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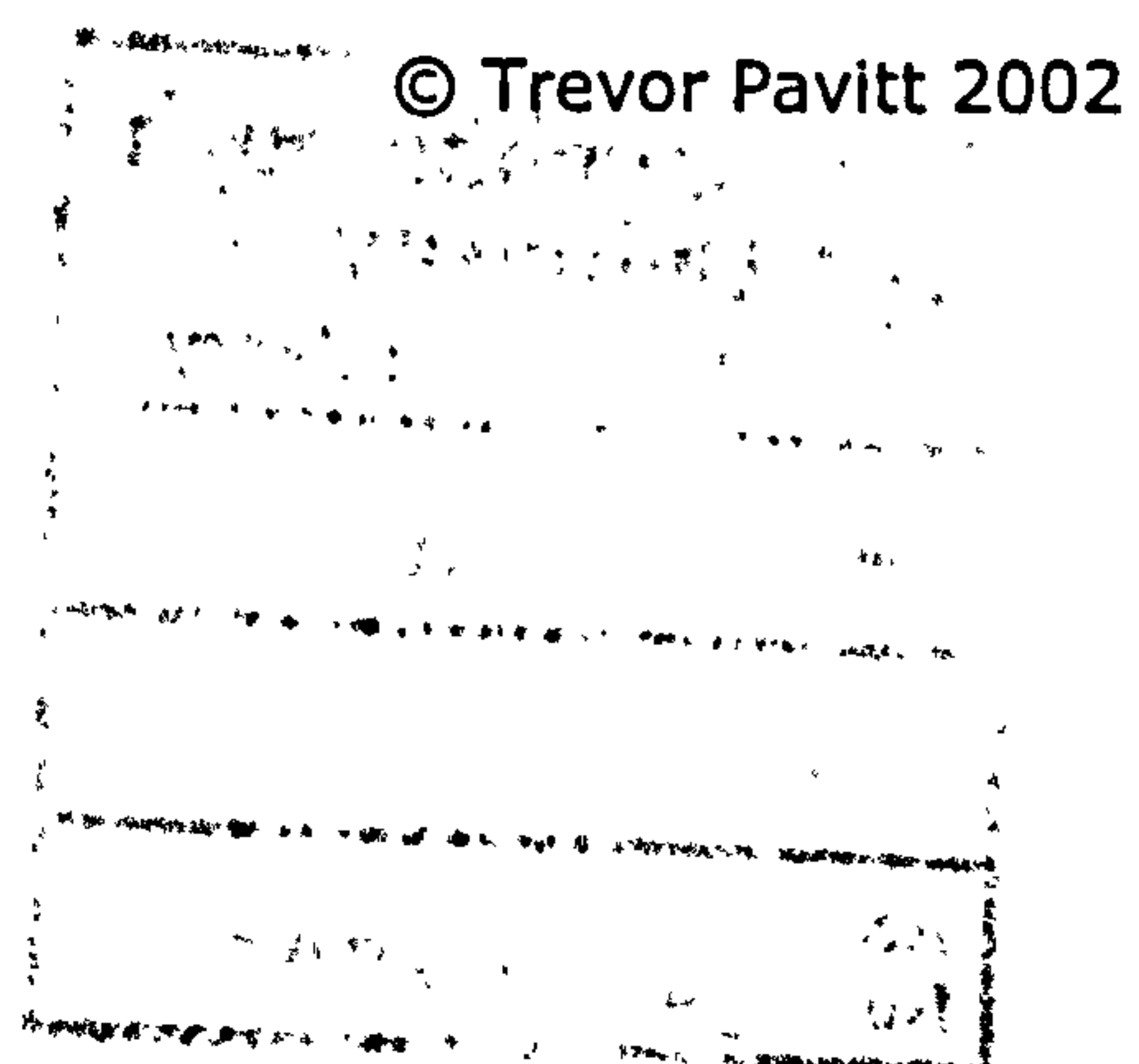
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**MANAGING CONSTRUCTION INTERFACES
WITHIN THE BUILDING FAÇADE**

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ABSTRACT

Interfaces, joints and connections between different elements or sections cause more problems than most of the rest of the building. There are challenges during design, manufacture and construction as well as implications throughout the life of the building. These challenges are particularly relevant for the building envelope. Here the joints must perform at the same level as the main areas of wall or roof, but the pressures on them are invariably much greater. They must keep out the weather but, at the same time, accommodate tolerances and inaccuracies and cater for movements both during construction and for as long as the building lasts.

Managing construction interfaces is an important part of delivering a construction project without time delays or cost additions. However the lack of written publications on how to manage interfaces within construction is a problem discovered by the author very early in the research. Therefore the main aim of the research was; *to improve the management of interfaces within the construction industry, with particular reference to interfaces within the building façade.*

The research was based on an EPSRC funded project entitled CladdISS "A standardised strategy for window and cladding interfaces". The methodology included industrial workshops, interviews, regular steering group meetings and a questionnaire. The strategy proposed to increase productivity, quality, reduce waste and reduce costs in design, manufacture, installation, and the building life cycle. The research highlighted a wide range of interrelated problems. However, the two main issues were:

- Poor communication between the design team and specialist contractors;
- Poor interface detailing.

The following situations typically exist:

- The interface responsibility is assigned too late if at all;
- The term 'by others' often leads to the interfaces being poorly managed;
- The design team does not have a good enough understanding of the construction and manufacturing tolerances of materials at the interfaces;
- Often the design team does not have appropriate understanding of the cladding system they are designing;

- The specialist cladding contractors do not have enough input to the design of the cladding and interfaces early enough.

Using the CladdISS strategy will enable the supply chain to be organised and provide a template for effective interface management.

