see Appendix A, are classified as standard, semi-standard and innovative, which have been used as categories of uncertainty. The factors these projects have been assessed against are:

- Parts variety
- Costing figures
- Manufacturing constraints
- Aesthetic impact
- Parts complexity

The results from each questionnaire have been fed into a structured spreadsheet to analyse the trends of the uncertainty level in relation to the internal employee's knowledge of the product and the results will be analysed in Chapter 5.

Answers to the Internal Questionnaire were based upon the opinions of employees in the author's company and therefore may be considered qualitative. However these answers quantify the situation in the case-study company and provide a mathematical trend which provides the basis for further evaluations. Therefore, after collecting this data, opinions and analysis will be needed from the wider industry to validate the answers obtained. Sections A and B in the External Questionnaire focused on the numerical quantification of the results from the Internal Questionnaire based on a wider industry application as will be discussed in Section 4.4.4.

4.5.3.2 Project Data Sheets and Risk Assessment & Case-study

The main aim of the Case-study was to draw general conclusions from a number of limited project cases with many complex variables by interpreting a series of events in a conclusive manner. Case Studies are one appropriate research approach to answer the "why" and "how" [4.28], [4.27].

Project Category	Human Factors	Project Factors	Product Factors	Manufacturing Factors	After-Sales Factors	Total Factors	Consolidated Total Factor or Certainty (C) (%)	Quantified Risk Factor 2 (%) or Uncertainty (100 – C)

Table 4.2 – Introduction of the Risk Assessment Data Sheet Analysed in Chapter 5.

The Internal and External questionnaires were aimed at quantifying the Risk Factors associated with different types of project. In addition the Case-study was used to apply the methodology and prove the applicability of the methods presented in this Thesis. To confirm the risk calculation and compare the Risk Factors calculated from the questionnaires with the actual risk factors calculated from live projects collected from the case-study. The data collected from the projects are based on the initial quotation compared with the actual cost and profitability of the projects. The data resulting from these sheets was analysed in Chapter 5 in more detail and compared with the results extracted from the External and Internal Questionnaires. The other method that was used in this Thesis is the risk assessment project data sheets, Appendix F & Table 4.2. This assessment was based on allocating variables related to risk and giving them a weight according to its impact on the costing value of any project. The Risk Assessment Sheet focuses on the allocation of the main variables linked to the level of certainty associated to each type of projects. The variables have been divided into five sections:

- Human Factor
- Project Factor
- Products Factor
- Manufacturing Factor
- After-sales variables Factors

Each section contains a list of variables weighted from 1-5 by the senior management of the case-study company. The research applied this assessment to the exemplar projects demonstrated in Appendix A on this assessment sheet to compare the results. Each estimator was asked to answer questions related to each project and score the certainty level by a scale 1-5. The impact is allocated by the management at the start of the assessment, allowing it to be changed using the historical data collected from completed project. The data can be collected using the existing ERP technology being fed directly through the utilization of the database that is already structured in the ERP system. The estimation process, project related data and company related variables identified in Appendix F can be updated at set time intervals. The multiplication of their impact factor leads the senior management to obtain a level of uncertainty can then give an average figure for the certainty level associated with that project. The certainty calculated will be presented as a percentage associated with the entropy on the scale of 0-100%. The certainty figures obtained are then referred to numerical predicted Risk Factor. The uncertainty level is directly linked to the risk associated with each project. The more variables in the project the more uncertainty and the more risk. The results from this actual data collection can help in quantifying some of the subjective results gathered in the Internal Questionnaire. The results from the Project Data and the Risk Assessment in addition to the Interview with Industry Specialist presented in Appendix B. can confirm the applicability of the research in specific characteristics of cladding companies.

4.5.4 Qualitative Methods

Qualitative research often categorises data into patterns as the primary basis for organizing and reporting results. Qualitative researchers typically rely on the following methods for gathering information: Participant observation, Non-participant observation, field notes, reflexive Journals, structured interview, unstructured interview, analysis of documents and materials [4.27].

The qualitative methods to be used in this Thesis are the External Questionnaires and the Interviews with industry specialists that have been conducted. The qualitative methods that will be used in this Thesis are the live study from the cladding industry and the collection of actual data collected from the projects completed by PSP the case-study company. The data collected will be used to confirm the assumption concluded in the industrial Internal Questionnaires and Project Data Sheets collected from the case-study.

Firstly respondents could be asked to complete the questionnaire with the researcher not present.

Secondly respondents could be asked to complete the Internal Questionnaire verbally, which in this Thesis counts as an interview. Interviews can be conducted using closed or open questions. Closed questions produce quantitative responses, for example from yes or no answers [4.39] while open questions produce qualitative responses. This quantitative section will concentrate on the External Questionnaires using closed questions, while open questions will be reserved for the Interviews in the qualitative section.

4.5.4.1 Interviews with Industry Specialists

Qualitative interviewing encouraged interviewees to describe their experiences in the cladding industry in depth, revealing more clearly the quality of its accomplishments, as shown in Appendix B. This involved a more open-ended conversation directed at a limited number of Industry Specialist rather than the formal questionnaires above. This technique can be used before formal survey development or as a follow-up strategy to dig deeper into anomalies and reveal changes needed to maximize success in the research [4.39].

The interviews were used to confirm the validity of the assumptions behind the research. Some of the Industry Specialists were interviewed using structured prepared questions related to the new contribution of this Thesis toward the scientific approach of cost estimation, technology integration and risk management in the cladding industry. The questions were designed to draw upon the experience and the background of the specialist. The main purpose of the interviews was to confirm or otherwise the applicability of the methodologies used. The answers from the interviews have been used as part of the industrial application and Case-study in Chapter 6.

4.5.4.2 External Questionnaires

This External Questionnaire, see Appendix D, is an extension of the Internal Questionnaire used to validate its results from the points of view of architects and contractors, external to the case-study company.

The main aim of the External Questionnaire was to collect subjective external industry information, giving an impression of the risk trends in the external market for the different project types, to back up the main argument from this Thesis and prove the applicability of methods proposed. Appendix D lists the pre-structured questions designed to collect industry expert responses in relation to the certainty levels related to the costing, manufacturing and aesthetic factors. The External Questionnaire was divided into two main parts. The first section A, B focused on the numerical quantification where a trend could be compared with the results calculated from the Internal Questionnaire. Section A and B of the questionnaire were aimed to quantify the results from the internal questionnaire. Section C and D were based on subjective qualitative answers. Section C. of the questions was based on confirming the importance of the cladding companies' involvement in the early stages of the design and to confirm the importance of technology integration importance to the accuracy of the estimation process. Section D. summarised the future recommendation from the industry experts on which stage the cladding manufactures should be involved in. Finally the questions confirm the best used method of communication between cladding manufactures and architects. The questions highlight the recommendation of using certain design and operational system that support data integration between architects and its suppliers. Chapter 5 will analyse all data collected from the completed External Questionnaire.

4.6 Summary

This Chapter has demonstrated the risk associated with the variables involved in the analysis of data generated from this Thesis. Risk management and uncertainty control have been added to the AMS developed in the earlier Chapters. To answer the fundamental questions underpinning this Thesis, an entropy methodology was used to quantify uncertainty and risk in cladding projects. The higher the entropy, the more the uncertainty and the higher the risk associated with the project. The accuracy of some data generated from the cladding industry may be questionable due to the effects of many internal and external variables in that industry, leading to project uncertainty.

5 RESULTS AND ANALYSIS

5.1 Introduction

The first section of this Chapter will focus on the data produced from the Internal Questionnaire. The data was collected through interviewing PSP's internal design and management team. The results focused on the team's uncertainty level related to the costing and manufacturing constraints in the procurement stages of different cladding design, manufacturing and installation projects identified in Appendix A. The second section will focus on the data produced from the External Questionnaire, which adopted a similar question structure to the Internal Questionnaire but expanded the questionnaire's application to architects, contractors and cladding manufacturers in the UK and international cladding architectural related organisations. The External Questionnaire covered additional areas related to the applicability of technology integration, the importance of costing and manufacturing constraints and finally the involvement of cladding manufacturers in the early stages of the product and project design.

A state of the art analysis of Risk Factor calculations related to the different types of cladding projects will be discussed in detail in the following sections. A risk assessment datasheet will be used to prove the effect of some of the factors revealed in the Internal and External Questionnaires to the Risk Factor of any project. PSP operational data will then be used to prove the applicability of Risk Factors calculated based on real projects. The analysis was based on Risk Factors, certainty level, calculated from the Internal Questionnaire and actual Risk Factor calculations based on the data collected from the projects.

5.2 Summary of Results

The results for the projects in Appendix A will be summarised in Table 5.1 based on the Risk Factors defined in Chapter 4. The results of the Internal and External questionnaires evaluated in Appendix C, D and E will also be analysed in the context of data uncertainty. Table 5.2 will summarise the results from the Risk Assessment sheets in Appendix F. The data collected through the different methods are linked and analysed according to the product and project categorisation defined in Chapter 4. Finally quotes from industry specialist will be used to backup the numerical results.

5.3 Analysis of the Internal Questionnaires

5.3.1 General

The Internal Questionnaires subjectively assessed the entropy or uncertainty level (0-100%) of different phases in the cladding procurement process, based on costs, manufacturing constraints and numbers of parts. The answers to the questionnaire also considered different product categories, based on the standard, semi-standard and innovative definitions. This section will present the results based on the costing, aesthetic Impact and complexity and mass factors, See Appendix C for the detailed Questionnaire figures used in this Chapter.

The phases of the cladding life-cycle shown in Table 2.1 were combined and summarised to form a structure used in the Internal Questionnaire as follows:

I. Specification, summarising Phases A & B
II. Budget Quote, summarising Phases C & D
III. Final Quotation, Phase E
IV. Detailed Drawings, Phase F
V. Manufacturing, summarise Phase F
VI. As Built, summarising Phases H & I

The results described below are shown in Appendix C.

5.3.2 Costing Factor

A Costing Factor analysis was developed using the following Gross Margin guidelines along with the certainty of final the quotation stage, Appendix C, of different cladding industry product categories. The Gross Margin guidelines were obtained by interviewing Industry Specialist, Appendix B:

- Average Standard Products: 15%
- Average Semi-Standard (Mass) Products: 30%
- Average Semi-Standard (Complexity) Products: 25%
- Average Innovative Products: 40%

This section will compare the percentage uncertainty with the product Gross Margin guideline to predict Risk Factor 1 that cladding manufacturer's face as a result of variances in human judgment.

5.3.2.1 Standard Products

By analysing the figures obtained from the Internal Questionnaire in Appendix C, related to projects using standard products, it is concluded that the Costing Factor certainty increased from 75%, at the early budgeting and design stages, to 90% in the as-built which in this questionnaire refer to the installation stage. That is a decrease in uncertainty from 10% to 25%.

With cladding manufacturers pricing structures based on a Gross Margin of 15% for these products. In this case, the Risk Factor is effectively the difference between initial certainty in the final quotation stages and the as-built certainty and can be calculated using Predicted Risk Factor 1 presented in Chapter 4.

So in the example quoted above:

Predicted Risk Factor 1(Standard) = (100 - 75) - 15 = 10 %

5.3.2.2 Semi-Standard Products

This Thesis has subdivided projects built with semi-standard products into mass- or complexity-based, using an approach suggested by Dr. Stephen Ledbetter of Bath University in 2008. Starting with the mass-based subcategory in Appendix C, it shows an increase in certainty from 66.7% in the early budgeting and design stages to 77.5% in the as-built stage. In complexity-based projects the certainty increased from 41.7% to 77.7%. It was noticed also that in both types of project the certainty level can decrease during the detailed manufacturing and drawing stages, due to customer changes, which affect the costing figures.

So in the examples quoted above:

Predicted Risk Factor (mass) = (100 – 66.7) - 30 = 3.3%

Predicted Risk Factor (complexity) = (100 – 41.7) - 25 = 33.3%

From the calculation above it was noted that the Predicted Risk Factor in a pre-designed system, used for a semi-Standard Mass-based projects is low, due to the confidence of the design, production and sales team in an existing product design. In this case all the parties have been in involved in the pre designing of the system and the cost has already was calculated and evaluated. Whereas for a Semi-Standard complexity based projects the Predicted Risk Factor 1 is higher.

5.3.2.3 Innovative Products

The certainty percentage in the early stages of this type of projects as shown in Appendix C 3.3% is very low and at the final quotation stage is 18.3%. The certainty level may increase in the as-built stage to 40%. It can be noticed also that the percentage decreases in the detailed and manufacturing drawing stages, for the reasons given in the previous section.

So in the example quoted above:

Predicted Risk Factor 1 (Innovative) = (100 – 18.3) - 40 = 41.7 %

It can be concluded that the Risk Factor for projects involving innovative products is very high, but on the other hand, the gross margin is also high. Manufacturing companies need to balance between the high Gross Margin and high Risk Factor in innovative products in order to survive, especially in the rapidly changing cladding and construction industry and in the latest recession that has hit the industry very hard. Studying the profitability of the projects against the risk in Appendix A and Table 5.1, it can be noticed that high risk project profitability depends on the level of control of operational processes. Innovative projects profitability can vary depend on the level of control over the unknown variables associated with these types of projects.

5.3.3 Aesthetic Impact Factor

By analysing the Internal Questionnaire results Appendix C which is related to the building aesthetic impact and comparing factors for projects using semi-standard or innovative products compared to standard products the following can be concluded:

- A drop in the certainty in the detailed design and manufacturing design stages is due to changes being made to parts by the designer. In certain cases these changes adversely affect the parts and the overall building aesthetic. This problem can result from a poor communication between the architect and manufacturer. A gap in communication also was identified in both the External Questionnaire and the interviews with Industry Specialists. This Thesis suggests a level of standardisation of the manufactured parts is required and a control mechanism for the data transfer between systems should be established to allow the designers to supply architects with a better quality data
- The certainties measured for the mass-based semi-standard products in the as built stage are high 75% in specification stage to 100% in the as built stage as a result of the involvement of all the departments in the pre-design of the system
- The certainty in the innovative projects is low 20% in specification stage to 50% in as built stage due to the unknown factors and changes that the aesthetic impact.

5.3.4 Manufacturing Constraint Factor

By analysing the Internal Questionnaire results Appendix C related to building manufacturing constraints for the three project types the following was found:

- For those projects with standard products, the certainty level rose from 60% in the budget quote stage to 100% in the as-built stage. This is due to the simplicity of the manufacturing processes and the fact that all components are usually designed and drawn by the contractors.
- Those projects with semi-standard, mass-based products have a certainty level which is also high but rose from 75% in the budget quote and specification stages rising to 87.5% in the as-built stage. This is due to the pre-design of the system by all manufacturing departments.

- For those projects with semi-standard complex products, the certainty level was very low 25% in the budget quote and specification stages and its rise to 87.5% in the as built stage, due to the high dependency on contractor drawings.
- The same applied to innovative projects, which the certainty rise from 20% to 50%, but in this case the manufacturer was more dependent on architect drawings, which in most cases lack detail. Due to the high level of unknown factors in this type of project the certainty level remains below 50% level even in the as-built stage.

5.3.5 Part Complexity and Variety Factors

The effect on project certainty of part complexity and variety factors is similar between projects using standard (60%-100%) and innovative products (16.7% to 25%), Appendix C. It also follow the same trend in projects using semi-standard products. It can be concluded that the certainty of part complexity and variety factors in semi-Standard Mass-based products is 25% in specification stage and rise to 75% in as built stage. In the semi-standard complexity-based products the certainty rises from 10% in Specification to 75% in the as built stage.

Part complexity is also related to data size and manufacturing variation, both affecting risk. Appendix C demonstrates the data size for the different project categories where it will be noticed that Semi-Standard projects have the highest file sizes, due to the amount of detail available to the cladding manufacturer. Innovative projects also have large file sizes due to design complexity and the amount of data required for the designer to determine the manufacturing details. Entropy is related to data size and structure. No data means zero entropy. As discussed in Chapter 4 entropy will be used based on a constant amount of data. Entropy will measure the structure of the constant data in relation to the application of management framework proposed. The complexity of the parts is related to the number of parts and its similarity. Also the complexity can be based on the manufacturing constraints in relation to the specific part.

5.4 Analysis of External Questionnaires

The answers from the External Questionnaire, Appendix D, were used to analyse the problems that the cladding industry faces with regard to supply chain integration. The analysis is intended to indicate potential solutions to the uncertainty in the early design stages.

This section uses the results from External Questionnaires, to highlight weaknesses in the construction supply chain. The results show that certainty levels vary for different factors according to the categories of projects: standard, semi-standard or innovative. The questions were completed by cladding and architectural decision-makers in the UK. Their experience ranged from design, manufacture, installation, to raw material supply. Please see appendices D and E for more details on the Questionnaire content.

Analysis of the results of the External Questionnaire and comparison with the results of the Internal Questionnaire shows that there are similarities in the general opinions on the problems facing the cladding industry, regarding the supply chain and the risk involved. The External Questionnaire structure covers the following areas, project design certainty, project importance and how to improve the project.

5.4.1 Project Design Certainty

This section measures the level of certainty in the factors related to the cladding product life-cycle using the scales below and based upon assumptions gathered from the Industry Specialist Interviews:

- 1 = 90-100% Certain
- 2 = 50-90% General Overview but Uncertain
- 3 = 0-50% No idea or Uncertain

Factors that influence the certainty from the External Questionnaire are:

- Costing factor
- Manufacturing constraint
- Aesthetic impact

The phases of the cladding life-cycle as demonstrated in Table 2.1 was summarised and combined to form a new structure that is used in the questionnaire are as follows:

VII. Initial concept design, summarise Phase A & B
VIII. Final cladding design & specification, summarise Phase C & D
IX. Pricing, Phase E
X. Manufacturing, summarise Phase F & G
XI. Installation & handover, summarise Phase H & I

The results described below are shown in Appendix E.

5.4.1.1 Cost Factor

From the architect's point of view the trend of certainty increases from the structural design to the specification phases. The certainty level decreases between the specification phase and the manufacturing phase due to the impact of manufacturing costs. This factor can play an important role in creating wide differences between the estimated budget, for a cladding design and the final as-built cost resulting from the manufacturing and installation stages.

5.4.1.2 Manufacturing Constraint Factor

The degree of certainty increased throughout the construction phases. The only decrease occurred between the design and specification phases due to the aforementioned impact of manufacturing costs.

5.4.1.3 Aesthetic Impact Factor

The general trend of the aesthetic impact follows the same trend as the manufacturing process. Professor Alan Brookes said in Appendix B, that unexpected manufacturing cost impacts are largely caused by a lack of understanding, by architects and contractors, of the effect of aesthetic design of the building on the manufacturing phase. This in turn is caused by a lack of understanding of manufacturing processes and a lack of awareness of their effect on budgetary costs.

5.4.2 A Systematic Project Approach

The External Questionnaire results in Appendix E, demonstrate the argument in Chapter 2 in relation to the consideration of the aesthetic and cost factors are being the most important factors for architects and contractors, whilst the manufacturing constraints and part numbers are considered the least important. From the External Questionnaire most architects and contractors agree that cladding system suppliers should be involved in early stages of the design and such technology integration could improve the cost estimation process.

There was a mixed response regarding the categorisation of buildings as mass or complexity-based and manufacturing products as standard, semi-standard and innovative. Studying the answers from Section C in the External Questionnaires it can be noticed that the majority of architects agreed on the categorisation but a minority strongly disagreed. This may be due to a lack of understanding of manufacturing processes or a lack of awareness of their effect on budgetary costs.

5.5 Project Risk Factors Analysis

Following the definition of Risk Factor in Chapter 4, this section focuses on the result of the analysis of real life data collected from different types of construction projects.

The data collected was used to verify the Risk Factor definitions and to prove the applicability of uncertainty or entropy theory to calculate the risk associated to different types of constructions projects.

Due to the confidentiality of the data analysed, the projects have been assigned letters.

Finally a risk assessment sheet will be demonstrated in Table 5.2 based on the risk model used by insurance companies and bank was applied to assess the risk value of the projects considered in this Thesis.

5.6 Analysis of Project Data

The previous sections have explained the level of difficulty of extracting the operational data needed to develop knowledge based system. The process of collecting the data in Table 5.1 has proved the benefit of a structured approached to collecting and optimising from Appendix A and C the data for decision-makers.

Data related to profitability and for calculating uncertainty in projects is vital to allow decision-makers in cladding SMEs to analyse the pricing structure of cladding projects. The data in Table 5.1 has also proved the importance of collecting data related to predicted risk prior to the start of the project and predicting the risk during the project and calculating the actual risk after the project completion. The data was collected for Standard, Semi-Standard and Innovative based projects.

Parameters	Projects Analysed by Codes & Types																
	D (Innovative)	B (Innovative)	Q (Innovative)	M (Complex)	A (Complex)	K (Complex)	P (Mass)	R (Mass)	S (Mass)	C (Mass)	F (Mass)	H (Mass)	J (Mass)	N (Standard)	E (Standard)	G (Standard)	I (Standard)
Initial quoted price (£)	10562	64235	51000	39901	20000	20003	258121	258121	91150	325188	202620	37266	79264	32804	897000	1877.5	28289
Initial planned cost (£)	9506	32118	48450	33916	14000	18003	180685	180685	63805	260150	121572	33539	55485	16402	448500	939	22631
Initial planned margin (£)	1056	32118	2550	5985	6000	2000	77436	77436	27345	65038	81048	3727	23779	16402	448500	939	5658
Initial planned margin (%)	10%	50%	5%	15%	30%	10%	30%	30%	30%	20%	40%	10%	30%	50%	50%	50%	20%
Final price of project (£)	10562	59235	51000	39901	28977	20864	258122	258122	91150	325188	165872	37266	79263	32804	897000	1877	28289
Final cost of project (£)	14014	59068	53658	38524	20197	18861	168467	168467	61514	275800	100570	27786	55657	20508	465000	1498	16599
Final margin (£)	-3452	167	-2658	1377	8780	2003	89655	89655	29636	49388	65302	9480	23606	12296	432000	379	11690
Final margin (%)	-32.7%	0.3%	-5.2%	3.5%	30.3%	9.6%	34.7%	34.7%	32.5%	15.2%	39.4%	25.4%	29.8%	37.5%	48.2%	20.2%	41.3%
Certainty of Final Quote (from Internal Questionnaire – Appendix C)	39.3%	39.3%	39.3%	45.0%	45.0%	45.0%	65.3%	65.3%	65.3%	65.3%	65.3%	65.3%	65.3%	75.0%	75.0%	75.0%	75.0%
Predicted Risk Factor 1 (%)	50.7%	10.7%	55.7%	40.0%	25.0%	45.0%	4.7%	4.7%	4.7%	14.7%	-5.3%	24.7%	4.7%	-25.0%	-25.0%	-25.0%	5.0%
Actual Risk Factor 1 (%)	93.4%	60.4%	65.9%	51.5%	24.7%	45.4%	0.0%	0.0%	2.2%	19.5%	-4.7%	9.3%	4.9%	-12.5%	-23.2%	4.8%	-16.3%
Quantified Risk Factor 2, Predicted (%)	46.2%	49.7%	44.3%	46.5%	47.0%	43.2%	32.4%	30.8%	*	37.0%	*	37.8%	37.8%	*	32.2%	*	*
Margin Difference Risk Factor 3 (%)	-42.7%	-49.7%	-10.2%	-11.5%	0.3%	-0.4%	4.7%	4.7%	2.5%	-4.8%	-0.6%	15.4%	-0.2%	-12.5%	-1.8%	-29.8%	21.3%

Table 5.1 - Project Analysis Risk Factor Table for PSP Architectural ltd.

The Risk Factors used in Table 5.1 have been defined in Chapter 4. Items marked '*' are such that Quantified Risk Factor 2 is not available because these are historic jobs and pre-production risk information was not available.

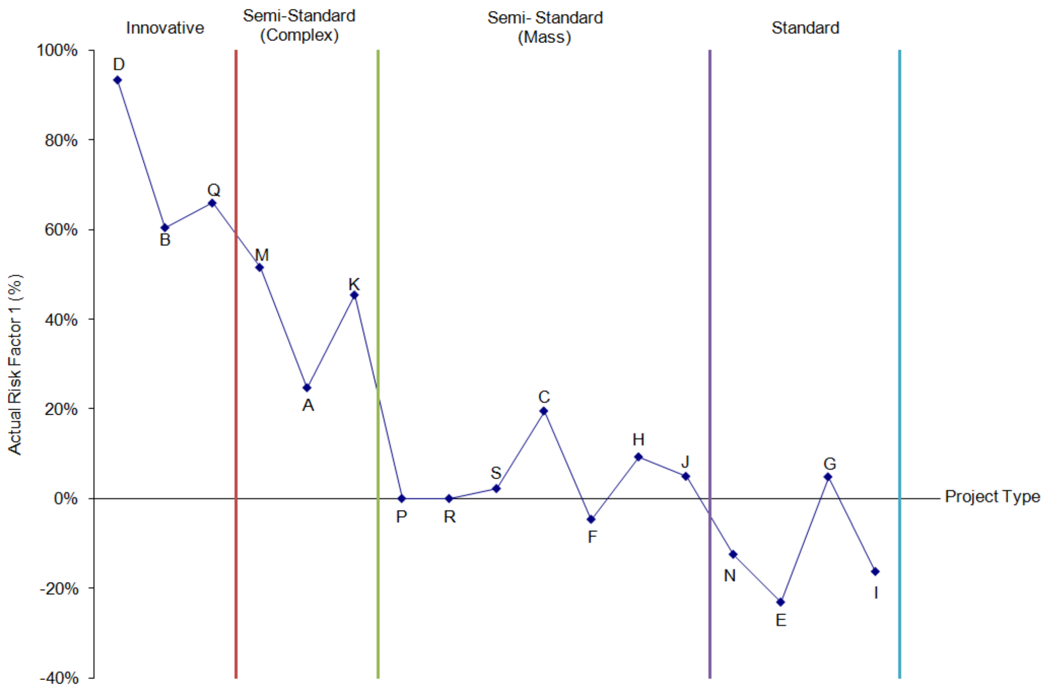


Figure 5.1 - Actual Risk Factor 1 Trend Captured from Table 5.1

By analysing the projects in the Risk Factor Table in relation to the product categorisation (innovative, semi-standard and standard)., From figure 5.1 it can be seen that the trend of actual risk percentage captured in Table 5.1 proves the principle of categorising projects according to their certainty and complexity from innovative to standard types of project. The variation between the Predicted and Actual Risk Factor summarised by the Margin difference Risk Factor 3 in Table 5.1 reflects the same trend. The same applies for the Quantified Risk Factors, which will be discussed in more detail in Section 5.7.

The Predicted Risk Factor 1 calculation also demonstrates that the percentage certainty obtained from the Internal Questionnaire does reflect the Risk Factors calculated in the project case-study considered in this Thesis. Reading the results from Table 5.1 and Figure 5.1 it can be seen that the percentage of Actual Risk Factor 1 varies from 93.4% in project D in the innovative projects to -23.2% in project E in the standard projects.

Different companies could give different results in each case, as the percentage risk will depend on the organisational character, size and structure. However, the process of obtaining the results will remain the same and, in the end, risk is the acceptance rate that adverse events will take place. Each company needs to decide the level to which costly contingency measures can be implemented on the basis of such risk assessments. Looking at Figure 5.1 it can be noted that there is noticeable gap between the Risk Factor for complex and mass based Semi-Standard projects. The aim is to move the complex -based to mass- based projects by standardising the individual parts to form a complex shape achieved by the mass of the components in the cladding of the building. The result in Figure 5.1 reflects the strategy that was adopted by PSP to move the complexity-based projects to the mass market by adopting an integration strategy between the design and operations systems as will be discussed in more details in the implementation strategy in Chapter 6. It can be noted that the results are based on 7 mass based projects in comparison with only 3 complexity-based project datasets collected from PSP. The results of the analysis have also shown the importance of taking the percentage Risk Factor into consideration during the initial quotation. This can protect the company from unexpected events in the project that could reduce the company's profit. Risk Factor 3 can be calculated to give an assessment of the factors that can affect the final project margin. Manufacturing companies should assess the risk involved in any project in a similar way to insurance companies and banks. Manufacturing and insurance companies should sell products with a high risk to customers by charging a premium to cover that risk. This is only can be achieved successfully by controlling risk and all the factors related to uncertainty associated to the project. This Thesis has focused on the control of the manufacturing operation and the system integration of the supply chain to provide a competitive solution to the customer solution by the use of risk estimation to control cost.

Risk is related to uncertainty which is also related to project cost. The more risk the company takes the higher the margin needs to be. Companies calculate risk in the price, but if all the variables have been controlled as predicted, risk is reduced and its value can turn into extra margin. Companies adopt risk control methodologies to minimise risk, by controlling their processes. Section 5.7 will demonstrate from the results methods of calculating risk associated with projects by allocating certain variables to them in the quotation stages.

5.7 Risk Assessment Sheet

Why cost risk analysis is considered important? Its ultimate purpose is to determine the budget that will be needed to execute a project and the variability includes dealing with the risks a project faces by properly funding against those risks. Risk is a legitimate element of cost. It is important to determine the real risk that faces any project, identified and assessed against the probability of its accruing. This approach was used in the aerospace industry, the program included a formal risk identification and assessment that must be executed and then revisited periodically in order to evaluate and deal with the changes of the factors [5.1].

	Projects Analysed By Codes & Types											
	D (Innovative)	**B (Innovative)**	**Q (Innovative)**	**M (Complex)**	**A (Complex)**	**K (Complex)**	**P (Mass)**	**R (Mass)**	**C (Mass)**	**H (Mass)**	**J (Mass)**	**E (Standard)**
Human Factors	6.9	5.0	6.9	6.3	5.0	5.3	7.0	6.1	6.6	5.3	5.3	7.7
Project Factors	4.5	4.8	5.3	5.4	4.8	5.3	6.7	6.9	5.7	5.1	5.1	4.7
Product Factors	5.6	5.0	5.6	5.1	6.2	6.2	7.0	6.9	7.1	7.7	7.7	7.8
Manufacturing Factors	6.4	6.8	6.2	6.0	6.6	7.0	7.8	9.0	7.2	7.8	7.8	8.2
After-Sales Factors	3.5	3.5	3.8	4.0	3.9	4.6	5.3	5.7	4.9	5.8	5.8	5.5
Total Factors	***26.9***	***25.1***	***27.8***	***26.8***	***26.5***	***28.4***	***33.8***	***34.6***	***31.5***	***31.7***	***31.7***	***33.9***
Consolidated Total Factor or Certainty (C) (%)	53.8%	50.3%	55.7%	53.5%	53.0%	56.8%	67.6%	69.2%	63.0%	62.2%	62.2%	67.8%
Quantified Risk Factor 2 (%) or Uncertainty (100 – C)	**46.2%**	**49.7%**	**44.3%**	**46.5%**	**47.0%**	**43.2%**	**32.4%**	**30.8%**	**37.0%**	**37.8%**	**37.8%**	**32.2%**

Table 5.2 - Internal Questionnaire Risk Assessment Sheets using Entropy

Risk identification and analysis is part of the much larger risk management process, which includes planning, handling and monitoring.

The risk planning activity deals with the organisation and scheduling of the risk management function with respect to the other programmatic activities. Risk assessments include the identification and analysis of the individual risk items that affect the budget or cost of any project. Risk handling and control involve in monitoring the process in which the risk occurs and the effectiveness of the controls that are applied to handle them can be tracked and verified [5.2].

To illustrate how risks are captured from the Internal Questionnaire, Table 5.2 and Appendix F show risk assessments result for the exemplar projects. The results from the Risk assessment confirm the outcomes of Table 5.1 on the level of uncertainty associated with standard, Semi-Standard and innovative projects. It can be seen that the uncertainty level increases with the decrease of project standardisation. The Quantified Risk Factor 3 from Table 5.2 has also been shown in Table 5.1. The certainty level was calculated based on the average sum of the weighted factors for human, project, product, manufacturing and after-sales. The average 0-10 sum was transferred to % of certainty by multiplying the average by 10 to give us a certainly % figure. The uncertainty or entropy calculation was based on 100- certainty, as shown in Appendix F and Table 5.2. The results proved the consistency of the increase of risk factors with innovative and complexity-based projects and decrease in the standard and mass-based projects. The Quantified Risk Factors varies from 49.7% for innovative to 32.2% for standard projects. The figures associated with standard and mass projects vary from 30.8 - 37.8%. In the case of innovative and complexity-based projects it varies from 43.2 - 49.7%. The variation in the figures from innovative to standard was 17.5% which was less significant than the variation from the Actual and Predicted Risk Factors summarised in Table 5.1. This is due to the structure of the questions asked and the uncertainty in the sales estimators answers which reflects the current uncertainty in the cladding industry. The cost estimation process in the cladding industry is dependent on risky assumptions rather than a fixed mathematical prediction. As mentioned in Chapter 4 the insurance industry bases their risk assessment on a complex structure of mathematical models. This Thesis recommends the use of data extracted from the ERP system and AutoCAD to be used as part of the risk assessment model to estimate a more accurate percentage of risk based on the weighted factors mentioned above.

Table 5.2 demonstrates a qualitative and quantitative risk approach using the entropy approach. Data extracted from the ERP system and analysed by a structured and organised manner to reflect weighted risk impact measurement can be considered as quantitative. These data can be related to manufacturing waste and process inefficiency which increases entropy as described in Chapter 4. Key Performance Indicators (KPI) could be measured in most cladding SMEs to quantify their operational and process performance, which would affect the system uncertainty and complexity. Data collected from questions directed to the estimator team can be considered as a qualitative entropy approach, reflecting opinions and experience, concluding a future risk leading to a higher entropy. Both of this approach has to be considered in the risk assessment to give decision-makers a mixture of structured manufacturing data, related to processes and product, and subjective trends based on human experience, to form a simple prediction of gross margin variation.

The results from this technique should allow cladding companies to be alerted to risky projects and take more accurate decisions about the internal risk. The definition of internal risk in this Thesis will be based on the risk associated with the internal processes of the case-study company.

5.8 Interviews with Industry Experts

To subjectively qualify the results, several interviews with industry experts have been completed, Appendix B. The main conclusions from the interviews have focused in on the lack of organisation and standardisation in the cladding industry. The interviews also focused on the importance of the relation between risk and product complexity in UK cladding industry.

Dr. Stephen Ledbetter confirmed the importance of system integration and the standardisation in controlling costs in the cladding industry. He also confirmed that building projects can be categorised according to the standardisation of products used in their construction. The aesthetic of certain projects can be achieved by both product complexity and product mass distribution as for the Sage building in Newcastle, See Chapter 1. He reconfirmed the validity of the analysis and the finding that risk is directly related to the project type. Complexity-based projects and innovative projects risk factors were high risk in comparison with the standard and mass-based projects.

In a more detailed interview with Mr. Ron Fitch he also summarised the result of the implementation of the ERP at PSP and its integration with the project estimation system. It was proven that there is a direct relationship between the level of integration and the risk factor associated to any project. PSP's attempts to integrate the design system with the operational data have resulted in more standardisation of products. It was noted that after the system integration process, the complexity of the products started to shift towards the standardised. The recession in 2009 also forced companies to supply complex products with low prices, so the shift towards the standardisation of products by investing in technology integration starts to be more essential.

Architect Angus Campbell commented regarding the involvement of cladding manufacturing in the early stages of design: *"In a project as large as Wembley Stadium the cladding manufacturers were involved in the early stages of the design. Suppliers were asked to give a* *budget estimate for the cost to help the architects give the client an estimated budget related to the total project".*

Professor Alan Brookes commented on how this Thesis could be relevant to the current industry status. He is one of the leading academics and consultants in the European cladding industry. His work was published in several books and papers all around the world. He has commented that the cladding industry is not as organised as others. Many organisations had tried to standardise their systems, but had failed. Mr. Heath Hindmarch managing director of PSP was interviewed to comment on the result of the implementation of the AMS at PSP. Mr. Hindmarch said:*"The data integration has allowed the higher management of PSP to analyse the actual costing data before and after the completion of the projects. The data analysis has allowed us to consider the amount of risk associated with the complex and innovative type of projects within PSP."*

Finally Dr. Watson also supported the need for integration and standardisation in the industry. Most of the views expressed by the interviewees supported the argument behind this Thesis. The data analysis in Chapters 4 and 5 also supported the main findings that risk within the cladding information system is related to project data type and also to the integration of systems. It was found that the integration of systems can reduce risk and move product categorisation towards more standardisation.

5.9 Risk Management and Control

Risk in the cladding industry can be divided in to business or technical related risk. Technical risk can be determined by using mathematical calculation based on the probability associated with any activities.

The business related risk depended on the business processes and usually associated with the project budget [4.4].

This section will demonstrate the control mechanism that can be used by companies to control the risk associated to cladding industry. The cost management techniques described in Chapters 2 and 3 will be used as the framework for risk management techniques that will be demonstrated in this section.

As a result of the effects of applying technology integration and cost management strategy on the case-study company, it can be concluded that the risk management strategy follows the same principle. In standard projects the estimation process is done using a standardised model extracted from historical data provided by the ERP system. The same applies to the semi-standard projects, which are mass-based. Controlling the process of estimation, by using recalculated models to estimate cost reduces, also the risk associated with a project.

In the complex and innovative projects there was less integration available in the system due to project complexity and a lack of knowledge associated with the manufactured product. As mentioned in Chapter 3, any system integration implemented as part of the cost management strategy will lead to full operational control of the data. This control will lead to a risk management strategy which can use the historical data collected to calculate future risk.

Standard projects are already controlled and costs are estimated by using structured historical data which is available in most cladding manufacturing companies in UK. Semi-Standard Mass-based product costing data started to be controlled with the evolution of ERP system.

The results presented in this Chapter, obtained through External and Internal Questionnaires and Risk Assessment Sheets demonstrated in Table 5.1 and Table 5.2, have shown that projects estimated from historical structured data carried less risk than the innovative projects that involved new manufacturing data. The output from this Thesis was to prove that system integration can affect the estimation process by reducing the entropy or uncertainty in the calculated cost.

5.10 Summary

This Chapter has presented the results of risk measurements in the cladding industry and its effect on the certainty of any project especially in the design stage. The higher the certainty, the lower the risk, which demonstrated that risk in the cladding industry can be predicted based on certainty factor.

The questionnaire result have shown the importance of involving cladding manufacture in early stages, but the main problem remained the time and skills required to give architect accurate budget even if the cladding companies has not secure the order of the project.

Another challenge presented this Chapter is the cost of risk; the cost of risk should allow for the calculated risk percentage to be added on the total project price to cover for unexpected increases especially in the innovative projects. On the other hand if cladding manufacturers cost that risk they may be uncompetitive in standard projects.

Chapter 6 will demonstrate the strategy adopted by PSP to implement the models presented in Chapter 2 and 3 for the semi-standard complexity-based project and some innovative projects to reduce the initial risk associated with these types of projects, which are currently remain too high.

6 INDUSTRIAL APPLICATION AND CASE-STUDY

6.1 Introduction

6.1.1 Overview of Cladding Industry in North East of England

This Chapter will apply the research described in the previous Chapters to a Case-study in the UK cladding industry. Chapter 2 described the cladding industry and summarised the key characteristics of cladding companies forming the building aesthetic and procurement supply chain. This Chapter will focus on the application of the methods described in Chapter 3,and 4 and analysed in Chapter 5 to a specific UK SME cladding based company.

The UK construction industry was worth over £100 Bn in 2008-2009 [1.7]. PSP Architectural Ltd, a cladding company based in the North East of England who manufactures products including rain screen systems and general metal cladding products and systems will be used as a Case-study to demonstrate the integration and risk management of cladding projects. Most of the data collected in Chapter 4 and 5 was collected from PSP's operations and project portfolio. PSP's turnover was £4 million in 2007, equivalent to 30,000m^2 of rain screen panels in a UK rain screen panel market for that year of 600,000m^2 [1.7]. Therefore PSP had a 5% share of the rain screen market. PSP's percentage share of the UK rainscreen market was significant but its share of the construction market was small. Assuming the average rain screen market price varies in the UK from £60-£120/m^2, the market size based on the 600,000m^2 can be calculated as equal to £36 - 72 million. Mr Ron Fitch, specialist in the building cladding industry (see Appendix B), has valued the cladding envelope as a percentage of the total building cost as approximately 10 - 15%.

Although PSP's market share is small, the principles behind this Thesis can be applied to a wide range of larger or smaller companies. This PSP Case-study will demonstrate in detail the applicability of the system integration and risk management models presented in the previous Chapters on the type of company is representative of cladding industry in the north east of England.

Whereas Chapter 2 described on the wider rain screen market and the different materials used to fabricate rain screen systems, Since PSP is a North East cladding company this Chapter will start with a brief introduction of the history behind the cladding industry in the North East of England. , Most of the different cladding fabricators established in the North East especially in the Co. Durham area have developed from the expansion of Hathaway Roofing in Co. Durham.

Hathaway Roofing Limited (Hathaway) was formed in 1967 by Bernard Hathaway and has over 40 years experience in the construction sector. Their first contract was for the warehouse of the "Brian Mills" catalogue in Sunderland. Since then Hathaway's have grown into a nationwide business. The business has a strong family culture with loyal, experienced and, in many cases, long serving employees [6.1]. Many of the other fabricators in the North East of England have been setup by ex-Hathaway employees and hence they have inherited the same structure. Hathaway currently turns over an average of £40 million per annum and employs > 50 employees [6.1]. Hathaway's structure is based on the fabrication and installation of the metal cladding products. Other Cladding companies have been established as a result of the availability of fabrication skills in the region and also because of the high demand of cladding product. CA roofing Ltd. (CA) was established in the late 80s, follows the business model of Hathaway to fabricate and install cladding products in the same area. The existence of CA and Hathaway in the area and the availability of the metal cladding fabrication and contracting skills encouraged many other cladding companies to locate in the North East to service the growing market. The structure of cladding companies varied from installation and contracting specialists to metal pressing fabricators and specialists such as PSP. When the company first established in 1998 Pressed Steel Products Ltd was setup with the same manufacturing and operational characteristics as CA and Hathaway. However, Pressed Steel Products Ltd. did not get involved in the contracting and installation of the cladding products as CA and Hathaway did which puts Pressed Steel Products Ltd. at a slightly different level in the supply chain. Pressed Steel Products Ltd. has concentrated on the supply of specialist architectural products only, meanwhile CA and Hathaway have operated as a metal cladding sub-contractors who provide full cladding solutions.

Many of Pressed Steel Products Ltd. employees have worked for either CA or Hathaway Roofing. With the rapid changing business environment, Mr. Heath Hindmarch current Managing Director of PSP, former Senior Manager at CA started Pressed Steel Products in 1998, based on a new business model. He was involved in the implementation of the ERP system and ISO 9001 during his employment at CA. This has inspired him to develop a new business model that addresses all the issues and problems that CA has faced during the implementation. The model was supported by Durham University and a Knowledge Transfer Partnership (KTP) project to implement a fully operational ERP system and use it as the main platform for integrating costing data throughout the organisation. This has allowed Pressed Steel Products Ltd. to expand rapidly to become one of the main players in the rain screen market in the UK. In 2008 as a result of a management buyout Pressed Steel Products Ltd. has changed its name to trade as PSP Architectural Ltd. The new company name reflected the change in specialisation from standard pressed steel to architectural cladding design and systems.