Keywords: *Interface management, Cladding, Interface responsibility, Specialist contractors, Workpackages, Interface warranties, Buildability Building façade.*

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List of Symbols and Abbreviations

ADePT	Analytical Design Planning Technique
BAA	British Airports Authority
BOOT	Build Own Operate Transfer
BRE	Building Research Establishment
CAD	Computer Aided Design
CIB	Conseil International de Bâtiment
CIRIA	Construction Industry Research Information Association
CladdISS	Cladding Interface Standardised Strategy
CP	Cladding Process
CWCT	Centre for Window and Cladding Technology
CWSC	Curtain Wall Specialist Contractor
DBFO	Design and Build, Finance and Operate
DETR	Department of the Environment, Transport and the Regions
DOE	Department of the Environment
DPM	Damp Proof Membrane
ECI	European Construction Institute
EPDM	Ethylene Propylene Diene Monomer
EPSRC	Engineering Physical Sciences Research Council
FISCC	Fully Integrated Specialist Cladding contractor
GRC	Glassfibre Reinforced Cement
GRP	Glassfibre Reinforced Plaster
IM	Interface Management
ISO	International Organisation for Standardisation
IT	Information Technology
LOIR	Levels Of Issue Resolution
M&E	Mechanical and Electrical
NBS	National Building Specification
PFI	Private Finance Initiative
PSA	Property Services Agency
PSG	Project Steering Group
RA	Research Assistant
RIBA	Royal Institute of British Architects
RSC	Rainscreen Specialist Contractor
SCM	Supply Chain Management

Chapter 1 Introduction

1.1 Introduction

Interfaces, joints and connections between different elements or sections cause more problems than most of the rest of the building. There are challenges during design, manufacture and construction as well as implications throughout the life of the building. This is especially prevalent when constructing the building facade. Here the joints must perform at the same level as the main areas of wall or roof, but the pressures on them are invariably much greater. They must keep out the weather but, at the same time, accommodate tolerances of different materials and cater for inaccuracies and movements both during manufacture, installation and for as long as the building lasts.

To exacerbate these difficulties the building designers usually want to minimize the visual impact of the joints (in fact many would do away with them completely if they could). In building, Interface Management (IM) is critical in a number of areas, including those of technical design detail, overall design, logistics, external influences and human relationships (Pavitt & Gibb, 1999).

1.2 Purpose of the Research

1.2.1 Research question

The question addressed by this research is:

How can interface management in the building façade be better understood and managed to improve construction projects?

Managing construction interfaces is an important part of delivering a construction project without time delays or cost additions. However the lack of written publications on how to manage interfaces within construction is a problem discovered by the author very early in the research. Furthermore the lack of a coherent model explaining how projects are delivered within this field implores the need for this research. The thesis maps the cladding interface issues of the construction industry by identifying the major factors that influence successful project delivery.

1.2.2 Aim of the research

At the outset the stated aim of the research was;

To develop a tool for the management of interfaces within the construction industry, with particular reference to the building facade.

1.2.3 Objectives

The literature search and review described in chapter three, refined the research problem into the following specific objectives:

- Review and establish present interface management within the construction industry via current literature
- Review and establish interface problems that occur in the construction industry, in particular the cladding sector
- Establish the most problematic interfaces within the cladding sector
- Produce a standardised strategy for managing cladding interfaces
- Establish specific areas for improved interface management
- Validate and disseminate the research findings

1.3 Scope of the works

The research was 50/50 industry/government funded through the LINK scheme, Meeting Client's Needs through Standardisation (MCNS). This scheme was jointly funded by the Engineering and Physical Sciences Research Council (EPSRC) and the Department of the Environment, Transport and the Regions (DETR). The project was entitled CladdISS "a standardised strategy for window and cladding interfaces".

The research was undertaken by a research team from Loughborough University. The team was led by Alistair Gibb, a senior lecturer at the University, and two research assistants, Gary Sutherland (RA 1) and Trevor Pavitt (RA 2), the author of this thesis. The research was aided by the expert guidance from an industrial steering group.

Industrial partners in the project included: architect Brookes Stacey Randall; the Centre for Window and Cladding Technology (CWCT); structural engineer and cladding consultant Ove Arup; airports client BAA; contractor HBG construction; contractor and cladding test house Taylor Woodrow; precast cladding supplier Trent Concrete; curtain walling supplier Kawneer; and consultant the Building

Performance Group. These companies formed the steering group for the research.

1.3.1 Aims of CladdISS

The aim of the research was to facilitate a cultural change in the cladding sector of the construction industry. It was considered that this would be achieved by enhanced management of the design development process particularly concentrating on the technical and management aspects of construction interfaces.

- Technical aim;
To develop a strategy for standardisation of cladding interfaces by collating appropriate standardised, technical details for different cladding types and their relevant interfaces, with particular emphasis on buildability (This technical work was predominantly undertaken by Gary Sutherland).
- Management aim;
To develop a strategy for mapping a process between scope design, detail design, fabrication and installation of the different cladding types and other building elements.
- To benchmark best practice requirements for contractual arrangements, performance testing, design development, tolerances, warranties and interface responsibility producing a strategy for Improvement.

The CladdISS management aim is the main subject of this thesis.

1.4 Definitions

The Longman English dictionary (1988) defines interfaces as *"a place or area where different things meet and have an effect on each other"*. To manage is defined as *"to control, to succeed in dealing with a difficult movement or action"*. Cladding is defined as *"a protective covering put on the surface of a material or the outside walls of a building: metal, plastic, brick or timber."*

Terms associated with interface management are discussed and defined in section 3.15. Furthermore cladding types and terminologies are explained in section 3.4.

1.5 Justification of the research

Identification of the research problem (section 1.2.1) and the justification for the research is made on three counts.

- Industrial significance
- Current knowledge
- Application of findings

1.5.1 Industrial significance

First, the motive of the research lies in the significance of interfaces to the problematic construction industry. Gibb (1996) states *"problems in large scale complex buildings are more likely to occur at the interface between components or elements of the building. This is particularly true for elements such as high performance, bespoke designed cladding, and affects design development, construction and long term performance of the building. The key to improvements in the efficiency of building design and construction lies in the area of interface management"*.