6.1.2 Overview of Agile Manufacturing System Application

Following the principles of Chapter 3 this section will demonstrate the data flow structure that can create an AMS for UK SME cladding manufacturers such as PSP. As mentioned in the previous sections, the main structure will concentrate on technologies, such as ERP systems linked to other systems such as warehouse management, advance accounting systems, or document management systems. Latterly technologies and software are being developed to match the standard organisational structure and the data flows throughout the business lifecycle from the design department to the sales department, production, capacity planning, purchasing and material management, shop floor data capture and delivery, then finally to finance.

The main aim of the AMS for PSP is to supply the architects with a quick feed-back as to the impact their proposed design has on product engineering and cost.

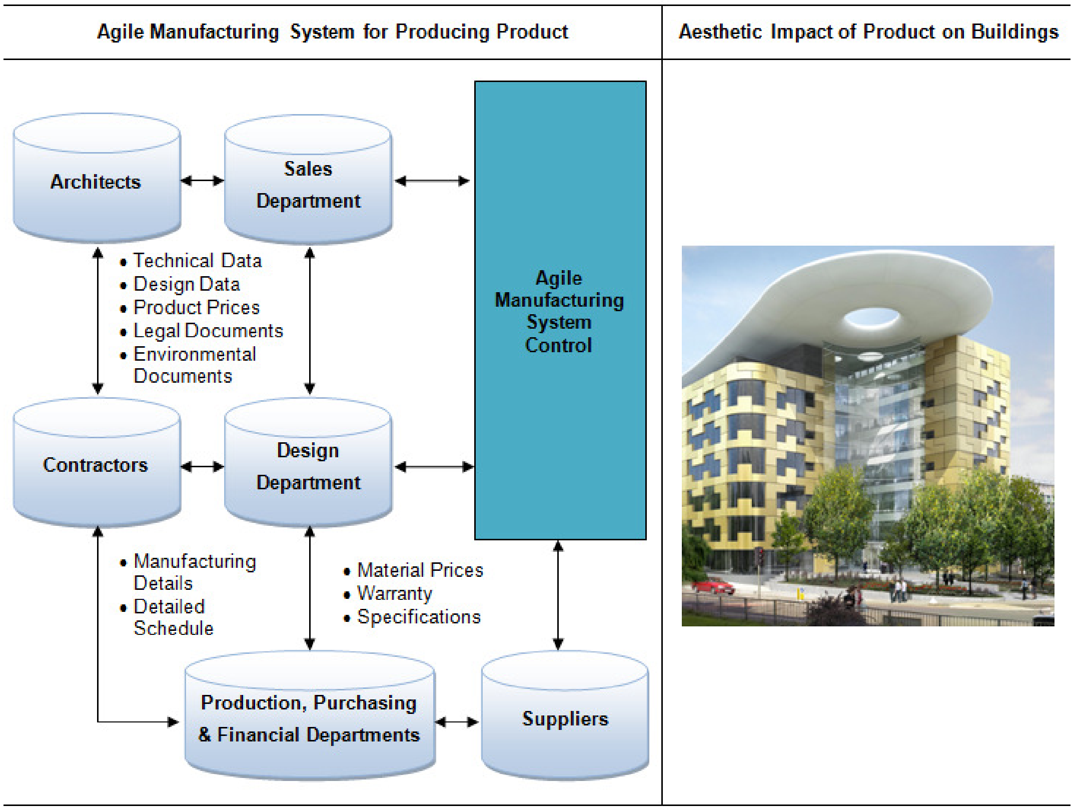


Figure 6.1 - Summary of the Agile Manufacturing System, linked with a modern aesthetically demanding project

Figure 6.1 shows the structure of the AMS which controls the data flow between the different operational and design systems of architects, manufacturers, contractors and suppliers.

The AMS maps the data required from the architects and compares it with the data available in the knowledge based system which is obtained directly from production and other systems. Usually, architects send drawings in standard AutoCAD file format to the sales or the design department of an SME. In some cases drawings will be attached to product specification documents, depending on the contract stage. These drawings and specifications can be read by the manufacturers design office. The drawing files can be extracted using systems such as Inventor and SolidWorks. These systems can extract the different parts the file contains and import all the relevant costing data related to each part, to other systems such as RADAN and the manufacturing ERP system [1.2].

The ERP system can export labour costs, material costs and overheads. The latest and the most advanced ERP systems work with the actual material costs obtained from the supplier's databases and the actual labour cost reported from the shopfloor work centres. Other ERP systems are directly linked with systems such as RADAN where the system estimates the CNC machine time. Then the ERP system can calculate the estimated cost directly related to the part and the feature [6.5].

Based on the observations from the case-study in the cladding industry it can be found that the manufacturing process is more labour intensive than expected despite there being a high degree of CNC automation.

Excel spreadsheets or other standard Microsoft tools can be used to extract costing data based on certain input parameters to provide an average processing rate, for example per m^2 of product. In the case of some standard products that have a pre set list price, the product cost is directly configured by using the ERP's cost estimation capabilities. These systems can extract labour cost formulas used by the ERP system to estimate the part or the feature's manufacturing cost [1.2].

It is of little use providing architects with quick cost budgets without considering production rules and constraints. Systems such as Inventor and SolidWorks are capable of applying constraint rules for the manufacturing process in order to check if designs proposed by the architects are achievable.

As a result of studying the development of the cladding in the North East of England, it was found that the involvement of all parties involved during the early design stages is vital in order to control the project budget and lead time. The adoption of the AMS can allow companies to control the external risk associated to data transferred between the cladding manufacture and architects. Through studying the strategy followed by PSP to adopt the AMS it was found the internal risk associated to the internal data needs to be addressed.

6.2 Industrial Case-study PSP Architectural Ltd.

PSP as shown in Figure 6.2 like other similar cladding manufacturers use a range of design software that allows them to transfer a building's architectural design to a manufacturing design using RADAN, Inventor and AutoCAD. PSP product categorisation varies from standard to innovative. In recent years the number of Standard projects has declined compared to Semi-Standard and Innovative Projects due to the decrease in market prices. More than 70% of PSP projects parts manufactured are now Semi-Standard compared with 10% Innovative and 20% Standard in 2010. Most of the Semi-Standard projects parts manufactured are Mass-based, rather than Complexity-based. This is due to the level of control and standardisation achieved in the design process. Semi-Standard, Complexity-based and Innovative project parts require a clear channel of communication between the cladding designer and the architect.

Figure 6.2 - PSP Factory in Shildon, County Durham

PSP receive drawings from architects in the early stages of the design. The drawings are first analysed and broken down into modules by the design department, then sent to the sales and estimation department to produce a budgetary cost. This service to architects can be costly for cladding manufacturers, especially where there is no guarantee of receiving an order, as the design of the building is at an early stage. It is vital to evaluate the percentage of project quoted to projects that have been transferred to orders. The higher the percentage the more successful the pre-sales strategy is. The cost of the involvement in the early stages can be justified by the number of orders and specification secured in this stage. PSP measured this performance indicator using feed-back from the CRM module in the ERP system.

With the help of Durham University, PSP initiated a KTP program where they selected and implemented new technologies to bridge the gaps identified in Chapter 2. The project was summarised by four different phases, which will be discussed in details in the following sections:

- Phase I of the project involved the selection and preparation for the technology implementation. The technologies implemented have assisted PSP provide a high quality service to their customers with minimum cost.

- Phase II of the project involved the development and integration of the system where PSP used the ERP system to build up a library that contains formulas for manufacturing time estimation. This has helped the company gain better control over the estimation process.

- Phases III and IV will be implemented as part of the long term strategy of PSP to build up a centralised knowledge library that updates its data from the ERP system and then extracts all the data linked to the manufacturing features of Inventor or SolidWorks to be used during the design of the processes.

6.3 Phase I: Technology Implementation Preparation Strategy

This phase started in 2002 as a core part of the KTP project. PSP allocated a team selected to represent each department at PSP. The team included the Managing Director of PSP Mr. Heath Hindmarch, the Finance Manager and the Production Manager in additional to the KTP Associate as a Project Manager. A project plan was agreed and a budget of £100K assigned to the project.

Phase I started with the selection of the technology that best fitted with PSP's vision and requirements for expansion and growth. The team also started the preparation of the company system and work force to accept the new technology. Temporary systems were implemented to facilitate the transition which will be demonstrated in detail in the following sections. The selection process of the ERP software was achieved by short listing two final ERP providers and Epicor Vantage were then selected. PSP assigned a Project Manager from Epicor to coordinate with PSP Project Manager on the implementation and time scale of the implementation. This included a budget and a detailed project plan with deadlines. PSP also decided to select AutoCAD Inventor and RADAN technology for the design of its products. This phase was completed in 2004 with the full implementation of Vantage and AutoCAD Inventor. The project was completed on time and under the 100K budget allocated. This project has won the KTP award in 2005 as a result of the smooth implementation of the system.

The first methodology, demonstrated in this Thesis, was related to the selection of the technology and the system implementation stages. This Thesis has supported the importance of the work force involvement in the success of any system implementation, proven by the implementation of the ERP system at PSP and its effect on the collection of operational data which allowed the management to take more strategic decisions related to the business. The Second methodology, the integration of technology, allows the designer to take more accurate decisions related to cost. PSP developed standard systems which utilised standard software such as Microsoft Office and the Epicor Vantage ERP system, Section 3.3.2.4. Its standard commercial operation is the costing of time to be used in a system configuration that builds a BOM based on built-in formulae. The system has proven its effectiveness, with the estimation process starting to become more accurate, which in turn has lowered the risk factor level.

In relation to the operational design integration, Teesside University Engineering School have demonstrated research to link an ERP system directly to SolidWorks design software and to be able to export the BOM directly from the ERP to SolidWorks. Also the latest design software can allow the allocation of manufacturing constraints against each part as explained in Chapter 3. The latest versions of commercial software available in the market are developed to have more flexibility for integration and cladding companies have started to invest in more sophisticated software in the past few years, as demonstrated in the interview with Dr. Alastair Watson, Appendix B.

The results of this Thesis have demonstrated that there is a relationship between the risk factors and the project type. Also it proved that the relation between the risk and the level of integration within the system is noticeable after analysing the data collected from the real life projects completed by PSP. The applicability of this is unique for the cladding industry and only applies on a certain characteristic of UK companies. Some of the industry experts have been interviewed to support the argument behind the application of the methodology in the UK cladding industry such as PSP. Finally UK consultants such as Wintech Façade Engineering are using the integration between SolidWorks and a flexible PDM system to do value engineering on some of the most complex façades in the world [6.7], this integration could allow the designer to change the design of the product from innovative and complex to standard products in which the total mass of it can create the complex shape.

This section presents three models. The first two sequential models present the strategy that was used to implement a successful AMS in PSP. As ERP plays a very important role in the management, storage and retrieval of costing data throughout the organisation, these two models present a strategy that was developed for the pre-implementation stages of ERP, CAD and Cost estimating systems implementation within PSP.

6.3.1 Preparation Model

The pre implementation model is a recommended strategy for preparing organisations to accept new systems rather than embracing high technology solutions for cost management. Adopting this model will help to prepare an organisation to accept cost management and later, to implement a continuous improvement culture. The strategy involves objective setting, worker and management involvement and continuous improvement as shown in Figure 6.3.

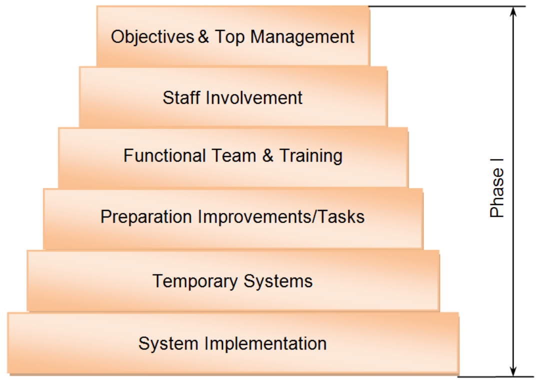


Figure 6.3 - Pre-implementation model (Technology Management)

The following sections demonstrate the model components with examples from PSP.

6.3.2 Top Management Involvement, Allocating the Objectives

Without clear objectives [6.3] of what the management wants from the system, it is difficult to create an effective implementation plan or commit resources and times to actions. Usually the heads of departments that will be affected by the new system should agree objectives and realistic timescales should be allocated. Objectives set at this stage mostly relate to customer needs; however it is important to anticipate future customer needs over the life of the system.

No project or improvement action can be established without the support of the top management [1.1]. As a result of the PSP case-study, it was noted that top management must be committed to the project at an early stage.

6.3.3 Worker's Involvement

Change management and managing resistance toward change are key issues in any system implementation [1.1]. People usually resist change due to lack of understanding or fear of what is coming.

For a successful implementation of any cost management system it is vital to ensure active involvement from the top management down to the work force. This can be achieved by providing the right training in order to reduce resistance to change and other fears. If the top-level management believe in the objectives, this will inculcate a culture that inspires all improvement activities within the company. Techniques must be employed to make sure that improvements have been monitored and good performance was rewarded [1.12].

Once management are on board, the involvement of other employees means that their creative and synergistic efforts can also be used to solve operation problems and ensure continuous improvement. The case-study concludes that managing human resources and gaining their involvement is a very difficult issue for some companies, it needs enough time allocation prior to the system implementation.

6.3.4 Functional and Improvement Teams

Companies find it beneficial to use worker teams. Workers, or their teams, need to be empowered to make changes in processes [1.12]. First it is essential to choose the right team leaders to manage, control and encourage the team members to achieve specific objectives and to work effectively in a collaborative environment. To achieve this goal, training is vital since it was found that most individuals lack problem solving and project management skills. Project management for process improvement teams will help the team to integrate process analysis into a problem, create improvement and implement solution actions [6.4]. An ERP system will be used as an example for the technology implementation, as part of the Case-study. ERP systems provide information about problems to be collected and analysed. The ERP system should supply team leaders with real time data to evaluate problems before taking actions. Companies usually implement manual systems to obtain shop floor data, before the implementation of an electronic solution; for example, time sheets or supervisor's reports.

6.3.5 Preparation for Improvements

The term 'preparation improvements' can be defined as *the improvements that take place in organisations in order to prepare them before adopting any new technology.* Usually there are clear problems, which do not need any advanced data analysis or investigation. These problems can be identified and delegated to teams for action before the implementation of any system. Some technology implementation can require some early process re-engineering. This can help in preparing a culture of continuous improvement and prepare the entire organisation to accept and use the new system in an effective way in the future. PSP's management and production teams have identified problems such as poor shop floor layout, lost paper work and bottlenecks. Improvement actions were delegated to the improvement teams to create a suitable environment in which the new system could operate. The management team believed however, that the system would not reach its full potential without an organised manufacturing and administration environment in place prior to implementation.

6.3.6 Temporary Systems

The implementation of temporary systems or solutions is part of the preparation improvements stage. Temporary systems are defined as *temporary manual solutions for problems identified in the early stages*. They work along similar principles to the system that will be implemented, though in a manual sense. It was found within PSP that these systems have a great impact on organisational culture and help to manage change resistance. PSP utilised the concept of temporary manual systems to introduce their new ERP system, including a manual scheduling system that allocates time and resources to machines and processes, as well as paper based time sheets on the shop floor to prepare the staff to use any future data capture system. It was found that these systems helped to remove the fear and ambiguity before implementing the new system.

6.4 Phase II: System Integration and Cost Management

Phase I prepared and implemented the strategy adopted by PSP to implement the Vantage ERP system. This section will summarise the strategy that was adopted by PSP to implement the cost management strategy. The strategy was based on the creation of a simple model that allowed PSP to control the large amount of data generated from the ERP system, to allow manager and designer to take more accurate decisions regarding costing which is one of the main objectives addressed behind this Thesis. ERP systems can collect this information and formulate a report for further variance analysis [6.5]. An ERP system was used as an example of the implementation of technology using the above model.

PSP started building a knowledge based system that contains the manufacturing capabilities for each work centre in the manufacturing area identified in Section 2.4.3. Each work centre contains a number of machines which have certain limited capabilities to produce certain features. It was found that by linking the data generated by the ERP system with a knowledge system that contains manufacturing features formula, manufacturing time and feature parameters, for example: length, width and bends, can help in achieving more accurate estimate based on actual data. For example to estimate the pressing time in the bending machine work centre at PSP, the formulas used were based on the total number of bends of the part manufactured divided by the standard pressing rate collected from historical data stored in the ERP system. The welding work centre is another example for the estimation of the welding time based on the total product length required welding divided by the standard welding length time.

PSP has used the configurator tool in the Epicor ERP system to enable an estimator to enter their part name; the ERP system can then configure the features and processes that are involved. This was used for standard and Semi-Standard Mass based products with high aesthetic requirements where more advanced knowledge system is required.

6.4.1 Cost Management Implementation Strategy

Companies facing tough competition are forced to be ever more efficient and effective in what they do. The cost management model presents the predicted data flow between the ERP system, decision-makers and continuous improvement teams after the implementation of the costing system, as shown in Figure 6.4.

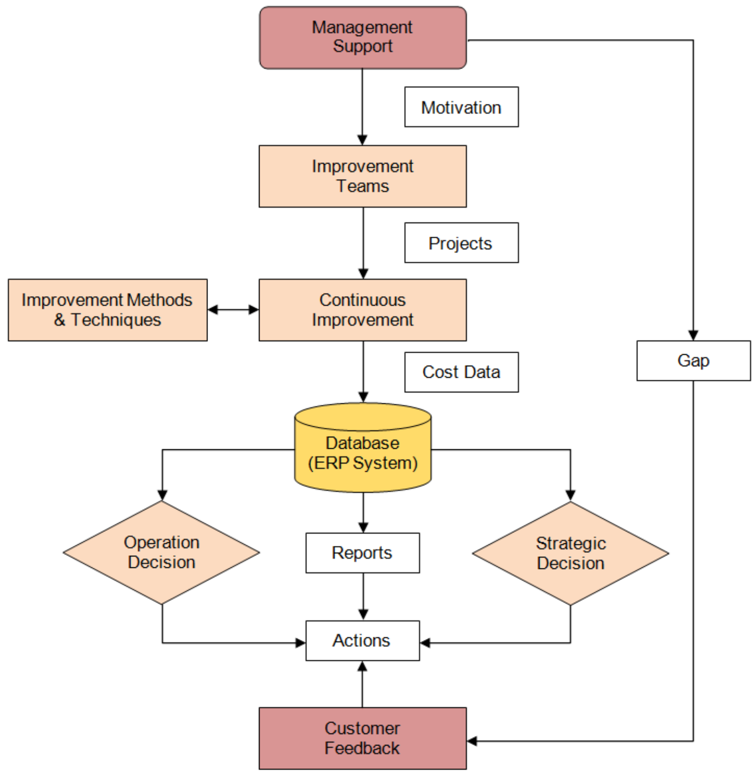


Figure 6.4 - System information flows of the Cost Management Model

This model gives an overview of the cost management strategy developed to assist PSP in making operational and strategic decisions. This strategy is summarised by filtering all the data generated from the ERP system using the standard Microsoft Excel application and data reporting software's such as crystal reports. As mentioned in Chapter 3 the required data fields can be mapped in into Excel and fields can be updated by importing data from the ERP system database. PSP management has found that identifying the output from the data required is vital to assist every department at PSP to take more accurate decision about costing and risk. Historical data from the ERP system can be filtered to feed the risk assessments sheets were information related to the estimators skills, project type, number of parts, customer credit and part complexity can be updated directly from the historical data stored in the ERP. Also reports can be generated automatically on a daily, weekly, or monthly basis that can calculate the cost and risk associated to project before they start.

The reports can give the management feed-back about the operation control mechanism which results in reduction of uncertainty and risk. The cycle in Figure 6.4 of evaluating allows the management to continue improving the process to control the cost wastes and variables that affect the risk in data.

6.4.2 Continuous Improvement Teams

If the preparation model readies the organisation to accept a culture of continuous improvement then at shop floor level the team leaders should be trained and teams formed, ready to operate with responsibility for improving the value-added activities and reducing the non value-added activities [6.4]. An effective costing system should assist in the attainment of operational excellence by providing timely and reliable information to the cost management system [1.12]. The analysis of information provided by the system can thus help in reducing product and operational costs, with the assistance of such techniques as Just-In-Time (JIT), Total Quality Management (TQM) and Kaizen [1.12]. Cost also has a direct effect on strategic decisions. Cost management systems use performance measures and report analyses from the ERP data capture system to guide operational decision-making, which in turn leads to continuous improvement actions for processes and activities [6.4]. Costing analysis helps in making strategic costing decisions which effect product pricing by producing a logical pricing policy that is related to the profitability of existing or new products. Both top management and team leaders should make decisions at this point and then actions can be controlled and managed by the continuous improvement team. This phase has demonstrated the operational and strategic loop of decision-making process at PSP. The loop demonstrate the application of the AMS in which the technology was implemented and costing data was collected and structured using Microsoft Excel systems to allow managers and designer to take more accurate decision regarding cost and risk. Also the model demonstrate the connection between the decision and process improvement activities that allowed PSP to assess the cost and implement a manufacturing control system that can control the variables associated to products complexity. The next section will demonstrate the link between the data mapped in this model and the design software used at PSP.

6.5 Phases III & IV: Knowledge Capture & AMS Implementation

Currently, PSP is going through Phase III where they are using the same configurator tool principle to generate manufacturing times, based on product features using a time formula that changes according to certain variables such as quality, rework and efficiency. The variables can be linked with the live ERP system and can be updated to ensure that the estimate is up to date. For example the ERP system can provide:

- The latest up-to-date materials cost from the database's “purchased part” field
- The operation time from the time formula calculated from the configuration as mentioned above,
- The overhead percentage which can be obtained from the financial section of the system.