1.5.2 Current knowledge

Secondly, grounds for the research originate from the lack of published literature addressing the issues, concepts and problems of generic construction interface management let alone cladding interface management. Most interface references concern interfaces within the computer or Information Technology (IT) industry. Literature published in the construction sector is either very generic or sometimes confused as supply chain management or is related to other processes, for example partnering (section 3.11.5) has been identified as a method of interface management.

1.5.3 Application of findings

Finally, the application of the CladdISS tool will benefit the construction process from its inception through to handover and facilities management. CladdISS is an interactive CD ROM software tool that provides a strategy for optimising technical and management aspects of cladding interfaces. CladdISS is targeted at all disciplines associated with the building envelope especially;

- **Designers/Architects:** making sure their design decisions do not compromise the interfaces.
- **Engineers:** making sure the cladding design is considered when designing the structure and all critical interfaces.
- **Construction Managers/Project Managers:** making sure that they manage and coordinate the interfaces to improve the project outcomes.
- **Specialist Cladding Contractors:** making sure their workpackages interface effectively with other workpackages.

The research output (CladdISS CD) was validated by a questionnaire. The main conclusions were;

- The majority (82%) thought the management information was useful.
- The majority (87%) thought CladdISS was a useful tool for the production of cladding on a project.
- 63 percent of the people surveyed would use CladdISS after seeing the presentation.

1.6 Methodology

The research can be classified as an investigation within the environment of construction management. The aims of the research are presented as a research question, aims and objectives, posed in section 1.2.3. A framework has been developed through propositions to the research based on empirical answers to the questions. The methodical decisions and approach is explained in chapter 2.

1.6.1 Overview

The objectives of the research were achieved by employing the following methods.

- A thorough literature search to help with understanding the cladding process and evaluate process implications within interface management.
- Qualitative interviews with construction professionals (in total 40 key experts were interviewed). These professionals were interviewed using a semi-structured format comprising a limited number of open-ended questions. The purpose of the interviews was to find out how cladding projects were procured within the construction industry and how the interfaces were managed as very little published information existed on these subjects.
- Process expert focus groups: Two workshops, involving key experts were convened to discuss the process aspects of cladding interface design and construction. The focus groups explored the key issues raised by the research work to date and in particular the interviews.
- Questionnaires to verify key issues: A questionnaire was used to verify the essential issues arising from the focus groups and interview findings. In total 165 questionnaires were sent out to industry, 64 of these were returned. The results were incorporated into CladdISS.
- The 'observer as participant' case study approach of 'live' projects allowed the author to see how the interfaces are actually managed within a

project. This also acted as validation of how the industry works. The purpose of the case studies was twofold;

- o To demonstrate the benefits of the CladdISS framework within a project.
- o To highlight industry "normal" working practices and demonstrates how using these methods can create problems.

1.7 Results of the research

The overall aim of this research project: to improve the management of interfaces within the construction industry, with particular reference to the building façade, was achieved by constructing a model within a generic construction process (based on the Process Protocol, see section 3.13). This shows when specific interface issues need to be addressed.

The research into cladding interface management highlighted a wide range of interrelated problems, most significant amongst these being lack of communication and detailing of the interfaces between the design team and the cladding contractors. The key areas identified were;

- The interface responsibility is assigned too late if at all
- The term "by others" often leads to the interfaces being poorly managed
- The design team does not have a good enough understanding of the construction and manufacturing tolerances of materials at the interfaces
- Often the design team does not have appropriate understanding of the cladding system they are designing
- The specialist cladding contractors do not have enough input to the design of the cladding and interfaces early enough.

1.7.1 Contribution to knowledge

Combining the three elements of cladding procurement, design manufacture and installation the CladdISS strategy allows the first ever-strategic guide for the design and management of interfaces for building cladding, this helps the following construction team members to:

- Designers/Architects: make sure their design decisions do not compromise the interfaces.
- Engineers: make sure the cladding design is considered when designing the structure and all critical interfaces.
- Construction Managers/Project Managers: make sure that they manage and coordinate the interfaces to improve the project outcomes.

- Specialist Cladding Contractors: make sure their workpackages interface effectively with other workpackages.

The strategy could also be developed further for other complex interfaces such as building services.

Using the process map the construction team will gain the following:

- Increased productivity
- Increased quality
- Reduced waste
- Reduce costs for design, manufacture, installation and the building life cycle.

The research introduces review points at crucial phases in the construction process that suggests specific management tasks.

1.7.2 Main findings

During the investigative research into interface management, several important conclusions were reached which provide justification for the improvement of cladding interface management. The conclusions formed constitute the main findings of the research and are listed below:

The main causes of problems associated with design, manufacture and installation of the cladding interfaces can be attributed to poor management and poor communication. This is manifest in design, manufacture and installation as follows:

Design

- Interface responsibility is not determined early enough sometimes not until site installation. Also in worst-case scenarios some do not want to take the responsibility.
- Contractors are not appointed early enough to aid the design.
- There can be too much "over specification" of the cladding, causing complicated and sometimes impossible designs.
- Lack of communication throughout the design stage.
- Incomplete design, especially of the interface.
- Insufficient design expertise from the specialist contractors.
- Often, insufficient money is allowed for the design of the interface because of this complexity.

Manufacture

- Lack of understanding of tolerances in manufacture and design. However, "the tolerance issue is not really a problem; it only becomes a problem when the interfacing specialists do not know the tolerances of the other products"¹.
- Managing the lead times for materials. "Glass invariably will be on the critical path, as it can take up to 14 weeks for delivery. Problems occur when there is a change in design late in the process, there is no consideration for the delays that may happen"².
- A cladding system may be complete in manufacture but often has to be altered due to insufficient design of the interface. This is either carried out at site or has to be returned to the manufacturer's factory for the modification.

Installation

- If a building is going to leak, 90% of the time it will be at the junction between two differing trades. More often than not it will be the roof to cladding interface, especially at complicated parapet details, up-stands and terraces.
- The term *by others* continues to cause problems. "Most contractors, to win work, especially with traditional procurement detail their own standard work and ignore anything over and above quoting *by others*"³.
- There are "unwritten" rules or assumptions made all the time with interfaces. For example, if there are windows installed inside precast openings, then the window installer should take the warranty of the interface, but this is rarely written down or agreed. Therefore the warranty "falls" by default (not by agreement) in the package of the last contractor.
- Frame to cladding interface. Invariably the two contractors are not formally appointed at the same time so assumptions have to be made. Exact fixing zones on the frame cannot be identified. So often, revisits or reworks are required. With steel frame, a method of rectifying this problem is to drill holes on site. However the cladding contractor does not like this because of the health and safety implications. Furthermore, to facilitate a hole in a steel frame at the factory is comparably cheap, but

¹ Unspecified quote from expert interview (Pavitt, 1999)

² Unspecified quote from expert interview (Pavitt, 1999)

³ Unspecified quote from expert interview (Pavitt, 1999)

on site is expensive. Precast concrete cladding can be the worst, due to the weight of the panels bearing on the frame. In all cases loads need to be agreed not assumed.

- Sealants at the interface tend to be overlooked because there is no clear identification as to whose package they are in.

From the problems uncovered during the research investigation the following conclusions have been developed to enable and encourage improved interface management;

- 1 Identify the interface responsibility as early as possible
- 2 Appoint the specialist contractor earlier
- 3 Ensure there is a greater understanding of all tolerances
- 4 Ensure there is a greater understanding of buildability
- 5 Develop tools that identify and aid interface management
- 6 Appoint cladding and frame contractors at the same time
- 7 Standardise interface designs
- 8 Reduce adversarial effects within the process
- 9 Risk assess designers' knowledge of cladding from past projects
- 10 Improve programming and sequencing at site level
- 11 Eliminate the term 'by others'
- 12 Ensure all installers have attended approved training courses

1.8 Guide to thesis

Chapter one introduces the thesis. The concept of Interface management is introduced, forming the generic issue for more specific topics covered in the subsequent chapters. The research question, aims and objectives that give rise to the research are posed and considered. Justification for the study is discussed. The chapter also gives a brief description of the CladdISS research project, the basis for this thesis. The chapter also gives a brief description of the methodology employed during the research.

Chapter two discusses the methodical approaches available for the research namely qualitative and quantitative. The implications and methodological possibilities are discussed and justified. Data collection strategies and analysis techniques are similarly discussed.

Chapter three reviews the published literature that helped determine the research objectives. The review further emphasises the need for the research due to the insufficient amount of literature written on the subject. Furthermore the author gained a good insight into the construction processes and obtained a perspective from previous researchers while reviewing the literature. The chapter identifies the resources used finding the literature and summarises the key findings; this also provided a background to managing construction Interfaces and cladding issues. The chapter has eleven main headings based upon the following key word search; cladding, interfaces, design, procurement, communication, specialist contractors, supply chain management and buildability and workpackages.

Chapter four explains the funded research project entitled CladdISS "a standardised strategy for window and cladding interfaces". It explains how CladdISS came into existence, the methodology behind the research and its final deliverables. The aim of CladdISS is to facilitate a cultural change in the cladding sector of the construction industry. It was considered that this would be achieved by enhanced management of the design development process particularly concentrating on the technical and management aspects of construction interfaces.

Chapter five presents the main data findings and analyses the results. The data collection used four methods:

- Interviews
- Focus groups
- Questionnaire
- Case studies

Chapter six develops the research results by producing a framework for improved management of cladding interfaces. Finally validation results are shown and discussed. The results are based on the management sections of CladdISS. Actions required at different project phases have been developed. They are presented as a process map that identifies significant cladding interface management actions and decisions in a project, from its inception through to facilities management.

Chapter seven concludes the thesis, highlighting the main findings of the research and the implications these have upon construction projects and the construction industry as a whole. The chapter culminates with recommendations for further research arising from the study. A graphical representation of the thesis is provided in figure 1.1 overleaf.