The overall figures should give the estimator the total cost of the product without taking into consideration the risk of inefficiency and variable rework. These variables can increase the total cost value and will affect the final product margin. Chapter 4 introduced the risk management as a solution for bridging the gaps related to the external risk associated with the communication with architect. This has highlighted the importance of internal risk management within the cladding manufacturing which would be highlighted in the fourth implementation phase.

Phase IV will be the transfer of this knowledge to some of the design software used. For example PSP wants to be able to access the costing data directly from RADAN, inventor and AutoCAD. The design software, such as Inventor and AutoCAD, contain their own libraries which can extract the features costing data generated from the ERP system and the knowledge system. It was found that if the features and part names match between the systems, data integration will be possible, especially with the latest technology. In 2010 PSP has launched a project to automate the process of designing standard and mass based products using RADAN macro technology. The project based on using the standard Microsoft office application to enter information in which it can be transferred to RADAN software to calculate all the required parameters for design and tooling of the product. The routine is summarised by reducing the amount of repetition in the drawing and tooling of PSP standard products. The technology also can allow the RADAN software to import costing data related to the feature designed. This project is expected to be complemented by the end of September 2010.

Finally, as a result of the recession which affected the UK construction market in 2008-2009, PSP has suffered from the increase of risk associated with project complexity and customer credit. The sales team at PSP started using the principle of risk evaluation for innovative and complex projects through the analysis of historical data. The checklist questions demonstrated in Chapter 4 was used to identify the category of the project and then the risk assessment technique that was used in Chapter 5 has highlighted the importance of the evaluation of internal risk factors at PSP. But due to the reduction of the margins and the high competition PSP could not consider the risk percentage as part of its parts costing structure. Risky projects have to be evaluated based on the operational capabilities at PSP and the customer credit history. PSP also reviewed its operational control strategy to make sure that all the variables associated with the risk market are controlled within the AMS recommended. As mentioned in Chapter 3 the AMS structured from the adoption of cost management, system integration and knowledge management techniques. PSP management believes that by controlling and filtering all the data generated from the ERP system and the design packages by using structured reports. The reports can give knowledge to the management and designer to take more accurate decision about controlling the internal and external variables to achieve the main aim from the AMS. PSP aim is to use the data generated to value engineer its products to allow the designers to design a more competitive products that helps PSP compete in a very competitive cladding market in the UK. Wintech Engineering consultancy based in the south of UK has used the concept of the integrating solid work system with the PDM to value engineer some of the most complex project in the world [6.7]. This integration has allowed them to create a complex aesthetic building model by using a mass volume of standard products that give the building its final architectural shape.

The concept of parametric design also was used to connect design model to excel spread sheet. Parametric design revolves around a basic knowledge of geometry and relation between entities. These properties can then be altered, giving different outcomes of form. This concept allows architects and main contractors to be involved in the financial side of the project and allow them to see how the cost of the project relates to the form. For example a tower that has a vertical rotation of floor plates can be seen in terms of cost and how a very twisted form costs more than a not so twisted form and then the architect can weigh up cost verses form. This concept has used on some prestigious projects in London such as City Hall [6.8]. The concept of gathering a parametric relation in geometry can have some similarities with the parametric costing methodology demonstrated in Chapter 3. As mentioned in earlier Chapter the implementation of AMS in the scope of internal and external technology integration and applying knowledge management strategy can enhance the use of the parametric concept in the smaller size projects that cladding SMEs can be involved in. The applicability of this concept demonstrated a reduction in cost estimation and project management time [6.8] . This Thesis will recommend a further research to be conducted in the area of parametric design and its impact on costing models used in cladding SMEs.

Finally PSP is planning to achieve this level of integration and knowledge to allow them to value engineering any project by reducing the complexity within the products in which will reduce the risk associated to it by 2012.

6.6 Summary

This Chapter has demonstrated the applicability of the methods and analysis in Chapters 4 and 5 when applied to the cladding Industry in the North East. PSP Architectural Ltd. was used as a case-study to test the applicability of the models on a north east cladding SME with a flat management structure.

The application of the methodology was presented in four phases, starting from the selection of the technology to the implementation and finally to the application of an AMS at PSP.

Finally Chapter 7 will discuss the applicability of the methodology to companies that are different in characteristic from PSP. Kingspan PLC and the steel industry briefly will be used as examples to highlight the applicability of the methods discussed in this Thesis.

7 DISCUSSION

This Thesis has focused on three main areas: the supply chain, the technology and agile manufacturing. It was found that the main gaps that affect the effectiveness of the communication between each of the parties involved are linked to the integration level of the system used by each of the parties and the level of standardisation of cladding products. The level of integration is a key factor in obtaining a better understanding of the impact of the architectural aesthetic design on costing. This Thesis has demonstrated the importance of the adoption of a flexible AMS to close the gaps identified through the analysis of the cladding supply chain. Analysing the cladding industry and the system integration impact on project costing has lead to the realization of the importance of risk as a major factor in the AMS structure. The AMS was adopted in the context of flat and wide management framework, therefore Cost, Knowledge and Technology Management integration has been demonstrated in that flat and wide context. The reason behind this approach is to simplify the AMS framework in the context of a cladding SME implementation. As mentioned in the research philosophy section that management framework can be considered usually as social science and it is difficult to quantify its results.

Risk and its relationship with uncertainty in this industry was linked to the entropy theory presented in Chapter 4 which was used to quantify the implementation of the framework. The research behind the theory focused on the idea that controlling the data transmitted between any two systems leads to tighter integration. The more disorganised the data , the less reliably the message will be delivered to the recipient. This has inspired this Thesis to use entropy theory to measure the uncertainty in the data referred to in cladding projects. The uncertainty was converted to a risk value which is directly related to the costing process and Gross Margin Variation used in the innovative and complexity-based cladding projects. It has proved the positive affect of structured integration of systems across UK cladding SMEs and its effect on the accuracy of costing. Based on this, designers will have the ability to estimate cost in the early stages of design. It was found that this process is directly linked to the risk associated to the type of project. This section will discuss all the findings of this Thesis under three main categories:

- Cladding Industry and Supply Chain Analysis
- AMS
- Risk Calculation in UK Cladding Industry

7.1.1 Cladding Industry & Supply Chain Analysis

Analysing the cladding industry supply chain stages has lead to the identification of the following missing items:

- A standard method of communication between the architect and cladding manufacturer in the early stages of the product design.
- Cost control in the cladding design process
- Cladding product standardisation that can allow architects to improve the accuracy of cost estimation in the early stages of design.
- AMSs that allow cladding manufacturers to analyse cost related to the product early design stages.

It was found that there is a need for a flexible methodology to be implemented to bridge the gaps identified in the analysis stages. This flexible and standard system was demonstrated through the application of the AMS framework that was proposed in this Thesis. As discussed in Chapter 2 the applicability of the system depends on the company characteristics. This Thesis focused on the cladding SMEs high growth characteristics of companies with a short product development life-cycle. The applicability of the simple management framework should reflect the risk associated with this type of project. The speed of the development can increase the risk and its impact to the project. The aerospace and automotive industries developed complex cost management and risk methodologies. The development time and resources allowed them to deal with the system complexity and manage the impact of risk. In the cladding industry time and resource limitations mean that the system should combined human judgment with data generated from the AMS. The impact of risk should also be clearly identified and considered by architects, designers, estimators and top management.

7.1.2 Agile Manufacturing System

The steps that lead to the formation of the AMS can be summarised as follows:

- Enterprise Integration Technologies for SMEs
- Cost Management
- Knowledge Management

7.1.2.1 Enterprise Integration Technologies for SMEs

It was found through the case-study that the success of system integration does not depend only on the technical aspects of system integration. Commercial software companies have devoted hundreds of programmers to enhance the integration capabilities of the tools discussed in Chapter 3. It can be concluded that in SMEs the integration depends more on the ability of the management team to use and control the system. Usually the team involved in such a process is called a continuous improvement team which has members from all the departments in the organisation.

The discussion about enterprise integration is that continuous improvement teams should be built in the early stages of a project, before implementation. Actions taken by teams such as preparing improvements and temporary work around solutions can prepare the right environment for the system to operate smoothly. These measures also help to prepare the workers for change, by removing fear and ambiguity. For companies that have flat management structures and characteristics similar to PSP, it was shown that these two models have both advantages and disadvantages. The primary advantage lies in facilitating the rapid implementation of cost management systems that provide competitive advantage and the right conditions for growth. The training that underpins these two models has wider benefits, including education of workers in continuous improvement methods not usually found in SMEs. The case-study also highlighted the fact that, in many small companies, team leaders have many demands on their time and may find difficultly devoting time to the analysis of data from the ERP system and continuous improvement tasks. Finally, it is felt that the cost of an integrated ERP system with other systems such as PDM may be a barrier to the adoption of these methods. The Microsoft Office suite was recommended as a cost effective tool for integration.

7.1.2.2 Cost Management

Cost estimation techniques have been explored in Chapter 3 to provide the literature background for cost estimation and management. Parametric- and feature-based costing techniques are widely used in the aerospace and the automotive industry due to the resources available and extended product development lead-times. As mentioned in Chapter 6 parametric costing was used in the construction and cladding industry but only in large-scale projects. The cost management concept that forms part of the AMS can facilitate the adoption of both feature- and parametric-based costing in a simpler way by structuring the historical data provided by the ERP system and PDM systems.

It was proven that the proposed cost management system depends on the integration of several management tools such as cost estimation, technology management and knowledge management as shown in Figure 3.2. Cost Management also has full control over the data flow after implementation of the tools discussed in Chapter 3. At the time of writing, this model has not been fully tested in the form of a case-study, but from analysing the capabilities of an ERP system to analyse operational data, it can be hypothesised that this could lead to powerful strategic and operational decision-making. The mixture between the Cost Management process and technological oriented initiatives can lead to a powerful strategy that can present historical costing data in a more structured and user friendly way. In the future this Thesis predicts that Neural Network-based (NN) costing will be adopted more widely in the aerospace and automotive industries. NN could be used in the cladding industry if the technology were embedded in off-the-shelf commercial software such as ERP systems. NN could also be applicable for applying the complex mathematical entropy concept to calculate risk occurrence and impact probabilities.

7.1.2.3 Knowledge Management

The main aim from any system integration implemented in a cladding SMEs is to establish knowledge to assist designers, managers and estimators to take more accurate decisions about costing, aesthetic and manufacturing constraints. It was found that capturing knowledge is one of the main challenges that face most of the researchers involved in cost estimation. This work focused on the adoption of a simple cost effective Microsoft Office tool to capture pre-defined variables that can be extracted from the ERP and PDM system. As mentioned in the earlier section, parametric estimating software and PDM can be costly to implement in an SME. But with the changes in technology in the past two years some of these tools have started to be developed to suit the needs of a wider range of companies. The combination of Enterprise Technology Integration, Cost Management and Knowledge Management has lead to the development of a powerful AMS.

7.1.3 Risk Calculation in UK Cladding Industry

Projects have been categorised as Standard, Semi-Standard and Innovative. The categorisation of the projects was based on a simple question-based checklist in Chapter 4, which gave the cladding SME a standard subjective approach. The issue with this categorisation is that projects can change subject to external or internal factors in the manufacturing environment, for example Innovative projects can become to Standard or Semi-Standard after the manufacture of the first parts, or by using simulation techniques, or by producing production samples. This will change the project-based categorisation based on knowledge level, data availability and risk. The defined checklist provides a clear and structured definition, which is important in the context of their utilisation in cladding SMEs, but he question raised is how the SME can measure risk and acquire knowledge within the projects to change their categorisation.

To answer the questions posed in Chapters 4 and 7 it was necessary to include the risk management and uncertainty control as part of the methodology that formed the main part of the research related to the development of the AMS.

Using the weighted risk approach has proven that the risk can be calculated as part of the total costing model and furthermore that it can be used to set the product price based on its level of complexity in the early design stage .

The results of the analysis have also shown the importance of calculating and taking into consideration the percentage Risk Factor in the initial quotation. Studying the Risk Factor 1 & 2 equations it can be noticed that the gross margin clearly depend on how certain internal cross-functional employees are in the costing data. Market prices dictate the planned gross margin for a cladding company but on the other hand, cross-functional employees' certainty can be improved by the adoption of the AMS. This can protect the company from unexpected events in the project that can reduce the company's profit. One of the proposed measures of risk, Quantified Risk Factor 2, can be calculated to give an assessment of the factors that can affect the final project margin. Manufacturing companies should assess the risk involved in any project in a similar way to insurance companies and banks. Cladding manufacturers, banks and insurers need to assess risk and sell high risk projects at a premium. This only can be successfully achieved if they have full control over the execution of the project and having the ability to accurately access market and project data.

Risk was shown to be closely related to uncertainty which in turn is related to project cost. The more risk the company takes, the higher the profit margin will be. Companies calculate risk when determining the price of a product, but if all the variables have been controlled as predicted, the risk value can be turned into extra margin by adopting a risk control methodology to minimise the risk effect and by controlling their processes. The thermodynamic concept of entropy was applied to information system data transmission to show how much was controlled within a manufacturing system.

By looking at the historical data collected from projects shown in Appendix A it was found that, as expected, in real projects the more disorder in the data the higher the measured entropy level. This data disorder can be related to the uncertainty in the project. On the other hand projects which displayed a low level of entropy were those considered less risky. For example Table 5.1 shows that project uncertainty or Actual Risk Factor 1 varies from -23.2% in standard to 93.4 in innovative projects. Also the Quantified Risk Factor 2 varies from 32% in standard to 49.7% in innovative projects. The variation between the Actual Risk Factor 1 and the Quantified Risk Factor 2 is due to the uncertainty in scoring the weighted factors demonstrated in Appendix F and Table 5.2. by the PSP sales team.

7.2 Applicability to Other Industries

As mentioned above, the applicability in the cladding industry for the methodology presented in this Thesis was proven in the early stages of development where traditionally there was a lack of standardisation. As all the models were based on the implementation on the PSP case-study, this section has briefly explored the applicability to other industries. The nearest industry that is closely associated with the cladding industry is the steel industry. This section will briefly discuss the potential of applying this Thesis to the steel industry and discuss how the standardisation in the steel industry helped in reducing the risk associated with projects. An interview with Dr. Haitham Ayoub, a specialist in the steel industry, combined with the interview with Dr. Watson to learn more about the industry structure.

Historically, the steel industry in the UK developed in a highly diverse and fragmented way. Originally sited on coal and later iron ore deposits, many of the firms which were established remained both small and relatively isolated. In an attempt to rationalise and modernise the industry, the 14 largest firms (representing around 90% of the UK's steel-making capacity) were taken into public ownership in 1967 to form the British Steel Corporation. This left a number of smaller producers outside the nationalised industry, several of which continue in operation. In 1988 the publicly owned British Steel Corporation was privatized, to form British Steel (BS) plc [6.6].

Dr. Ayoub in Appendix B argued that the adoption of the management models presented in the earlier sections is related to the company size and to the management structure more than the product and the industry. In his opinion the research demonstrated in this Thesis can be partially applied on the steel industry. In relation to the risk management and software integration, the steel industry has developed advanced design software that allow the designers to import and export any BOM and to be able to cost the project using this software. This was achieved by product standardisation and advances in software development. On the other hand the cladding industry uses different type of universal design, see Chapter 3, which lacks the product standardisation which was a more complex task to integrate with the production software.

Dr. Watson added that the steel industry, where procedures and standards have been developed over the years, is more mature than the cladding industry that has developed in just the last 30 years. From the design point of view the risk associated with a steel structure is higher than the cladding, where any variation in the structure of a building or a bridge can be critical.

It is important to understand that the position of the supplier in the supply chain. Cladding manufacturers usually are at the bottom of the contractual chain in comparison with the steel installer who, most cases, design, fabricate and install their own products.

Finally to analyse the applicability of the models to companies in the cladding industry, but which have different characteristics to PSP, Kingspan was used as an example. Kingspan have been grown to a larger company that specializes in insulated cladding products. They have posted a 28% rise in turnover to £1.4bn in 2007 as a result of standardizing its product portfolio [6.2]. They have moved toward product standardisation where the margin related to the product is constant as the variable related to the product is constant. This has allowed them to grow rapidly over the last few years. The applicability of the management and risk models does not apply on these types of companies, but some of the principles can be changed and re-structured to be applied.

7.3 Summary

These arguments have been demonstrated throughout the research and reflect some of the main issues that face UK cladding manufacturers. This Thesis has developed, as discussed in Chapters 3, 4 and 6, different tools and techniques that can be recommended to minimise the risk associated with the cost estimation process. Finally the author also applied some of the tools demonstrated in this Thesis on Galaxy Architectural Ltd. (Techtonic). Techtonic was established in late 2009 as result of a partnership between Red Architectural Ltd. and a local Jordanian company. Techtonic is specialised in the fabrication and installation of a wide range of metal and curtain wall cladding products for the Middle East market. The author currently holds the position of the president of the board of Techtonic along with his role as Operations Director for PSP.

8 CONCLUSIONS & FURTHER WORK

8.1 Conclusions

This section will conclude the implications of the research and also summarises the activities completed to achieve the main objectives demonstrated in Chapter 1. The development of the models and the demonstration of their applicability to industry has met all the objectives of this Thesis.

The research has shown the importance of involving the cladding manufacturers and contractors in the early stages of the product design to allow architects to determine a more accurate project budget. It is essential to understand the technologies that can help in achieving a standard communication channel between cladding manufacturers and architects. The system integration capabilities of modern design software have been used to build an effective AMS which has lead to a measurable improvement of the whole cladding supply chain. This was one of the main objectives of this Thesis and was successfully achieved at PSP.

Similar tools and techniques can be adopted by the wider cladding sector to integrate internal and external information systems. This Thesis discussed the effect of utilising such an internal integration of technologies within the cladding manufacturers on bridging the potential gaps identified in Chapter 2.

The focus of the research was to move from the technicality of technology integration to the development of a management models that can address the gaps identified. To bridge the gaps in the industry, the methodology has concentrated on the development of a knowledge based AMS. The system is based on tools, such as computer integrated design, to allow cladding manufacturers to manage cost and processes associated more effectively. The methodology came about be studying the potential for integrating information tools and techniques; such as cost management, enterprise integration of ERP systems with CAD/CAM and knowledge capture systems to form an AMS. The adoption of this system has offered solutions to:

- Solve the lack of integration of the cladding industry supply chain by applying a standard project categorisation to cladding industry SMEs
- Solve the lack of structured approach related to risk calculation
- Solve the lack of understanding of risk and its uncertainty in the cladding industry
- Encourage the adoption of structured approach in relation to the selection, implementation, control and integration of technologies related to the cladding industry
- Demonstrate an understanding of the impact of integration on the risk associated to the cladding projects
- Identify the key factors that impact the project costing estimation process
- Involve the cladding manufacturers in the early stages of product and project design

- Develop tools for designers to utilize historical ERP and design systems data to prepare a more accurate costing for new cladding product designs

In the early stages of this Thesis it was demonstrated that cost management, technology management and knowledge management tools are integral parts of the AMS. As a result of understanding the impact on the supply chain of unrealistic cost estimates during the early architectural design phase, this Thesis has recommended the development of an AMS that includes risk management to cope with the continuously changing demands on the cladding supplier, particularly in aesthetically demanding projects. To prove this, actual data from the industry was collected in order to understand the different qualitative and quantitative methods used by the industry. The data was analysed to identify the critical factors that can affect the (*uncertainty*) of the total product data. This raised some questions in relation to the measurement of the improvements resulting from the agile system and how to quantify the risk value.

Answering the question of how to measure the control of data, lead to other questions such as; what is the uncertainty in the data transferred? How can the cladding industry control and structure a high volume of data transferred between systems to produce more accurate cost models? The answers were found by applying a structured methodology for the selection, integration and control of technology involving human factors. This structured approach involved the use of the thermodynamic principle of entropy to measure the uncertainty associated with the data transferred. This structure advocated the categorisation of projects into innovative, standard and semi-standard, in which the uncertainty level can be predicted based on the historical data fed back from the ERP system. The methods and research have been applied in the form of a case-study; based on PSP, a small, fast-growing cladding manufacturer, which has adopted most of the methods documented in this Thesis.

Entropy was used to measure the uncertainty in the information system which formed the main basis of the risk calculation methodology highlighted in this Thesis. The entropy of data related to the design, manufacture and installation of cladding products was assisted by calculating a Risk Factor percentage utilising data from an internal questionnaire. The higher the entropy in the data collected the less the certainty therein and the higher the risk there will be in using that data for costing purposes. The entropy was used to quantify risk and apply the formulas on the case company to prove the applicability of research in a more mathematical approach. The other methodologies used were based on human opinions and answers to questions in which can be subjective.

The external questionnaire, which adopted a similar format to the internal questionnaire but expanded the application to architects, contractors and cladding manufacturers in the UK and international cladding architectural related organisations. The external questionnaire covered additional areas related to the applicability of technology integration, the importance of costing and manufacturing constraints and finally the involvement of the cladding manufacturers in the early stages of the product design.

One of the main recommendations of this Thesis is that these percent of risk factors should be considered in the early design and the quotation stages of cladding projects. The more variables and unknowns related to the project in the case of innovative and complex products, the more important is to consider the outcomes of these sheets. Using the operation management methodologies demonstrated in Chapter 4 can allow the smooth interaction of system and software across the organisation departments. The interaction of the different systems has allowed the optimisation of the critical factors related to variable allocated in the risk assessment worksheet after being compared with the actual data generated from the ERP system for historical projects.