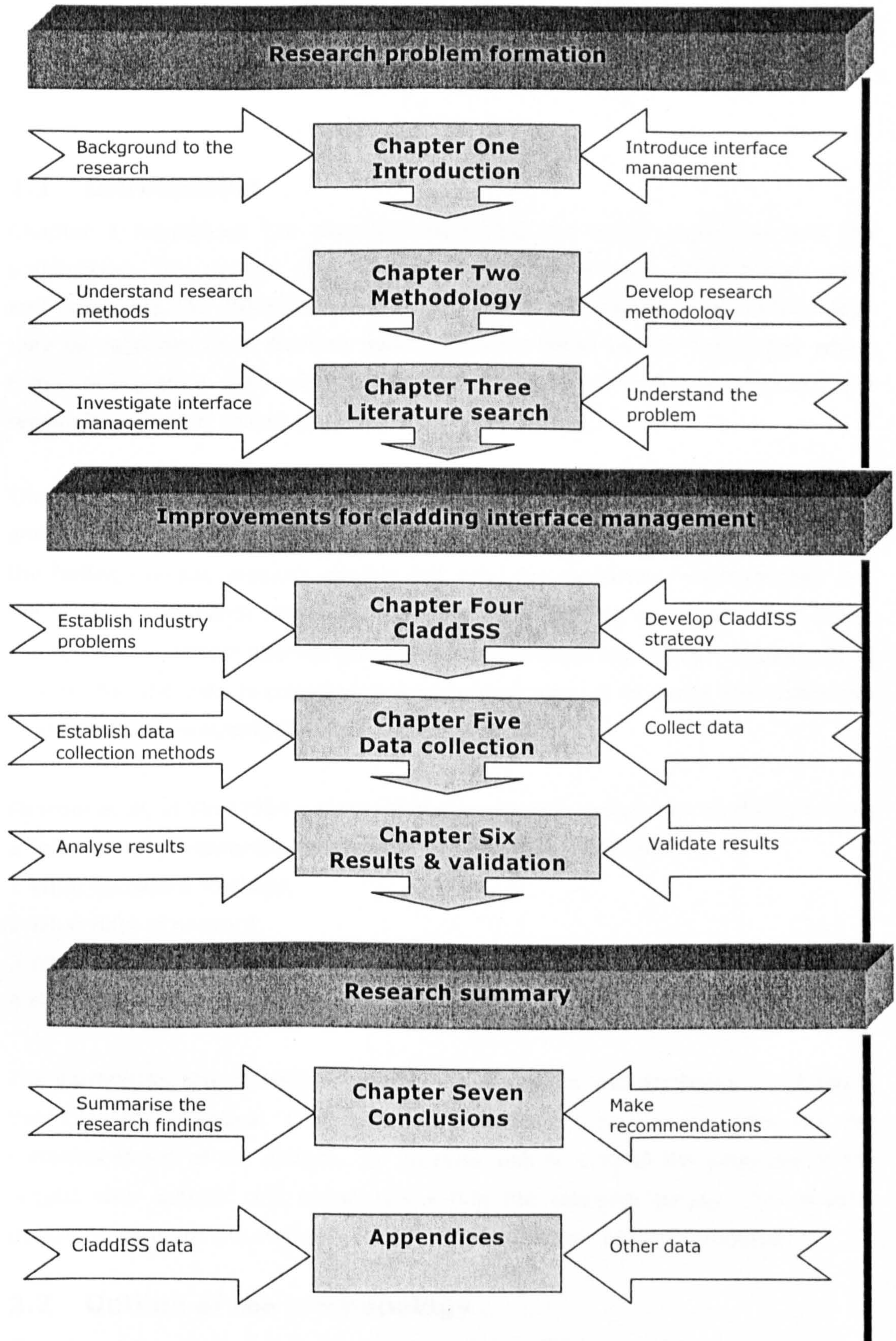


Figure 1.1: Graphical representation of the thesis

Chapter 2 Methodology

2.1 Introduction

Chapter 1 introduced the research explaining the aims, objectives and the justification. This chapter explains the research design and methodology used, and compares the different research types and approaches. The methodology may be regarded as a decision making process taken by the researcher which forms background assumptions that are proposed in order to organise the researchers view of reality (Birley and Moreland, 1998).

The methodology describes the methods by which research can be carried out, and lies at the heart of any research (Fellows, 1997). In order to ensure that the findings of any research project are valid the researcher must identify and follow certain research methods. This has three distinct purposes: 1) to assist the researcher collect appropriate data that relates to the chosen subject; 2) to ensure that the data is collected in a beneficial way; 3) to assist the researcher in aligning and analysing the data (Steel, 1999).

Phillillier *et al*, in Yin (1984), states that the research design can be thought of as a "blue print" of research, dealing with at least four problems:

- 1 What questions to study,
- 2 What data is relevant,
- 3 What data to collect, and
- 4 How to analyse the results.

The method for this research involved certain criteria and deadlines stipulated in the research proposal (CladdISS, described in chapter 4) prior to the commencement of the project. Its purpose was to control the progress of the project with outputs and milestones within the research period. This chapter details reasons for the methods used and the types of research employed.

2.2 Outline of the methodology

The aim of the methodology is to produce a beneficial research document, which will achieve the aims, objectives, and clarify the research question described in chapter 1.0. Figure 2.1 is a graphical representation of the methodology behind this thesis.

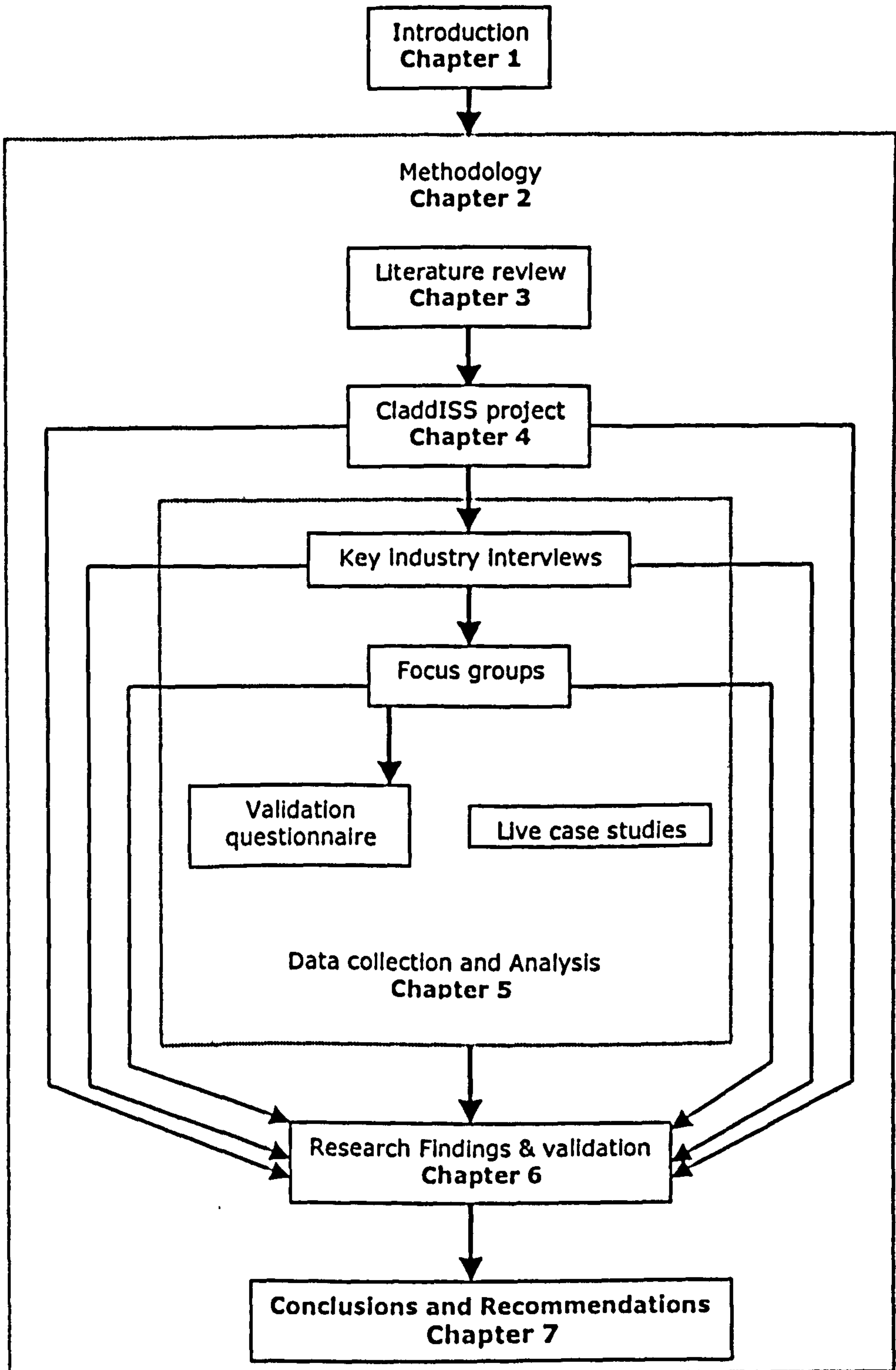


Figure 2.1: Graphical map of the research methodology

The first step of the research is to identify the subject area. In this case the area chosen was managing interfaces within the building envelope. The selection of the subject was chosen by the researcher due to an interest gained from previous research on the cladding process.

2.3 Methods of collecting data

As the research was part of a government funded research project the criteria for the research and data collection was partially dictated in the initial research proposal. The proposal highlighted that the researcher should conduct a sufficient number of interviews throughout the construction industry so that enough data would be gathered to achieve a representative understanding of the research problem.

Focus groups were organised by the researcher involving key industry practitioners in the construction industry, in particular representatives from the cladding sector. The researcher then produced a questionnaire, which was sent out to professionals associated with the cladding sector to verify the initial research findings.

The final findings of the research were then produced. Primarily they were mapped out using the process protocol (explained in chapter 3, literature review), a generic process-mapping tool designed by Loughborough and Salford University for use on any construction project. In order to validate the findings of the research, CladdISS was trialled with experts from general construction and the cladding sector.

Tucker *et al* (1997) stated that there are many effective methods for collecting data, such as interviews and questionnaires. They also mentioned that a questionnaire is one of the best and most efficient methods of data collection. Reasons for this are efficiency in producing data where the respondents are geographically dispersed and where a wide spectrum of respondents is required. A questionnaire was used in the research to validate the research data from the interviews and focus groups.

2.4 Planning the research

The plan of the research encompasses the research project guidelines as well as relevant investigation techniques required to produce the final research document. The research followed distinct steps in achieving this, namely:

1. Review existing literature in order to obtain background knowledge of the research subject.
2. Identify and carry out interviews with key industry practitioners.
3. Set focus group topics based on the information gathered from the interviews.
4. Establish appropriate attendees for the focus groups.
5. Conduct focus groups.
6. Develop and distribute a postal questionnaire to verify the research findings.
7. Analyse returned data.
8. Organise the research findings into a framework for managing interfaces.
9. Complete case studies of live projects to evaluate industry methods of managing interfaces and compare them to the research framework.
10. Validate the research findings by means of industry presentations and trialling with construction professionals, culminating with a validation questionnaire.

2.5 Literature search and review

Research should follow an established procedure of investigation, which normally starts with a thorough literature search and review. It not only justifies the approach to the research but also identifies gaps in knowledge (Hart, 1998).

The following key words were used to focus the literature search and review: cladding, interfaces, design development, procurement, communication, specialist contractors, supply chain management and buildability. The literature review is presented in chapter three with eleven main headings, these are:

- Historical development of cladding within building architecture.
- Implementation of cladding to the construction industry.
- Cladding of buildings.
- Construction design.
- Procurement processes within the cladding industry.
- Buildability.
- Specialist contractors and workpackages.
- Supply chain management.
- Interfaces within the construction process.
- Management processes within the construction and other related industries.
- Research for improvements within construction.

The literature review forms the foundation of any research with its primary task to evaluate current or previous information, which has been published in books, journals, conference proceedings or other relevant publications. Also the literature review is a starting point for the researcher to gain an understanding of the subject. It was carried out using the following resources:

- The Pilkington Library, Loughborough University
 - . OPAC Database (books, serials)
 - . CD-ROM Database (Ante, Bids Compendex, Citis, Evel)
 - . Internet
- The Nottingham Trent University library
- PhD. Construction Management Dissertations
- The Chartered Institute of Building (CIOB) library
- Centre for Window and Cladding Technology (CWCT) Library
- The Movement for Innovation (M⁴I) research papers
- Architectural Cladding Association library and videos

The literature review produced much information on the subject area of cladding and management issues, which formed the basis for development of the research problems. However it has highlighted that there is very little literature written on managing interfaces within construction let alone cladding, thus emphasising the need for the research.

2.5.1 Internet Search

With the advanced technology available the internet was used at the start of the literature review. Web based search engines were used to find information, with keywords such as *cladding*, *cladding types*, *precast*, *curtain walling* and *interfaces*. Numerous responses were achieved from the keywords. The literature review is summarised in chapter 3.0.

2.6 Project Steering Group

A project steering group helped oversee the research and provided expert knowledge to the project. The group consisted of professionals associated with construction, cladding design and management. Figure 2.2 shows the group members' professional roles.