The insurance risk calculation methodology and in particular how risk can be weighted in relation to different types of variables was considered in this Thesis. Using also PSP as a case-study this system was tested by calculating the risk associated to different types of completed projects. The risk percentage generated from the matrix was quantified in Table 5.1 compared with the actual and calculated risk factors demonstrated in Chapter 5.

The conclusion arising from the analysis of Table 5.1 focused on the difference and the applicability of the predicted and quantified risk factors and compared them with the actual risk results. The predicted and actual risk factor calculations are both based on the subjective answers and experience of PSP staff. Both the quantified and the predicted risk factors gave the same trend across all the project categories. The quantified risk factor gave a higher variation from actual in comparison with the predicted factors. This was almost certainly due to the size and structure of PSP in which most of the estimation process in based on people's experience and knowledge. So the answers from the questionnaire have proven capable of giving a clearer predication of the risk that will be associated with the project. This Thesis recommended to the use of the more data generated from the ERP system to evaluate the risk, or to use complex mathematical models similar to what is used in the insurance risk assessment can be complex and costly to SMEs. The quantified method is based on a weighted calculated formula with many variables that can affect the calculation value. The quantified risk factor method is applicable to other industries or companies with different characteristics to PSP, especially if generic questions are used. Studying Table 5.2 and Appendix F, data required for calculating the quantified risk factor can be obtained by technology integration between the ERP system and any other operation system used in the organisation.

Research was done to analyse the benefit that companies involved from this Thesis gained as a result of the implementation of models presented in Figure 6.3 and Figure 6.4. It is important to present the costing data that shows the saving done as part of the implementation of the standard design procedure model for costing and the implementation cost management strategy in the company through the adoption of Figure 6.3 and Figure 6.4.

As mentioned in Chapter 6, PSP was classified as a high growth, value added company with 50 employees and £5 million annual turnover in 2008. In PSP the implementation of the ERP system took 2 years and the cost of ERP implementation varied from £60K-100K per annum. This variation was based on the hidden cost that can be added to the total figures such as the time spent by the employees and management in the implementation of the system. Research done by Mabert showed that the average cost to implement ERP systems in small companies is equal to 5.53% of annual revenue and implementation takes on average 2.125 years. In medium-sized companies, the cost is 3.08% of annual revenue and it takes around 3 years to implement [3.5]. Based on this the implementation cost for PSP based on £3.5 million turnover during the implementation should be £120K, with average 2 years. This has proven that the system implementation model presented in Chapter 6 successfully controlled the technology implementation process at PSP which enabled them to achieve the above results. The implementation has also been followed by the adoption of a risk management strategy that uses the historical data and implementation model to calculate the risk associated to a certain kind of product type.

Evaluating the four implementation stages, the first phase can be considered as the basis in which the other stages depend. The first phase in implementation strategy focused on adopting the right preparatory steps and effectively linking ERP technology with improvement activities and strategic decision-making such that companies can achieve a quick return on their technology investment. The final phases involve the application of the strategy. At PSP this has also highlighted the importance of considering the internal risk associated with the company internal data flow. The research has concentrated on the external risk factors related to the external data flow with architects and contractors. The AMS suggested, should address both of types of risk as the integration, cost management, knowledge system and finally risk management methodologies should allow cladding companies such as PSP to control its process and systems to control cost and risk internally and externally.

Finally The aim of this Thesis was to prove that system integration can affect the estimation process by reducing the entropy “uncertainty” in the calculated cost. It was concluded that the more the operational data is structured and integrated within the organisation the less will be the disorder in the communication between the transmitter and receiver of the data. Disorder in the data communicated between two systems leads to higher level of variables and uncertainty related to the output results.

All the data presented through the external and internal questionnaires, risk assessment sheets and project risk assessment has proven that projects which have been estimated based on historical structured data carried less risk than the innovative projects that involved new manufacturing data.

8.2 Further Work

To maximise the benefit from applying these methods, several areas would benefit from further research. The potential research topics listed below have been identified throughout the course of this work:

- The development of software that can act as a central hub for all applications used within the cladding industry, this should allow the designer to standardise the process of cost estimation and budgeting. This software can be developed based on the same principle behind the development of the commercial curtain walling and steel design software currently available in the market. It is also necessary to consider further research in the area of parametric design and its effect on cladding SME costing models.
- The development of standardised methods of risk calculation associated with cladding projects. The system should use historical data stored in the ERP system to update the parameters and variables that affect the estimation of the project price. The banking insurance risk methodology should be explored in more detail to identify a methodology that suits the cladding industry.
- The application of the methodologies discussed in this Thesis on a wider range of companies characteristic and industries
- The exploration, in more detail, of the existing capabilities of commercial systems for product and process data integration. This is necessary due to fast changes in software capability as a result of the deployments of many designers and programmers by commercial software companies to enhance software integration capabilities. Design and operation systems such as AutoCAD and ERP systems have been developed to allow users to integrate with other different system such as Microsoft Office. The integration within these systems must allow data to be analysed in a more structured and user friendly way.

8.3 Addendum

During the midst of this Thesis, one of the worst financial recessions hit the UK cladding markets in 2008-2009. This made the findings of this Thesis very timely. Many construction projects stopped as a result of lack of bank funding, which made the application of an AMS such as the one described more important than ever for a large number of companies. This is because of the increased risk introduced by the recession due to the increase of market variables. The recession also highlighted the importance of risk calculation to the project budgeting process: as the margins reduced and companies could not afford any variation from the estimated prices.

APPENDIX A - EXEMPLAR CLADDING PROJECTS

This is a list of exemplar cladding projects carried out by PSP Architectural Ltd upon which the Risk Assessments in this Thesis were based.

Project Name:	**Solar System**
Contractor:	**RM Solar**
Product Type:	**Innovative**
Predicted Risk Factor 1 (%):	**51**
Actual Risk Factor 1 (%):	**93**
Note: The Predicted and Actual Risk Factor Percentage were obtained from Chapter 5	

Project Name:	**East Midlands Parkway Railway Station**
Contractor:	**White Young Green/Birse**
Product Type:	**Mass**
Predicted Risk Factor 1 (%):	**-5**
Actual Risk Factor 1 (%):	**-5**
Note: The Predicted and Actual Risk Factor Percentage were obtained from Chapter 5	

Project Name:	**Doxford Park, Sunderland**
Contractor:	**MDK Roofing**
Product Type:	**Standard**
Predicted Risk Factor 1 (%):	**-25**
Actual Risk Factor 1 (%):	**5**

Note: The Predicted and Actual Risk Factor Percentage were obtained from Chapter 5

Project Name:	**Manor Mills, Leeds**
Contractor:	**Williams Cooper**
Product Type:	**Mass**
Predicted Risk Factor 1 (%):	**-5**
Actual Risk Factor 1 (%):	**-10**
Note: The Predicted and Actual Risk Factor Percentage were obtained from Chapter 5	

Project Name:	**London Museum**
Contractor:	**Wilkinson Eyre/Durkin & Sons**
Product Type:	**Standard**
Predicted Risk Factor 1 (%):	**5**
Actual Risk Factor 1 (%):	**-16**
Note: The Predicted and Actual Risk Factor Percentage were obtained from Chapter 5	

Project Name:	Hammersmith, Residential
Contractor:	**RMA/St James**
Product Type:	**Mass**
Predicted Risk Factor 1 (%):	**-5**
Actual Risk Factor 1 (%):	**-8**
Note: The Predicted and Actual Risk Factor Percentage were obtained from Chapter 5	

Project Name:	Allerton Grange School, Leeds
Contractor:	**WGI/Interserve**
Product Type:	**Mass**
Predicted Risk Factor 1 (%):	**25**
Actual Risk Factor 1 (%):	**9**
Note: The Predicted and Actual Risk Factor Percentage were obtained from Chapter 5	

Project Name:	Kings Waterfront Pavilion
Contractor:	**Wilkinson Eyre**
Product Type:	**Innovative**
Predicted Risk Factor 1 (%):	**11**
Actual Risk Factor 1 (%):	**60**
Note: The Predicted and Actual Risk Factor Percentage were obtained from Chapter 5	

Project Name:	**Gloucester Quays**
Contractor:	**Foundation Architect**
Product Type:	**Standard**
Predicted Risk Factor 1 (%):	**-25**
Actual Risk Factor 1 (%):	**-12**

Note: The Predicted and Actual Risk Factor Percentage were obtained from Chapter 5

Project Name:	British Rail Car Park, Preston
Contractor:	**Coros Construction**
Product Type:	**Mass**
Predicted Risk Factor 1 (%):	**5**
Actual Risk Factor 1 (%):	**5**

Note: The Predicted and Actual Risk Factor Percentage were obtained from Chapter 5

Project Name:	The Hub, University of Leeds
Contractor:	**Carey Jones Architect**
Product Type:	**Mass**
Predicted Risk Factor 1 (%):	**15**
Actual Risk Factor 1 (%):	**19**

Note: The Predicted and Actual Risk Factor Percentage were obtained from Chapter 5

Project Name:	RVI Hospital, Newcastle
Contractor:	**Anshen/Laing O' Rourke**
Product Type:	**Standard**
Predicted Risk Factor 1 (%):	**-5**
Actual Risk Factor 1 (%):	**-10**
Note: The Predicted and Actual Risk Factor Percentage were obtained from Chapter 5	

Project Name:	Petergate
Contractor:	**Carey Jones Architect/AGF**
Product Type:	**Complex**
Predicted Risk Factor 1 (%):	**10**
Actual Risk Factor 1 (%):	**22**
Note: The Predicted and Actual Risk Factor Percentage were obtained from Chapter 5	

Project Name:	Ipsus Marketing Suite
Contractor:	**Fundacion/February London**
Product Type:	**Complex**
Predicted Risk Factor 1 (%):	**25**
Actual Risk Factor 1 (%):	**25**
Note: The Predicted and Actual Risk Factor Percentage were obtained from Chapter 5	

Project Name:	Audi, Edinburgh
Contractor:	**Taylor Design/SRS**
Product Type:	**Mass**
Predicted Risk Factor 1 (%):	**-5**
Actual Risk Factor 1 (%):	**-10**

Note: The Predicted and Actual Risk Factor Percentage were obtained from Chapter 5

APPENDIX B - INTERVIEWS WITH INDUSTRY SPECIALISTS

i. Dr. Stephen Ledbetter, Director of the Centre for Window and Cladding Technology
ii. Professor Alan Brookes, Director of Alan Brookes Consultants
iii. Mr. Ron Fitch, Business Development Director, PSP Architectural Ltd
iv. Mr. Angus Campbell, Partner Foster and Partners
v. Dr Alastair Watson, Senior Lecturer, Computer Aided Engineering Leeds University
vi. Dr. Haitham Ayoub, General Manager, Galaxy Aluminium, Jordan
vii. Mr. Heath Hindmarch, Managing Director, PSP Architectural Ltd

Dr. Stephen Ledbetter

Director of the Centre for Window and Cladding Technology , University of Bath

Stephen Ledbetter is a graduate civil/structural engineer from Dundee and Bristol Universities. He worked for a civil engineering consultancy before joining the University of Bath in 1981. He was Director of the Centre for Window and Cladding Technology (CWCT) since 1990 and participates in several international research groups and is chair of EU COST Action C13 on 'Glass and interactive claddings'.

He is Director of Studies for the MSc in Cladding Engineering. He teaches cladding construction and cladding engineering to undergraduates. Through CWCT he is also involved in education and training for CPD.

His research interests are in the field of cladding engineering, both the technical and business process issues. He is currently working on:

Structural performance of glass assemblies
Recycling of architectural flat glass
Process mapping of the construction industry
Cladding supply chain studies

Interview Notes, 13/03/2007, Bath University:
Dr. Ledbetter was presented with this PhD research in which the main contribution focuses on the integration of technology in the cladding industry and its effect on the costing model in cladding SMEs.

Q1. Dr. Ledbetter was asked to give his opinion and feed-back about the validity and importance of this Thesis.

Dr. Ledbetter confirmed the importance of technology integration to achieve more accurate costing figures for the cladding industry.

Q2. Dr. Ledbetter was asked to comment on the categorisation of projects into standard, Semi-Standard and innovative projects

Dr. Ledbetter agreed with the categorisation of cladding products as innovative, Semi-Standard and standard, but he suggested to add two main categories such as mass-based products and complexity-based products.

Professor Alan Brookes

Director of Alan Brookes Consultants

Alan Brookes was a Professor of architecture at TU Delft, Aachen & visiting Professor at Oxford Brookes & Singapore Universities as well as formerly a Principal Lecturer at Liverpool & South Bank Universities.

Professor Brookes has an international reputation as an Architect and Cladding Consultant. He is author of several books on Building Construction including; "Cladding of Buildings", "Connections", "Building Envelope" & "Innovation in Architecture" and he has also had numerous articles published in the architectural press.

Telephone Interview Notes,15/07/2009:

Q1. Professor Brookes was presented with this PhD research focusing on the integration of technology in the cladding industry. He was asked about the effect of technology integration on the risk associated with the cladding projects.

Professor Brookes started with an overview of the cladding industry. He confirmed that the percentage of metal cladding sector is small in comparison with other cladding materials supplied to the construction market. The main four cladding material elements used in the cladding industry are:

Curtain walling

Metal Composite

Rain screen

Professor Brookes said the main decision-making process related to the costing and the selection of the cladding is the responsibility of the sub contractors that install the products not the cladding manufacturers.

The costing factor is the most important factor that determines the selection of the cladding products. The only exception is for complex and innovative buildings, where the quality and the complexity of the design is as important a factor as costing. These types of projects are rapidly increasing in the last few years, but still form a small percentage of the total buildings.

Dealing with architects in the early stages of design can be very beneficial, as architects usually lack the understanding of the cladding manufacturing process. They prefer to find out about systems to be used on the building using standard catalogues such as Schucco, Kingspan and Alucobond materials.

Curtain walling fixed by sub contractors, doesn't allow many variables
Metal composite metal 80-85% of the market cheap high volume product
Rainscreen contracting mainly terracotta, stones and metal rain screen such as PSP and Tellings

The main reason for the failure of interaction between the different standard elements in the products design of complex and innovative products is the distribution of cost between the different elements.

Q2. Professor Brookes was asked to comment on the categorisation of projects as Standard, Semi Standard and Innovative and the effect of risk factors associated with the costing of each type of these projects.

The prediction of costing figures is very important and Prof Brookes agreed on the importance of risk factor in relation of complex and innovative product design and cost estimation. Risk related to the time required to manufacture the parts and the complexity of the parts.

"Standard products expect £60/m^2, bespoke up to £200/m^2 the higher the risk the more profit expect if variable related to the projects controlled".

Q3. Professor Brookes was asked to comment on the overall idea from the research.

This Thesis is not practicable in reality in the present industry but the principles involved will essential for the future industry.

Mr. Ron Fitch

Cladding Industry Consultant

Ron Fitch was active in the modular metal cladding industry since 1980, when "high tech" was the current trend, working with emerging architectural practices, including Fosters, Rogers, Grimshaw and Hopkins.

In the mid 1980s he set up with a partner a consultancy to design and develop metal-based construction systems for manufacturers like Don Reynolds. After 3 years work, mostly in the Middle East, the company moved into manufacturing, specializing in modular total cladding systems. As a consequence he worked on two buildings which won the Stirling prize, Stephen Hodder`s University of Salford and Chris Wilkinson`s Magna project. During this time he presented papers on the subject at the Institute for Advanced Architecture, York University and the Institute for Architecture, London, winning an award in 1991 for the best UK technical literature.

He worked at PSP and was responsible for the design and development of a range of metal-based modular cladding systems. The development programme is based around a new production unit, one of the most specialised its type in Europe, producing structurally bonded metal panel systems with expanded honeycomb or insulated cores.

Interview Notes, 28/10/2009, PSP Architectural Ltd, Shildon:

Q1. Mr. Fitch was presented by the concept of this Thesis focusing on the integration of technology in the cladding industry. He was asked about the effect of technology integration on the risk associated with the cladding projects.

Mr. Fitch shared his observation by working at PSP on the effect of the system integration on risk calculation and its calculation. The integration of our sales and design system with the actual operation at PSP allowed us to take more accurate decisions regarding the development of our products.

The decisions were based on the costing data that have been the ERP system produced combined with design data. This allowed us to design new products taking in consideration the risk associated especially in a rapid changing and difficult market.

Also the system allowed us to assist the risk associated to any project and calculate the risk factor in the pricing structure. As I have been involved over the past years in some state of the art innovative projects this system has allowed us to include the risk in the complexity-based and innovative products based projects.

Mr. Fitch also confirmed his knowledge of the general margins related to the cladding products are as follows:

Standard Products	*5-15%*
Semi-Standard (Mass) Products	*20-30%*
Semi-Standard (Complexity) Products	*15-25%*
Innovative Products	*30-40%*

Q2. Mr. Fitch was asked to comment about his experience in the cladding industry and his interactions with architects in the early design stages.

Although I have been involved in most aspects of the business, I spent most of my time developing cladding systems with architects, trying to turn an architectural concept into engineering reality. My background knowledge and understanding of manufacturing was invaluable for such a role.

Mr. Angus Campbell

Partner, Foster and Partners

Angus Campbell received a 1st class Hons BA in Architecture from Birmingham School of Architecture in 1990. He has a Diploma in Architecture with Distinction from the Bartlett School of Architecture in 1993 and became a registered member of the RIBA and ARB in 1997.

He joined Foster and Partners in 1990 to work on the mass and detail design of the top floors of the landmark DS2 tower in Canary Wharf. He then worked on a wide range of projects and building types including, a strategic masterplan for the City and for a casino and sports stadium in Cannes, France. He also contributed to the masterplans for the Kings Cross rail terminal in London, the Manchester 2000 Olympics bid, the winning Duisburg Harbour competition in Germany and the realisation of 'Albertopolis'.

He was promoted Associate in 1996 gaining a keen Interest in understanding and improving working relationships in the building Industry. He participated in the Supply Chain Management feasibility study for the Wattisham Physical Recreational Centre in 1998.

He gained valuable experience working onsite supervising the new Cambridge University Law Faculty building and developing the design scheme for the Commezbank Headquarters in Frankfurt. He went onto become the Project Architect for two Aquarium Centres, in Blankenberge and Birmingham respectively, completed in 1995 and 1996.

Interview Notes, 06/02/2007, London:

Q1. What software is used to design the external cladding of the building?

Mr. Campbell said Micro station and AutoCAD are the main two software used. The procedure of using this software is based on a product library that contains a list of standard products and samples given by different suppliers. The standard products can be loaded to the system and can be called when is required on the projects.

Q2. Do you communicate with the cladding companies in early stages of the building design?

Yes, they depend on the project.

Q3. If yes, in which stage of the product design the communication starts? And what's the technology used (file format exchange) to exchange technical drawing?

It depends on the project. In a project as large as Wembley Stadium the cladding manufacturers were involved in the early stages of the design. Suppliers were asked to give a budget estimate for the cost to help the architects give the client an estimated budget related to the total project.

Q4. Do you have different systems for different product categories (standard, Semi-Standard, innovative products)?

Yes, a general view of the m^2 rate for each feature depends on the product category. In the case of innovative cladding products companies are asked to give an estimated budget cost based on the m^2 area of the project.

<u>Dr Alastair Watson</u>

Senior Lecturer in Computer Aided Engineering Leeds University

Dr. Watson has a BTech in Civil and Structural Engineering and PhD in Civil and Structural Engineering and is the Deputy Head of the Engineering School, University of Leeds. He was a Senior Lecturer in Computer-Aided Engineering from 1994 to present.

His early research at Leeds was on CAD systems, calculation processing and knowledge based systems developed into an ongoing focus on digital information as the underpinning of construction projects. Understanding was further increased by similar work in the field of building cladding and reinforced concrete frames and through participation in a significant number research projects in which information management and information sharing have been a common theme. These projects include: CIMsteel (computer integrated manufacture of constructional steelwork), eLSEwise (European large scale engineering wide integration support effort), EIME (engineering information management executive), CI-PM - creation and use of product models in the construction industry, ProCure (ICT at work in the LSE procurement chain), CIMclad (computer integrated manufacture of cladding systems), LANTERN (Leeds health air pollution, noise, traffic and emissions research network). All these research projects are collaborative, many at a pan-European level.

Telephone Interview Notes, 28/10/2009:

Q1. Dr. Watson was presented by this research contribution which focused on the integration of technology in the cladding industry. Also he was asked about the effect of technology integration on the risk associated with the cladding projects. Dr. Watson also was asked on the applicability of our research on other industries such as the steel industry in UK.

The cladding industry in the UK has changed in the past few years. The need for a more complex system to manage the integration between design and customer requirements start to be vital to manage the risk associated to any project.

Dr. Watson agreed that the cladding industry is not as organised and standardised as the steel industry. He also added that the cladding industry is using very basic design technologies and software compared to the steel industry.

Design and build projects are becoming more common in the cladding industry. cladding companies try to avoid design and build due to the risk associated with it.

Q2. Dr. Watson was asked to comment on the categorisation of projects as Standard, Semi Standard and |innovative.

Dr. Watson agreed with the categorisation of products used in projects. It was found that in this economic climate companies' have started to provide complex and innovative cladding products at the same price as mass and standard products. Without the powerful of information system companies will then struggle to provide these complex and innovative products cost-effectively without more accurate risk assessment. Manufacturing control will also play an important role in controlling the variables associated with complex and innovative products.

Q3. Dr. Watson was asked on his experience in the steel industry and to compare it with the cladding industry from the standardisation and systems utilisation in both industries.

Dr. Watson recommends that the cladding industry follows the steel and other industries in standardisation processes. This will allow cladding companies to manage the variables that increase the risk factor associated to complex and innovative products, which will allow them to become more agile.

Dr. Haitham Ayoub

General Manager, Galaxy Aluminium, Jordan

Dr Ayoub has a BSc in Civil Engineering from Yarmouk University in Jordan, an MSc in Civil Engineering specialising in construction and public works management and a PhD from Marquette University in the US. His other qualifications include Certified ISO9001 Internal Auditor and Internal Auditor of the American Institute of Steel Construction Certification at the Butler Manufacturing Company. He has published widely on issues related to the construction industry.

He has over twenty years experience in civil and manufacturing engineering with over fifteen years spent in steel manufacturing. Previously he worked as engineering manager for International Buildings Systems Factory, pre-engineered steel buildings division manager for NegemCo. And division engineer for the Butler Manufacturing Company in the US. He also previously held positions at the City of Milwaukee's Sewer and Environmental Engineering Research and Advanced Planning's division, Marquette University's Civil Engineering Department and Inland Buildings.

He is currently General Manager and Partner in Techtonic Middle East based in Jordan.

Interview Notes, 27/12/2009, Amman, Jordan:

Q1. Dr. Ayoub was asked to comment on his experience in the steel industry and to compare it with the cladding industry from the point of view of standardisation and systems utilisation.

Dr. Ayoub confirmed the comments made by Dr. Watson regarding the level of standardisation in the steel industry compared to the cladding industry. Dr. Ayoub mentioned that glazing and curtain walling type of cladding has standard design and estimation software provided by system suppliers, such as SAPA and Schucco. This is based on the steel industry which has a standard design packages allowing engineers to design and produce a full bill of materials using a single, standard software.

Dr. Ayoub said that the metal cladding sector lacks the availability of these kinds of software.

Mr. Heath Hindmarch

Managing Director, PSP Architectural Ltd.

Mr. Hindmarch has a BSc (Hons) in Management in addition to further professional qualifications in Operation and Financial Management.

He has had 22 years experience in the cladding industry, including a 4 year period as a Sheet-Metal Worker, 5 years as QA Manager and 5 more years as Commercial and Technical Manager in CA Roofing, Evenwood, County Durham. This experience inspired Heath to establish PSP in 1998 so he is the founder and Managing Director of PSP Architectural Ltd.

Interview Notes, 13/02/2010, PSP Architectural Ltd, Shildon:

Q1. Mr. Heath Hindmarch was asked to comment on the results of the integration of the manufacturing and design systems within PSP Architectural Ltd. and its effect on the risk associated with Semi-Standard, complex and innovative projects.

Mr. Hindmarch confirmed the benefits that PSP obtained through the adoption of structured methodologies by the selection, implementation and integration of PSP software packages.

"The data integration has allowed the higher management of PSP to analyse the actual costing data before and after the completion of the projects. The data analysis has allowed us to consider the amount of risk associated with the complex and innovative type of projects within PSP."

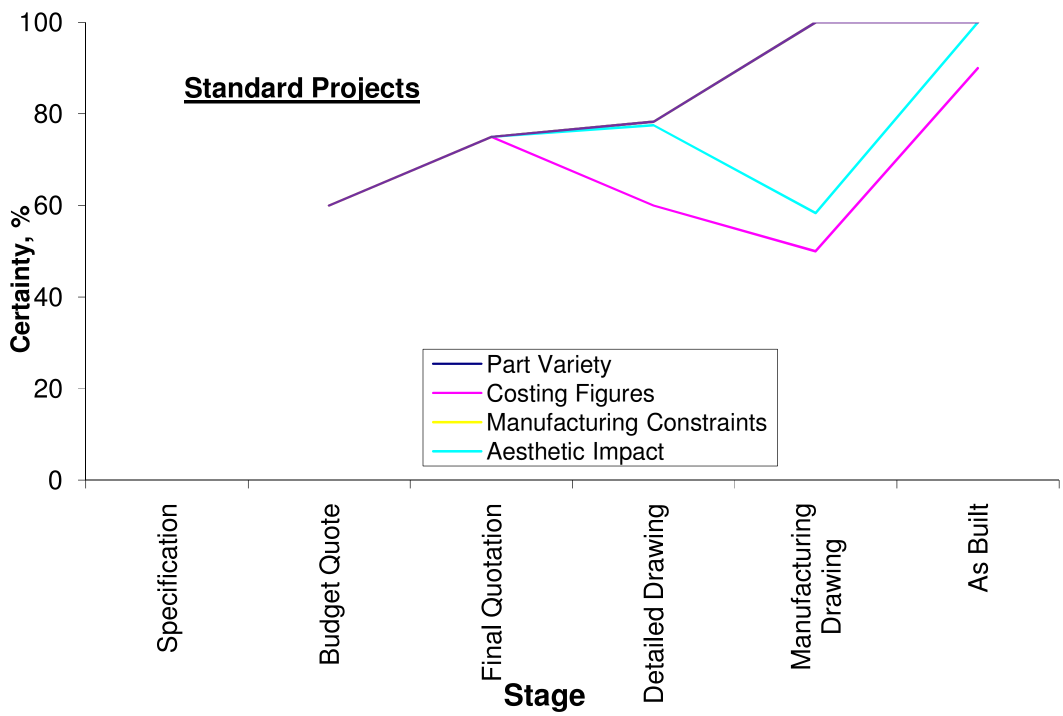
I do recommend that the type of risk assessment used by the insurance companies should be applied to the cladding industry. Complex projects can be assessed on associated risk and the risk percentage could be calculated. Customers are willing to pay extra for specialised and innovative products. The risk should be added to the price of these products. In the case of standard projects the risk factor cannot be applied as price is very competitive. In this case variables should be controlled by organisational operations control systems, especially in the current economic climate.

APPENDIX C - INTERNAL QUESTIONNAIRE & RESULTS

Internal Questionnaire entropy results summarised from data gathered from PSP Architectural Ltd Design, Sales and Production teams for the aggregated projects listed in Appendix A. These values give a level (0-100%) gathered from PSP design, sales and production team members from their views on the degree of certainty a list of project factors has at the various stages of the project lifespan.

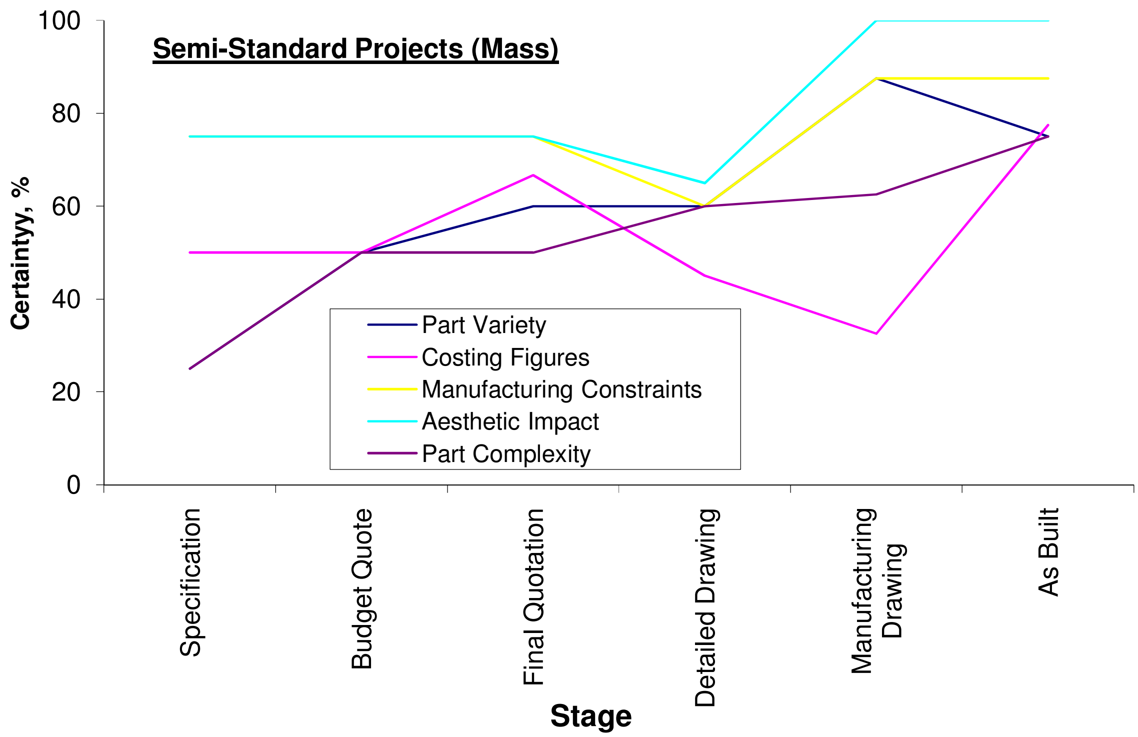
Project A: Standard Projects

	Specification	Budget Quote	Final Quotation	Detailed Drawing	Manufacturing Drawing	As Built
Part Variety		60.0	75.0	78.3	100.0	100.0
Costing Figures		60.0	75.0	60.0	50.0	90.0
Manufacturing Constraints		60.0	75.0	78.3	100.0	100.0
Aesthetic Impact			75.0	77.5	58.3	100.0
Part Complexity		60.0	75.0	78.3	100.0	100.0
Average		60.0	**75.0**	74.5	81.7	98.0



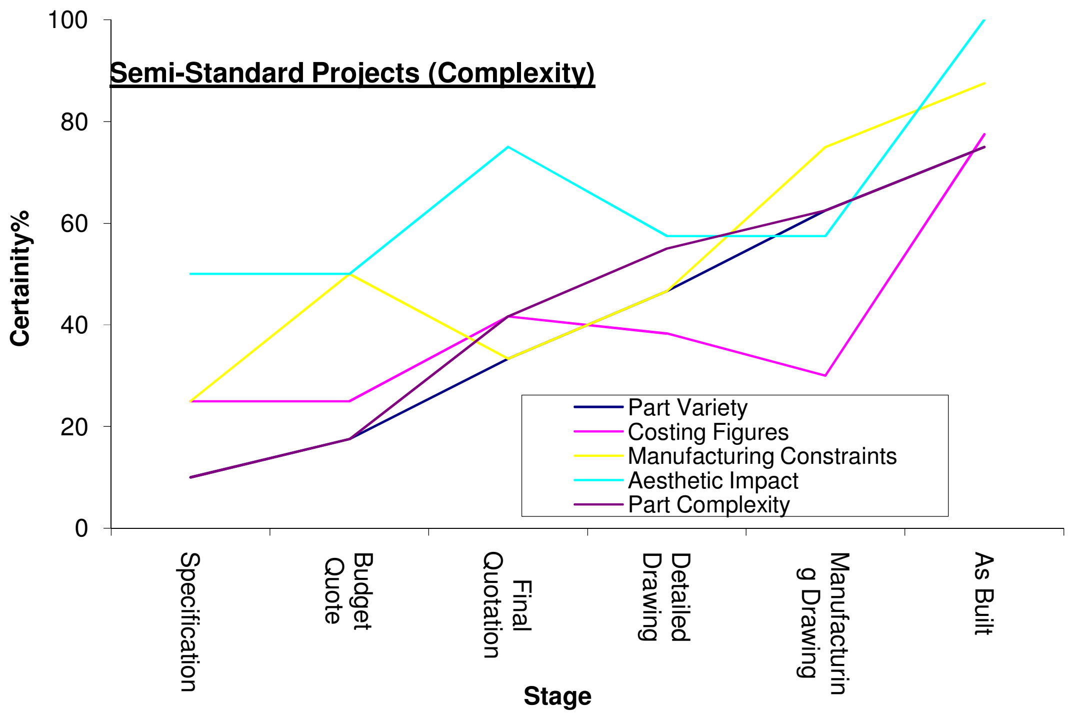
Project B: Semi-Standard Projects (Mass)

	Specification	Budget Quote	Final Quotation	Detailed Drawing	Manufacturing Drawing	As Built
Part Variety	25.0	50.0	60.0	60.0	87.5	75.0
Costing Figures	50.0	50.0	66.7	45.0	32.5	77.5
Manufacturing Constraints	75.0	75.0	75.0	60.0	87.5	87.5
Aesthetic Impact	75.0	75.0	75.0	65.0	100.0	100.0
Part Complexity	25.0	50.0	50.0	60.0	62.5	75.0
Average	50.0	60.0	**65.3**	58.0	74.0	83.0



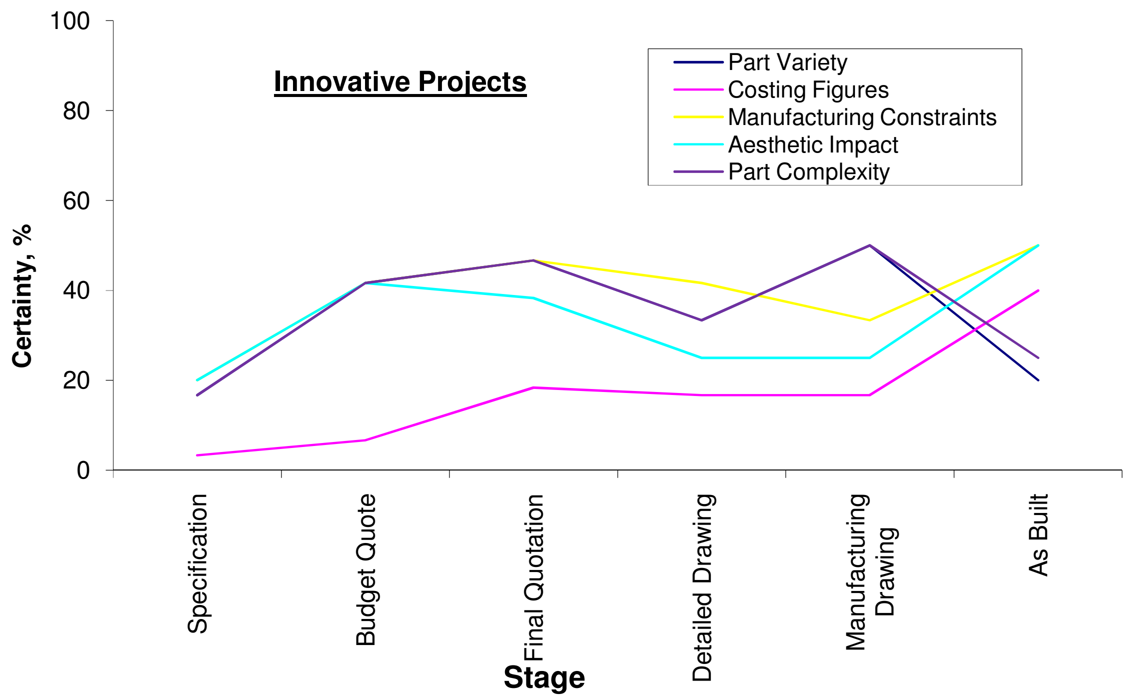
Project B: Semi-Standard Projects (Complexity)

	Specification	Budget Quote	Final Quotation	Detailed Drawing	Manufacturing Drawing	As Built
Part Variety	10.0	17.5	33.3	46.7	62.5	75.0
Costing Figures	25.0	25.0	41.7	38.3	30.0	77.5
Manufacturing Constraints	25.0	50.0	33.3	46.7	75.0	87.5
Aesthetic Impact	50.0	50.0	75.0	57.5	57.5	100.0
Part Complexity	10.0	17.5	41.7	55.0	62.5	75.0
Average	24.0	32.0	**45.0**	48.8	57.5	83.0



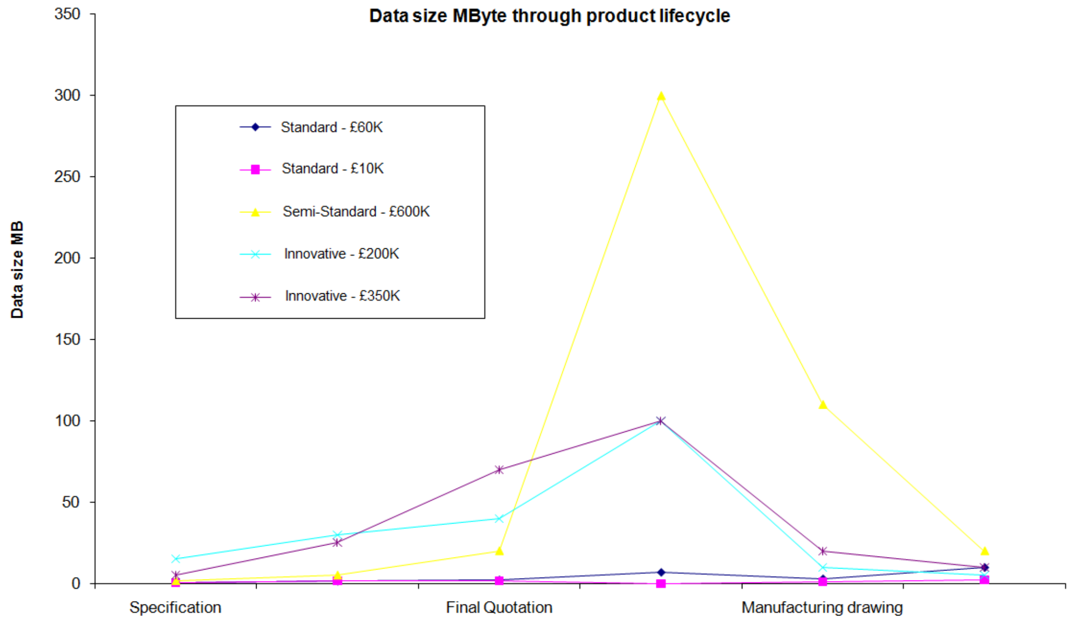
Project C: Innovative Projects

	Specification	Budget Quote	Final Quotation	Detailed Drawing	Manufacturing Drawing	As Built
Part Variety	16.7	41.7	46.7	33.3	50.0	20.0
Costing Figures	3.3	6.7	18.3	16.7	16.7	40.0
Manufacturing Constraints	20.0	41.7	46.7	41.7	33.3	50.0
Aesthetic Impact	20.0	41.7	38.3	25.0	25.0	50.0
Part Complexity	16.7	41.7	46.7	33.3	50.0	25.0
Average	15.3	34.7	**39.3**	30.0	35.0	37.0



All Projects – Data Size

Below is a summary of the sample data size (in MByte) through a product lifecycle for various different types and values of projects.



APPENDIX D - EXTERNAL QUESTIONNAIRE

Name:
Date:
Company/Department:

Introduction:

This Questionnaire is part of ongoing research between Durham University and PSP Architectural Ltd. in County Durham. The focus research will be on cost management and systems integration in the cladding supply chain in order to improve our performance to our customers.

The research forms a part of a PhD. research, for which this questionnaire will be part of an analysis section. This questionnaire`s aim is to identify the integration gaps in the cladding supply chain, from the architects and building designers point of view. The answers from the questionnaire will be used as part of the analysis to quantify the problem that faces the supply chain integration in the cladding industry and find potential solutions to the uncertainty level in the early design stages.

I will report back to you the results of this questionnaire.

The questionnaire is divided into four sections:

- Section A. Design Certainty in a Project
- Section B. Importance to a Project
- Section C. How to improve a Project
- Section D. Future Recommendations for a Project

Section A - Design Certainty in a Project

Please fill the Table with the number (1, 2 or 3) that reflects your answer on the level of certainty to the factors demonstrated and the cladding product life-cycle stage:

- 1 = 90-100% Certain
- 2 = 50-90% General Overview but Uncertain
- 3 = 0-50% No idea or Uncertain

Factors that will be demonstrated as part of this questionnaire:

- Costing Figures
- Manufacturing constraints and complexity
- Aesthetic impacts of parts design

Phase description in the Table for the cladding life-cycle stages are as following:

I. Initial concept design
II. Final cladding design & specification
III. Pricing
IV. Manufacturing
V. Installation & handover

	Phase I	**Phase II**	**Phase III**	**Phase IV**	**Phase V**
Costing Figures					
Manufacturing Constraints					
Aesthetic impact					

Section B - Importance to the Project

Please rank the following factors according to their importance from the architect's point of view, 1-4:

[ ] Number of Parts
[ ] Costing Figures
[ ] Manufacturing constraints and complexity
[ ] Aesthetic impacts of parts design

Section C - How to improve the Project

Please answer Yes or No to the following questions

1. Suppliers should be involved in the early stages of products design.

   YES NO

2. Do you agree with categorising the building as standard, Semi-Standard and innovative?

   YES NO

3. Do you agree with categorising the building by mass or the complexity of the aesthetics of the building?

   YES NO

4. Do you think the building design and structure has an effect on the design files sizes and the efficiency of data transferred between architects and manufacturing companies?

   YES NO

5. Integration of CAD system between architects and manufacturing suppliers can improve the certainty level of costing in the early stages of product design.

   YES NO

Section D - Future Recommendations for a Project

Please select from the following options:

1. In reference to the supply chain stages summarised below, please select the stage that manufacturing companies SHOULD be involved in (select more than one if required)?

   A. *Structure Design*
   B. *Primary design*
   C. *Final cladding Design*
   D. *Specification*
   E. *Pricing*
   F. *Job Planning and Scheduling*

2. In reference to the supply chain stages summarised below please select the stage that manufacturing companies are currently asked to be involved in (select more than one if required)?