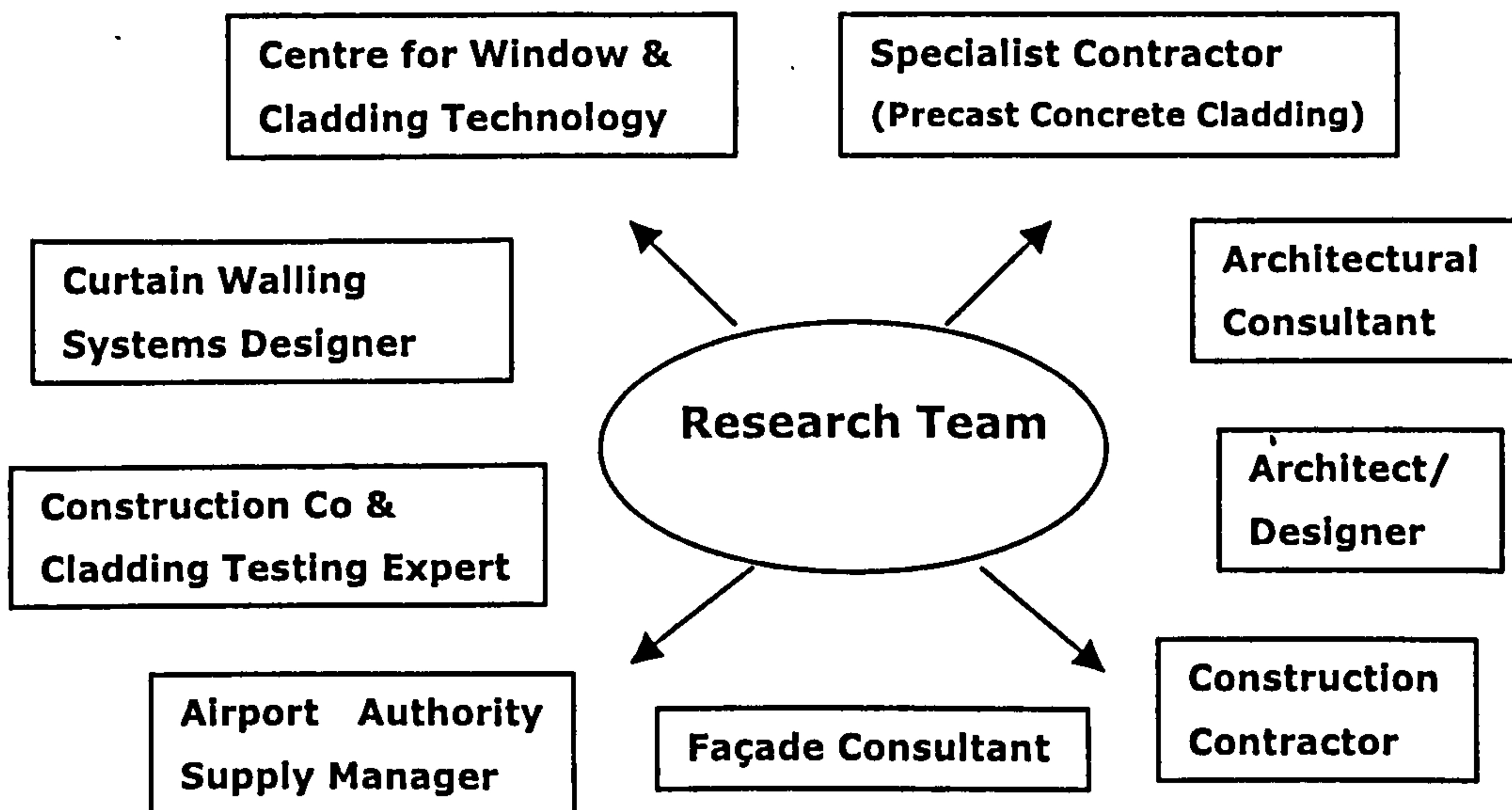


Figure 2.2: Steering Group Members' Professional Roles

2.7 Qualitative v quantitative research methods

Before embarking on the data collection the issue of which method should be used was addressed. It is necessary that the investigative method used would be appropriate to deliver a robust response to the research problem. There are two possible methods; qualitative and quantitative. Ackroyd and Hughes (1992) state that *"it is not about antimony requiring choice within the context of social research, it is the nature of the research problem"*.

Furthermore Walker (1997) maintains that "quantitative research compares factual data with theory, how many and how much? Compared to qualitative which seeks to find out individual beliefs by asking how and why"? Modern construction management research has benefited from the merits of both approaches (Seymour and Rooke, 1998, 1995 and Wing et al, 1998). One benefit from this research has identified that construction management is as much social as technological; therefore choosing one over the other could have a negative effect on the research. Therefore a methodology that uses both methods is at least desirable if not necessary.

2.8 Interviews

This section describes the methodology behind the interviews. After the initial literature review had been completed it was necessary to gather information on the subject from key industry practitioners. During the literature review the

author compiled a list of professions that could explain and expand upon the critical issues that had manifested in the literature search.

In total there were forty practitioners interviewed. To be able to gain a true understanding and concept of how the cladding process is currently managed, particularly on how interfaces are dealt with in the industry, the interviews had to include representatives from all parts of the cladding and construction sectors. Therefore the interviews included consultants, cladding installers, designers, system designers, engineers and research organisations. Figure 2.3 shows a breakdown of the interviewees' role in the industry.