   A. *Structure Design*
   B. *Primary design*
   C. *Final cladding Design*
   D. *Specification*
   E. *Pricing*
   F. *Job Planning and Scheduling*

3. Which method of integration do you recommend to be adopted (select more than one if required)

   A. *AutoCAD integration*
   B. *Meetings and email*
   C. *Invited to participating in writing the specification*
   D. *None*

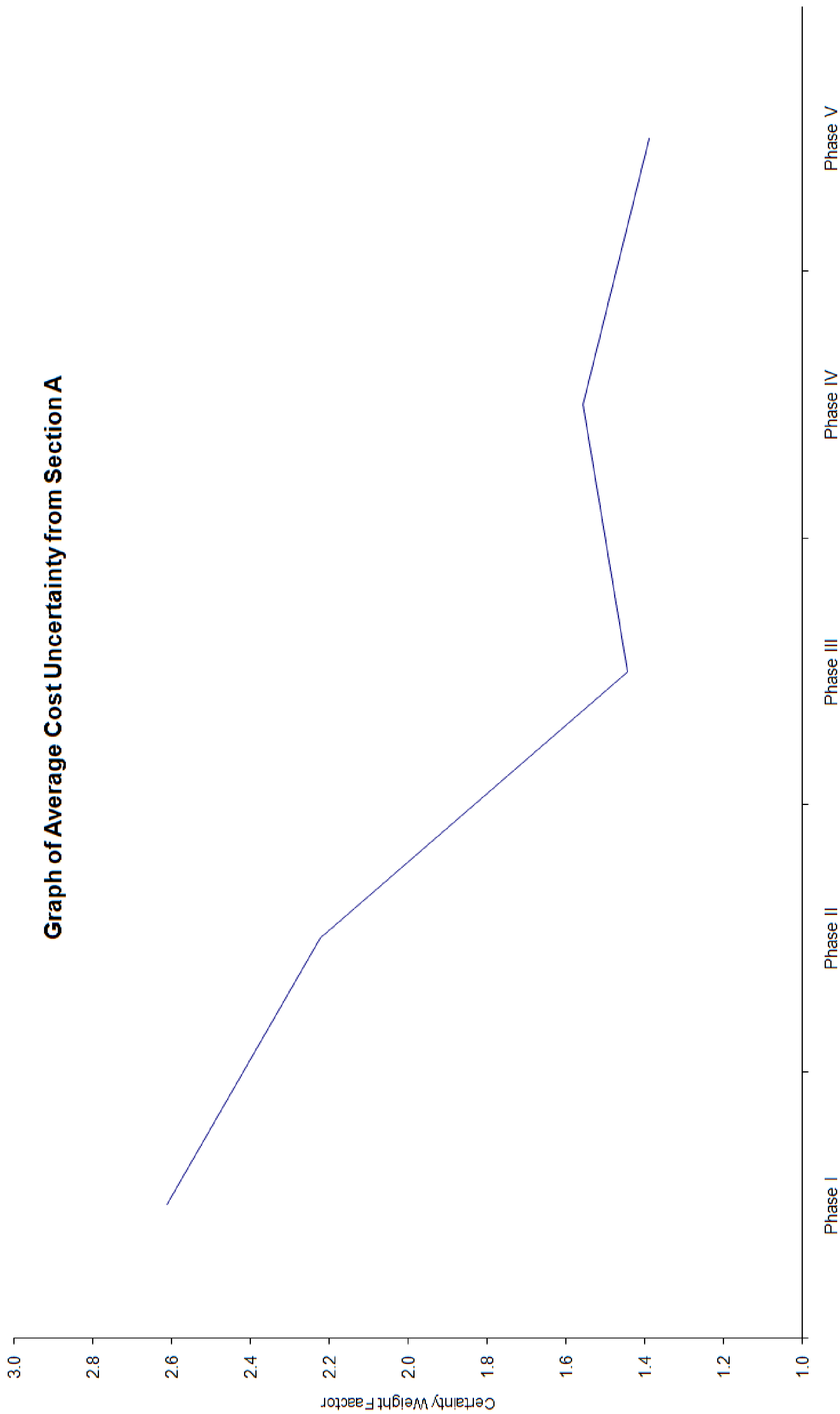
APPENDIX E - EXTERNAL QUESTIONNAIRE RESULTS

The following summarises the results of the External Questionnaire, Appendix D

Section A – Design Certainty of a Project

A1. Cost

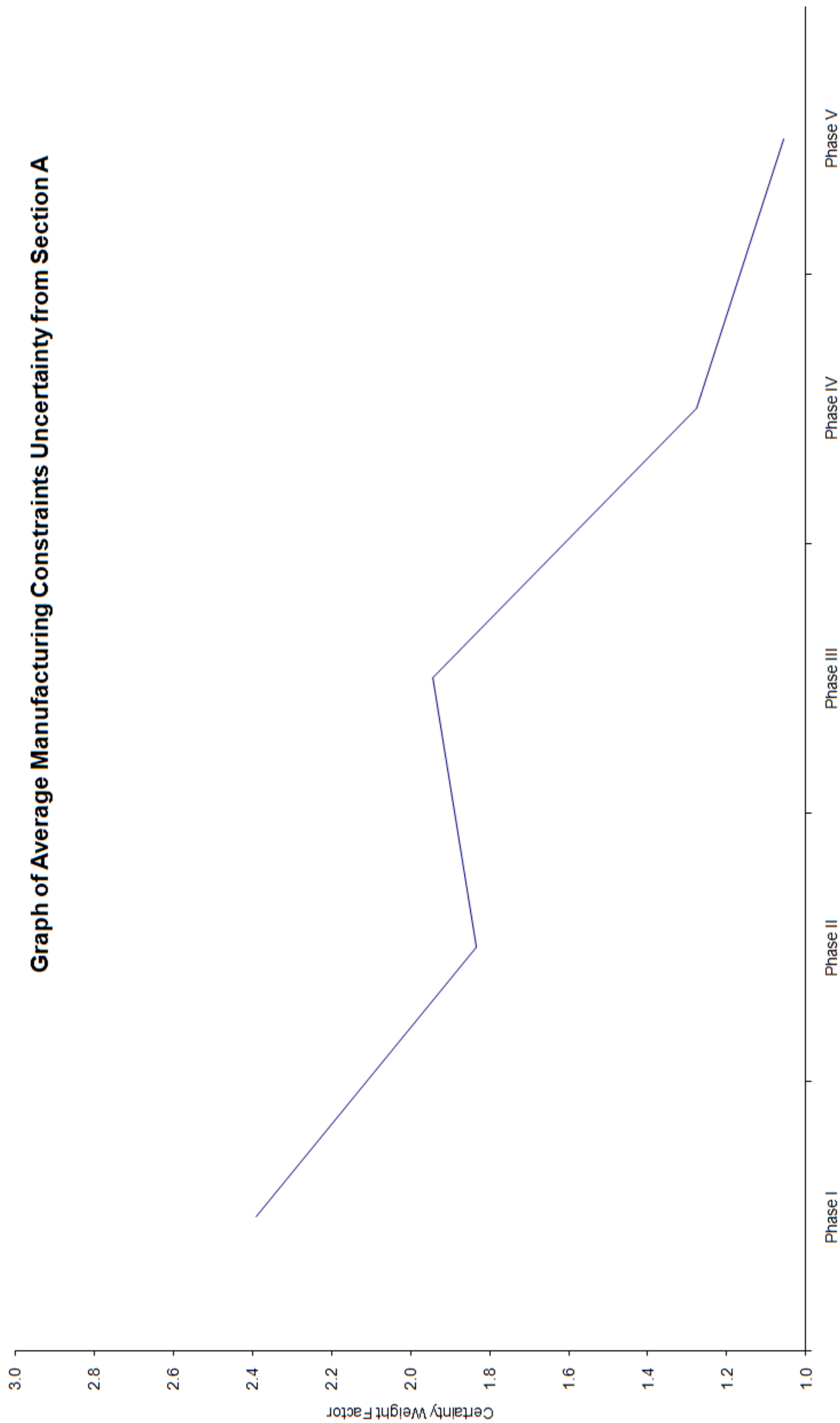
Cost Uncertainty								
Company	**Title**	**Respondent**	**Sector**	**Phase I**	**Phase II**	**Phase III**	**Phase IV**	**Phase V**
Foster & Partners	Associate Architect	Omar Omari	Architect (UK)	3	3	2	1	1
Foster & Partners	Architect	Maher Matar	Architect (UK)	2	2	2	2	1
Umicore	Sales Manager	Paul Carter	Architect (UK)	3	2	2	2	2
PSP Architectural Ltd	Director	Ron Fitch	Architect (UK)	3	2	2	2	2
PSP Architectural Ltd	Director	John Burrell	Cladding Manufacturer	3	2	1	1	1
MK Trading Co.	President	Kamal Ashraf	Cladding Manufacturer (Middle East)	3	3	1	2	2
MDK Roofing Ltd.	Managing Director	Dave Elder	Cladding Installer (UK)	2	1	1	1	1
MDK Roofing Ltd.	Director/ Share Holder	Mark Romain	Cladding Installer (UK)	2	1	1	1	1
FM Consultants	Architect	Zeina Aoun	Architect (Middle East)	2	3	2	2	1
Kingspan	Director	Gary Crosby	Cladding Contractor & Manufacturer (UK)	2	1	1	1	1
NCP Architecture	Architect	Nizar Cortas	Architect (Middle East)	2	3	2	2	1
Allies & Morrison	Architect	Mark Taylor	Architect (UK)	3	2	1	1	1
Yousef Nour	Architect	Yousef Nour	Architect (Middle East)	2	2	1	1	1
PSP Architectural Ltd	Managing Director	Heath Hindmarch	Cladding Manufacturer (UK)	3	2	1	1	1
Broadley Roofing Ltd.	Construction Manager	Dave Parkinson	Cladding Installer & Manufacturer	3	2	1	1	1
Corevista Ltd.	Managing Director	Geoff Layland	Cladding Manufacturer & Designer (UK)	3	3	3	3	3
eGram	Managing Director	Joe Scully	Cladding Contractor (UK)	3	3	1	2	2
Techtonic Architectural Ltd.	General Manager	Haitham Ayoub	Cladding Manufacturer (Middle East)	3	3	1	2	2
		Average Uncertainty (Cost)		**2.6**	**2.2**	**1.4**	**1.6**	**1.4**



Graph of Average Cost Uncertainty from Section A
Certainty Weight Faactor
3.0
2.8
2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
Phase I
Phase II
Phase III
Phase IV
Phase V

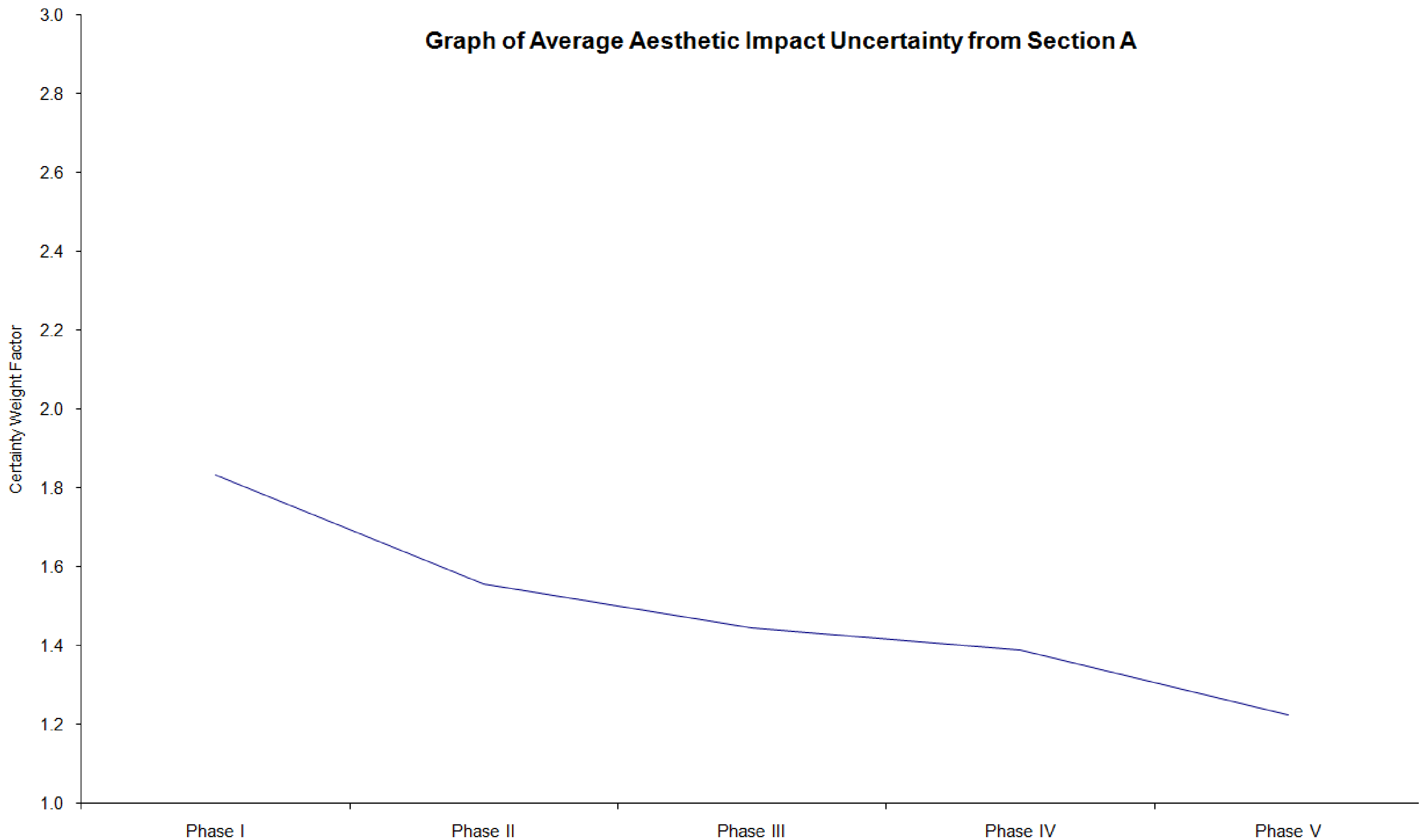
A2. Manufacturing Constraints

Manufacturing Constraints Uncertainty								
Company	**Title**	**Respondent**	**Sector**	**Phase I**	**Phase II**	**Phase III**	**Phase IV**	**Phase V**
Foster & Partners	Associate Architect	Omar Omari	Architect (UK)	3	2	2	1	1
Foster & Partners	Architect	Maher Matar	Architect (UK)	2	1	2	1	1
Umicore	Sales Manager	Paul Carter	Architect (UK)	3	2	2	2	1
PSP Architectural Ltd	Director	Ron Fitch	Architect (UK)	3	2	2	2	1
PSP Architectural Ltd	Director	John Burrell	Cladding Manufacturer	2	2	2	1	1
MK Trading Co.	President	Kamal Ashraf	Cladding Manufacturer (Middle East)	2	2	2	1	1
MDK Roofing Ltd.	Managing Director	Dave Elder	Cladding Installer (UK)	3	2	2	2	1
MDK Roofing Ltd.	Director/ Share Holder	Mark Romain	Cladding Installer (UK)	3	2	2	2	1
FM Consultants	Architect	Zeina Aoun	Architect (Middle East)	3	2	2	1	1
Kingspan	Director	Gary Crosby	Cladding Contractor & Manufacturer (UK)	3	2	2	1	1
NCP Architecture	Architect	Nizar Cortas	Architect (Middle East)	3	2	2	1	1
Allies & Morrison	Architect	Mark Taylor	Architect (UK)	2	2	2	1	1
Yousef Nour	Architect	Yousef Nour	Architect (Middle East)	2	1	1	1	1
PSP Architectural Ltd	Managing Director	Heath Hindmarch	Cladding Manufacturer (UK)	2	2	2	1	1
Broadley Roofing Ltd.	Construction Manager	Dave Parkinson	Cladding Installer & Manufacturer	2	2	2	1	1
Corevista Ltd.	Managing Director	Geoff Layland	Cladding Manufacturer & Designer (UK)	1	1	2	2	2
eGram	Managing Director	Joe Scully	Cladding Contractor (UK)	2	2	2	1	1
Techtonic Architectural Ltd.	General Manager	Haitham Ayoub	Cladding Manufacturer (Middle East)	2	2	2	1	1
	Average Uncertainty (Manufacturing)			**2.4**	**1.8**	**1.9**	**1.3**	**1.1**


Graph of Average Manufacturing Constraints Uncertainty from Section A
Certainty Weight Factor
3.0
2.8
2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
Phase I
Phase II
Phase III
Phase IV
Phase V

A3. Aesthetic Impact

Aesthetic Impact Uncertainty								
Company	**Title**	**Respondent**	**Sector**	**Phase I**	**Phase II**	**Phase III**	**Phase IV**	**Phase V**
Foster & Partners	Associate Architect	Omar Omari	Architect (UK)	3	2	2	2	1
Foster & Partners	Architect	Maher Matar	Architect (UK)	2	1	2	1	1
Umicore	Sales Manager	Paul Carter	Architect (UK)	2	2	2	2	1
PSP Architectural Ltd	Director	Ron Fitch	Architect (UK)	2	2	2	2	1
PSP Architectural Ltd	Director	John Burrell	Cladding Manufacturer	2	2	1	1	1
MK Trading Co.	President	Kamal Ashraf	Cladding Manufacturer (Middle East)	2	2	1	1	1
MDK Roofing Ltd.	Managing Director	Dave Elder	Cladding Installer (UK)	1	1	1	1	1
MDK Roofing Ltd.	Director/ Share Holder	Mark Romain	Cladding Installer (UK)	1	1	1	1	1
FM Consultants	Architect	Zeina Aoun	Architect (Middle East)	1	1	1	1	1
Kingspan	Director	Gary Crosby	Cladding Contractor & Manufacturer (UK)	2	1	1	1	1
NCP Architecture	Architect	Nizar Cortas	Architect (Middle East)	1	1	1	1	1
Allies & Morrison	Architect	Mark Taylor	Architect (UK)	2	1	1	1	1
Yousef Nour	Architect	Yousef Nour	Architect (Middle East)	2	1	1	1	1
PSP Architectural Ltd	Managing Director	Heath Hindmarch	Cladding Manufacturer (UK)	2	2	1	1	1
Broadley Roofing Ltd.	Construction Manager	Dave Parkinson	Cladding Installer & Manufacturer	2	2	1	1	1
Corevista Ltd.	Managing Director	Geoff Layland	Cladding Manufacturer & Designer (UK)	3	3	3	3	3
eGram	Managing Director	Joe Scully	Cladding Contractor (UK)	1	1	3	3	3
Techtonic Architectural Ltd.	General Manager	Haitham Ayoub	Cladding Manufacturer (Middle East)	2	2	1	1	1
	Average Uncertainty (Aesthetics)			**1.8**	**1.6**	**1.4**	**1.4**	**1.2**


Graph of Average Aesthetic Impact Uncertainty from Section A
Certainty Weight Factor
3.0
2.8
2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
Phase I
Phase II
Phase III
Phase IV
Phase V

Section B – Importance to the Project

Company	Title	Respondent	Sector	Parts No.	Costing Figures	Manufacturing Constraints	Aesthetic Impacts
Foster & Partners	Associate Architect	Omar Omari	Architect (UK)	4	3	2	1
Foster & Partners	Architect	Maher Matar	Architect (UK)	2	3	4	1
Umicore	Sales Manager	Paul Carter	Architect (UK)	4	2	3	1
PSP Architectural Ltd	Director	Ron Fitch	Architect (UK)	4	2	3	1
PSP Architectural Ltd	Director	John Burrell	Cladding Manufacturer	2	1	3	4
MK Trading Co.	President	Kamal Ashraf	Cladding Manufacturer (Middle East)	2	1	3	4
Kyotec	Commercial Director	Gary Benger	Cladding Installer (UK)	4	2	3	1
MDK Roofing Ltd.	Managing Director	Dave Elder	Cladding Installer (UK)	4	2	3	1
MDK Roofing Ltd.	Director/ Share Holder	Mark Romain	Cladding Installer (UK)	4	2	3	1
FM Consultants	Architect	Zeina Aoun	Architect (Middle East)	4	2	3	1
Kingspan	Director	Gary Crosby	Cladding Contractor & Manufacturer (UK)	3	2	4	1
NCP Architecture	Architect	Nizar Cortas	Architect (Middle East)	4	2	3	1
Allies & Morrison	Architect	Mark Taylor	Architect (UK)	4	2	3	1
Yousef Nour	Architect	Yousef Nour	Architect (Middle East)	4	2	3	1
PSP Architectural Ltd	Managing Director	Heath Hindmarch	Cladding Manufacturer (UK)	4	3	2	1
Broadley Roofing Ltd.	Construction Manager	Dave Parkinson	Cladding Installer & Manufacturer	4	1	2	3
Corevista Ltd.	Managing Director	Geoff Layland	Cladding Manufacturer & Designer (UK)	3	2	4	1
eGram	Managing Director	Joe Scully	Cladding Contractor (UK)	4	3	2	1
Techtonic Architectural Ltd.	General Manager	Haitham Ayoub	Cladding Manufacturer (Middle East)	4	3	2	1
		Average Importance Rating		**3.6**	**2.1**	**2.9**	**1.4**

Section C – How to Improve a Project

Company	Title	Respondent	Sector	Q1	Q2	Q3	Q4	Q5
Foster & Partners	Associate Architect	Omar Omari	Architect (UK)	Y	Y	Y	Y	Y
Foster & Partners	Architect	Maher Matar	Architect (UK)	N	Y	Y	Y	Y
Umicore	Sales Manager	Paul Carter	Architect (UK)	Y	Y	Y	Y	Y
PSP Architectural Ltd	Director	Ron Fitch	Architect (UK)	Y	Y	Y	Y	Y
PSP Architectural Ltd	Director	John Burrell	Cladding Manufacturer	Y	Y	Y	Y	Y
MK Trading Co.	President	Kamal Ashraf	Cladding Manufacturer (Middle East)	Y	Y	Y	Y	Y
Kyotec	Commercial Director	Gary Benger	Cladding Installer (UK)	Y	Y	Y	Y	Y
MDK Roofing Ltd.	Managing Director	Dave Elder	Cladding Installer (UK)	Y	Y	Y	Y	Y
MDK Roofing Ltd.	Director/ Share Holder	Mark Romain	Cladding Installer (UK)	Y	Y	N	Y	Y
FM Consultants	Architect	Zeina Aoun	Architect (Middle East)	Y	Y	N	Y	Y
Kingspan	Director	Gary Crosby	Cladding Contractor & Manufacturer (UK)	Y	N	N	N	N
NCP Architecture	Architect	Nizar Cortas	Architect (Middle East)	Y	Y	N	Y	Y
Allies & Morrison	Architect	Mark Taylor	Architect (UK)	Y	N	N	Y	Y
Yousef Nour	Architect	Yousef Nour	Architect (Middle East)	Y	Y	Y	Y	Y
PSP Architectural Ltd	Managing Director	Heath Hindmarch	Cladding Manufacturer (UK)	Y	Y	Y	Y	Y
Broadley Roofing Ltd.	Construction Manager	Dave Parkinson	Cladding Installer & Manufacturer	Y	Y	Y	Y	Y
Corevista Ltd.	Managing Director	Geoff Layland	Cladding Manufacturer & Designer (UK)	Y	Y	Y	Y	N
eGram	Managing Director	Joe Scully	Cladding Contractor (UK)	Y	Y	Y	Y	Y
Techtonic Architectural Ltd.	General Manager	Haitham Ayoub	Cladding Manufacturer (Middle East)	Y	Y	Y	Y	Y

Section D – Future Recommendations for a Project

Company	Title	Respondent	Sector	Q1	Q2	Q3
Foster & Partners	Associate Architect	Omar Omari	Architect (UK)	C, D	E, F	A, B
Foster & Partners	Architect	Maher Matar	Architect (UK)	A, D	C, D	A, B
Umicore	Sales Manager	Paul Carter	Architect (UK)	B, C	B, C	B
PSP Architectural Ltd	Director	Ron Fitch	Architect (UK)	B, C	B, C	B
PSP Architectural Ltd	Director	John Burrell	Cladding Manufacturer	ALL	E, F	A, B
MK Trading Co.	President	Kamal Ashraf	Cladding Manufacturer (Middle East)	A, B	B, C, E	A, B, C
Kyotec	Commercial Director	Gary Benger	Cladding Installer (UK)	B, C	B, C	B
MDK Roofing Ltd.	Managing Director	Dave Elder	Cladding Installer (UK)	ALL	C, D, E	A, B, C
MDK Roofing Ltd.	Director/ Share Holder	Mark Romain	Cladding Installer (UK)	ALL	C, D, E	A, B, C
FM Consultants	Architect	Zeina Aoun	Architect (Middle East)	B, E	B, C, D	A, B, C
Kingspan	Director	Gary Crosby	Cladding Contractor & Manufacturer (UK)	ALL	C, D, E	A, B
NCP Architecture	Architect	Nizar Cortas	Architect (Middle East)	B, E	B, C, D	A, B, C
Allies & Morrison	Architect	Mark Taylor	Architect (UK)	B, C, E	B, C, E	A, B
Yousef Nour	Architect	Yousef Nour	Architect (Middle East)	A, B, C	A, B, C	A, B
PSP Architectural Ltd	Managing Director	Heath Hindmarch	Cladding Manufacturer (UK)	ALL	E, F	A, B
Broadley Roofing Ltd.	Construction Manager	Dave Parkinson	Cladding Installer & Manufacturer	ALL	ALL	A, B, C
Corevista Ltd.	Managing Director	Geoff Layland	Cladding Manufacturer & Designer (UK)	ALL	E, F	A, B, C
eGram	Managing Director	Joe Scully	Cladding Contractor (UK)	C, F	E, F	A, B
Techtonic Architectural Ltd.	General Manager	Haitham Ayoub	Cladding Manufacturer (Middle East)	A, B	B, C, E	A, B, C

APPENDIX F - PROJECT RISK ASSESSMENTS

Human Factors

Innovative Projects

			Project D (Innovative)		**Project B (Innovative)**		**Project Q (Innovative)**	
		Importance to Company (0-5)	Certainty (0-5)	Total Factor (Importance + Certainty)	Certainty (0-5)	Total Factor (Importance + Certainty)	Certainty (0-5)	Total Factor (Importance + Certainty)
Employee Name	Enter to ERP	*1*	3	4	3	4	3	4
Department	Collect from ERP	*4*	4	8	3	7	4	8
Age		*3*	4	7	0	3	4	7
Qualification		*2*	5	7	2	4	5	7
Experience in industry		*5*	5	10	1	6	5	10
No. of Years at the company		*3*	1	4	1	4	1	4
Order Conversion Rate		*5*	3	8	2	7	3	8
	Average	***3.3***	***3.6***	***6.9***	***1.7***	***5.0***	***3.6***	***6.9***

Complex Projects

			Project M (Complex)		**Project A (Complex)**		**Project K (Complex)**	
		Importance to Company (0-5)	Certainty (0-5)	Total Factor (Importance + Certainty)	Certainty (0-5)	Total Factor (Importance + Certainty)	Certainty (0-5)	Total Factor (Importance + Certainty)
Employee Name	Enter to ERP	1	3	4	3	4	2	3
Department	Collect from ERP	4	3	7	3	7	3	7
Age		3	4	7	0	3	1	4
Qualification		2	4	6	2	4	2	4
Experience in industry		5	1	6	1	6	2	7
No. of Years at the company		3	3	6	1	4	1	4
Order Conversion Rate		5	3	8	2	7	3	8
	Average	**3.3**	***3.0***	***6.3***	***1.7***	***5.0***	***2.0***	***5.3***

Mass-Based Projects

			Project P (Mass)		Project R (Mass)		Project C (Mass)		Project H (Mass)		Project J (Mass)	
		Importance to Company (0-5)	Certainty (0-5)	Total Factor (Importance + Certainty)	Certainty (0-5)	Total Factor (Importance + Certainty)	Certainty (0-5)	Total Factor (Importance + Certainty)	Certainty (0-5)	Total Factor (Importance + Certainty)	Certainty (0-5)	Total Factor (Importance + Certainty)
Employee Name	Enter to ERP	1	4	5	2	3	4	5	2	3	2	3
Department	Collect from ERP	4	4	8	4	8	3	7	3	7	3	7
Age		3	4	7	3	6	4	7	1	4	1	4
Qualification		2	3	5	3	5	3	5	2	4	2	4
Experience in industry		5	4	9	3	8	4	9	2	7	2	7
No. of Years at the company		3	3	6	2	5	2	5	1	4	1	4
Order Conversion Rate		5	4	9	3	8	3	8	3	8	3	8
	Average	***3.3***	***3.7***	***7.0***	***2.9***	***6.1***	***3.3***	***6.6***	***2.0***	***5.3***	***2.0***	***5.3***

Standard Projects

			Project E (Standard)	
		Importance to Company (0-5)	Certainty (0-5)	Total Factor (Importance + Certainty)
Employee Name	Enter to ERP	1	5	6
Department	Collect from ERP	4	4	8
Age		3	4	7
Qualification		2	4	6
Experience in industry		5	5	10
No. of Years at the company		3	5	8
Order Conversion Rate		5	4	9
	Average	**3.0**	***4.4***	***7.7***

Project Factors

Innovative Projects

		Importance to Company (0-5)	Project D (Innovative) Certainty (0-5)	Project D (Innovative) Total Factor (Importance + Certainty)	Project B (Innovative) Certainty (0-5)	Project B (Innovative) Total Factor (Importance + Certainty)	Project Q (Innovative) Certainty (0-5)	Project Q (Innovative) Total Factor (Importance + Certainty)
Project name	Enter to ERP	*2*	1	3	5	7	2	4
Project address		*2*	1	3	1	3	4	6
Customer name		*1*	2	3	1	2	2	3
Profit Margin	Collect from ERP	*5*	1	6	2	7	2	7
Discount		*0*	1	1	0	0	2	2
Relation with customer		*2*	2	4	0	2	2	4
Credit rate		*5*	3	8	4	9	3	8
Customer turnover		*3*	2	5	2	5	2	5
Customer trading history		*4*	1	5	2	6	3	7
Quality of customer input		*4*	2	6	2	6	2	6
Project complexity level	System	*5*	1	6	1	6	1	6
	Average	***3.0***	***1.5***	***4.5***	***1.8***	***4.8***	***2.3***	***5.3***

Complex Projects

		Importance to Company (0-5)	Project M (Complex) Certainty (0-5)	Project M (Complex) Total Factor (Importance + Certainty)	Project A (Complex) Certainty (0-5)	Project A (Complex) Total Factor (Importance + Certainty)	Project K (Complex) Certainty (0-5)	Project K (Complex) Total Factor (Importance + Certainty)
Project name	Enter to ERP	*2*	1	3	5	7	2	4
Project address		*2*	1	3	1	3	4	6
Customer name		*1*	2	3	1	2	2	3
Profit Margin	Collect from ERP	*5*	1	6	2	7	2	7
Discount		*0*	1	1	0	0	2	2
Relation with customer		*2*	2	4	0	2	2	4
Credit rate		*5*	3	8	4	9	3	8
Customer turnover		*3*	2	5	2	5	2	5
Customer trading history		*4*	1	5	2	6	3	7
Quality of customer input		*4*	2	6	2	6	2	6
Project complexity level	System	*5*	1	6	1	6	1	6
	Average	***3.0***	***2.4***	***5.4***	***1.8***	***4.8***	***2.3***	***5.3***

Mass-Based Projects

			Project P (Mass)		Project R (Mass)		Project C (Mass)		Project H (Mass)		Project J (Mass)	
		Importance to Company (0-5)	Certainty (0-5)	Total Factor (Importance + Certainty)	Certainty (0-5)	Total Factor (Importance + Certainty)	Certainty (0-5)	Total Factor (Importance + Certainty)	Certainty (0-5)	Total Factor (Importance + Certainty)	Certainty (0-5)	Total Factor (Importance + Certainty)
Project name	Enter to ERP	*2*	5	7	3	5	5	7	5	7	5	7
Project address		*2*	3	5	3	5	2	4	1	3	1	3
Customer name		*1*	4	5	4	5	3	4	1	2	1	2
Profit Margin	Collect from ERP	*5*	4	9	4	9	3	8	2	7	2	7
Discount		*0*	4	4	4	4	1	1	2	2	2	2
Relation with customer		*2*	4	6	5	7	3	5	0	2	0	2
Credit rate		*5*	4	9	5	10	3	8	3	8	3	8
Customer turnover		*3*	3	6	4	7	2	5	2	5	2	5
Customer trading history		*4*	3	7	4	8	2	6	2	6	2	6
Quality of customer input		*4*	3	7	3	7	3	7	2	6	2	6
Project complexity level	System	*5*	4	9	4	9	3	8	3	8	3	8
	Average	***3.0***	***3.7***	***6.7***	***3.9***	***6.9***	***2.7***	***5.7***	***2.1***	***5.1***	***2.1***	***5.1***

Standard Projects

			Project E (Standard)	
		Importance to Company (0-5)	Certainty (0-5)	Total Factor (Importance + Certainty)
Project name	Enter to ERP	*2*	5	7
Project address		*2*	3	5
Customer name		*1*	4	5
Profit Margin	Collect from ERP	*5*	4	9
Discount		*0*	4	4
Relation with customer		*2*	4	6
Credit rate		*5*	4	9
Customer turnover		*3*	3	6
Customer trading history		*4*	3	7
Quality of customer input		*4*	3	7
Project complexity level	System	*5*	4	9
	Average	***3.0***	***3.7***	***6.7***

Product Factors

Innovative Projects

		Importance to Company (0-5)	Project D (Innovative) Certainty (0-5)	Project D (Innovative) Total Factor (Importance + Certainty)	Project B (Innovative) Certainty (0-5)	Project B (Innovative) Total Factor (Importance + Certainty)	Project Q (Innovative) Certainty (0-5)	Project Q (Innovative) Total Factor (Importance + Certainty)
Part name	Enter to ERP	*3*	3	6	2	5	3	6
Number of parts	Collect from ERP	*4*	3	7	1	5	2	6
Drawing format/ quality		*4*	3	7	1	5	2	6
Level of design required		*3*	1	4	0	3	1	4
Material used		*3*	1	4	2	5	3	6
Material tolerance		*4*	1	5	2	6	2	6
Part interface	System	*3*	2	5	1	4	1	4
Product complexity level		*5*	1	6	1	6	1	6
Bespoke product level		*5*	1	6	1	6	1	6
	Average	***3.8***	**1.8**	**5.6**	**1.2**	**5.0**	**1.8**	**5.6**

Complex Projects

		Importance to Company (0-5)	Project M (Complex) Certainty (0-5)	Project M (Complex) Total Factor (Importance + Certainty)	Project A (Complex) Certainty (0-5)	Project A (Complex) Total Factor (Importance + Certainty)	Project K (Complex) Certainty (0-5)	Project K (Complex) Total Factor (Importance + Certainty)
Part name	Enter to ERP	*3*	1	4	3	6	3	6
Number of parts	Collect from ERP	*4*	1	5	1	5	2	6
Drawing format/ quality		*4*	2	6	2	6	2	6
Level of design required		*3*	1	4	1	4	4	7
Material used		*3*	3	6	4	7	4	7
Material tolerance		*4*	3	7	4	8	4	8
Part interface	System	*3*	0	3	3	6	1	4
Product complexity level		*5*	1	6	2	7	2	7
Bespoke product level		*5*	0	5	2	7	0	5
	Average	***3.8***	**1.3**	**5.1**	**2.4**	**6.2**	**2.4**	**6.2**

Mass-Based Projects

			Project P (Mass)		Project R (Mass)		Project C (Mass)		Project H (Mass)		Project J (Mass)	
		Importance to Company (0-5)	Certainty (0-5)	Total Factor (Importance + Certainty)	Certainty (0-5)	Total Factor (Importance + Certainty)	Certainty (0-5)	Total Factor (Importance + Certainty)	Certainty (0-5)	Total Factor (Importance + Certainty)	Certainty (0-5)	Total Factor (Importance + Certainty)
Part name	Enter to ERP	*3*	4	7	4	7	3	6	4	7	4	7
Number of parts	Collect from ERP	*4*	3	7	1	5	4	8	4	8	4	8
Drawing format/ quality		*4*	3	7	1	5	3	7	4	8	4	8
Level of design required		*3*	4	7	2	5	3	6	4	7	4	7
Material used		*3*	2	5	4	7	4	7	4	7	4	7
Material tolerance		*4*	1	5	4	8	4	8	3	7	3	7
Part interface	System	*3*	4	7	4	7	3	6	4	7	4	7
Product complexity level		*5*	4	9	4	9	3	8	4	9	4	9
Bespoke product level		*5*	4	9	4	9	3	8	4	9	4	9
	Average	***3.8***	**3.2**	**7.0**	**3.1**	**6.9**	**3.3**	**7.1**	**3.9**	**7.7**	**3.9**	**7.7**

Standard Projects

			Project E (Standard)	
		Importance to Company (0-5)	Certainty (0-5)	Total Factor (Importance + Certainty)
Part name	Enter to ERP	*3*	4	7
Number of parts	Collect from ERP	*4*	5	9
Drawing format/ quality		*4*	3	7
Level of design required		*3*	4	7
Material used		*3*	4	7
Material tolerance		*4*	4	8
Part interface	System	*3*	4	7
Product complexity level		*5*	4	9
Bespoke product level		*5*	4	9
	Average	***3.8***	**4.0**	**7.8**

Manufacturing Factors

Innovative Projects

			Project D (Innovative)		Project B (Innovative)		Project Q (Innovative)	
		Importance to Company (0-5)	Certainty (0-5)	Total Factor (Importance + Certainty)	Certainty (0-5)	Total Factor (Importance + Certainty)	Certainty (0-5)	Total Factor (Importance + Certainty)
Machines	Enter to ERP	*5*	3	8	2	7	2	7
Assembly complexity	System	*5*	1	6	1	6	1	6
Quality history	Collect from ERP	*5*	1	6	2	7	1	6
Efficiency history		*5*	1	6	2	7	1	6
Labour skills		*5*	1	6	2	7	1	6
	Average	***5.0***	***1.4***	***6.4***	***1.8***	***6.8***	***1.2***	***6.2***

Complex Projects

			Project M (Complex)		Project A (Complex)		Project K (Complex)	
		Importance to Company (0-5)	Certainty (0-5)	Total Factor (Importance + Certainty)	Certainty (0-5)	Total Factor (Importance + Certainty)	Certainty (0-5)	Total Factor (Importance + Certainty)
Machines	Enter to ERP	*5*	2	7	3	8	3	8
Assembly complexity	System	*5*	0	5	2	7	1	6
Quality history	Collect from ERP	*5*	1	6	1	6	2	7
Efficiency history		*5*	1	6	1	6	2	7
Labour skills		*5*	1	6	1	6	2	7
	Average	***5.0***	***1.0***	***6.0***	***1.6***	***6.6***	***2.0***	***7.0***

Mass-Based Projects

		Importance to Company (0-5)	Project P (Mass) Certainty (0-5)	Project P (Mass) Total Factor (Importance + Certainty)	Project R (Mass) Certainty (0-5)	Project R (Mass) Total Factor (Importance + Certainty)	Project C (Mass) Certainty (0-5)	Project C (Mass) Total Factor (Importance + Certainty)	Project H (Mass) Certainty (0-5)	Project H (Mass) Total Factor (Importance + Certainty)	Project J (Mass) Certainty (0-5)	Project J (Mass) Total Factor (Importance + Certainty)
Machines	Enter to ERP	*5*	2	7	4	9	3	8	3	8	3	8
Assembly complexity	System	*5*	4	9	4	9	2	7	2	7	2	7
Quality history	Collect from ERP	*5*	2	7	4	9	2	7	3	8	3	8
Efficiency history		*5*	3	8	4	9	2	7	3	8	3	8
Labour skills		*5*	3	8	4	9	2	7	3	8	3	8
	Average	***5.0***	***2.8***	***7.8***	***4.0***	***9.0***	***2.2***	***7.2***	***2.8***	***7.8***	***2.8***	***7.8***

Standard Projects

		Importance to Company (0-5)	Project E (Standard) Certainty (0-5)	Project E (Standard) Total Factor (Importance + Certainty)
Machines	Enter to ERP	*5*	3	8
Assembly complexity	System	*5*	4	9
Quality history	Collect from ERP	*5*	4	9
Efficiency history		*5*	2	7
Labour skills		*5*	3	8
	Average	***5.0***	***3.2***	***8.2***

After-Sales Factors

Innovative Projects

			Project D (Innovative)		**Project B (Innovative)**		**Project Q (Innovative)**	
		Importance to Company (0-5)	Certainty (0-5)	Total Factor (Importance + Certainty)	Certainty (0-5)	Total Factor (Importance + Certainty)	Certainty (0-5)	Total Factor (Importance + Certainty)
Installation process	System	*3*	0	3	0	3	1	4
Type of transport		*2*	1	3	1	3	1	3
Method of packaging		*3*	0.5	3.5	0.5	3.5	1	4
Site storage		*3*	1	4	1	4	1	4
Site handling history	Collect from ERP	*3*	1	4	1	4	1	4
	Average	***2.8***		***3.5***		***3.5***		***3.8***

Complex Projects

			Project M (Complex)		**Project A (Complex)**		**Project K (Complex)**	
		Importance to Company (0-5)	Certainty (0-5)	Total Factor (Importance + Certainty)	Certainty (0-5)	Total Factor (Importance + Certainty)	Certainty (0-5)	Total Factor (Importance + Certainty)
Installation process	System	*3*	2	5	2	5	1	4
Type of transport		*2*	1	3	0.5	2.5	2	4
Method of packaging		*3*	1	4	1	4	2	5
Site storage		*3*	1	4	1	4	2	5
Site handling history	Collect from ERP	*3*	1	4	1	4	2	5
	Average	***2.8***		***3.95***		***3.9***		***4.6***

Mass-Based Projects

		Importance to Company (0-5)	Project P (Mass) Certainty (0-5)	Project P (Mass) Total Factor (Importance + Certainty)	Project R (Mass) Certainty (0-5)	Project R (Mass) Total Factor (Importance + Certainty)	Project C (Mass) Certainty (0-5)	Project C (Mass) Total Factor (Importance + Certainty)	Project H (Mass) Certainty (0-5)	Project H (Mass) Total Factor (Importance + Certainty)	Project J (Mass) Certainty (0-5)	Project J (Mass) Total Factor (Importance + Certainty)
Installation process	System	*3*	1	5	2	5	2	5	3	6	3	6
Type of transport	System	*2*	4	6	3.5	5.5	2	4	3	5	3	5
Method of packaging	System	*3*	4.5	7.5	4	7	2.5	5.5	3	6	3	6
Site storage	System	*3*	1	4	4	7	2	5	3	6	3	6
Site handling history	Collect from ERP	*3*	1	4	1	4	2	5	3	6	3	6
	Average	***2.8***		***5.3***		***5.7***		***4.9***		***5.8***		***5.8***

Standard Projects

		Importance to Company (0-5)	Project E (Standard) Certainty (0-5)	Project E (Standard) Total Factor (Importance + Certainty)
Installation process	System	*3*	2.5	5.5
Type of transport	System	*2*	2.5	5.5
Method of packaging	System	*3*	2.5	5.5
Site storage	System	*3*	2.5	5.5
Site handling history	Collect from ERP	*3*	2.5	5.5
	Average			***5.5***

These results have all been summarised in Table 5.2, the Internal Questionnaire Risk Assessment Sheet.

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