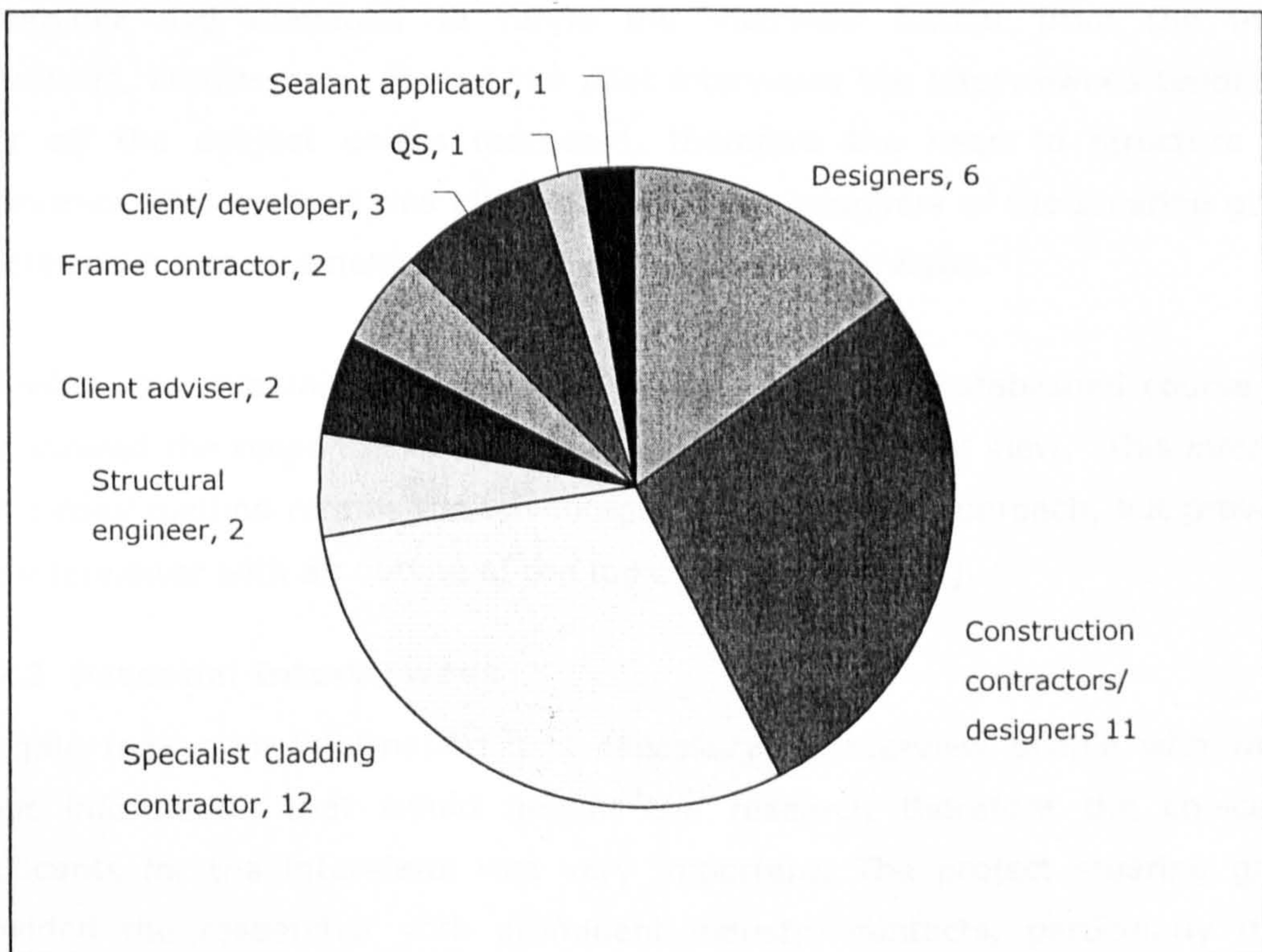


Figure 2.3: Breakdown of interviewees' roles

2.8.1 Pilot Testing the Interview Format

Before the interviews were conducted on interviewees unknown to the researcher it was necessary to pilot test the interview format. The importance of running a pilot test was stressed by Oppenheim (1992) stating " *questions do not emerge fully-fledged; they have to be created or adapted, fashioned and developed to maturity after many abortive test flights. In fact, every aspect of a survey has to be tried*". This process was carried out on four members of the steering group committee, gradually refining the interview format during the four

interviews. The main purpose of this was to ascertain the length of the interviews and to establish whether the interview format was addressing the main research issues.

The first two interviews took an *informal* approach. This form of interview lets the interviewee talk in a relaxed atmosphere, with non-directive questions which are not constrained to fixed answers (Cooligan, 1994).

After these first two trials the interviews took a different format, in that they were *informal but guided*. This method is often referred to as the semi-structured method of interviewing. This approach was taken because the researcher had managed to refine the interview format from the initial interviews. Furthermore, during the pilot interviews the interviewees tended to veer off the subject unless restricted, therefore the need to structure the interviews. This method was pilot tested on two members of the steering group before the commencement of the main key expert interviews.

Therefore the remaining interviews followed a relatively established course but still allowed the respondents to express their own points of view. This *informal but guided* method retains the advantage of the informal approach, but provides the interviewer with an outline of the topic (Cooligan, 1994).

2.8.2 Potential Interviewees

To gain maximum information it is necessary to interview people who would input information that would benefit the research therefore the choice of applicants for the interviews was very important. The project steering group provided the researcher with prominent industry contacts, particularly those within the cladding sector, who they thought would be willing to be interviewed.

As part of the preparation for the interviews the researcher informed the potential interviewees of the nature and intended outcomes of the research. A "fax" was sent to the potential interviewees requesting time for an interview with an overview of the research project. The interviewees were then contacted by telephone to arrange the interviews.

The interviews were conducted over a period of six weeks. Due to the contacts prior to the interviews, only one person refused an interview. Also it was made apparent by the interviewees that there was need for this research in the

industry. Many of the interviewees requested that they were kept informed of the research progress and its findings.

2.9 Focus Groups

Section 2.3 identified focus groups as a key part of the research methodology. As a form of qualitative research, focus groups are fundamentally group interviews, with the reliance put upon interaction within a group centred around topics predetermined by the researcher, who typically acts as a moderator throughout (Morgan, 1988).

2.9.1 Uses of the Focus Groups

From a social science point of view, focus groups are useful for the purpose of collecting qualitative and quantitative data. The strength of focus groups lies in the researcher's ability to observe interaction between the groups relating to the researchers topic (Morgan, 1988). Bellenger *et al* (1976) noted that interaction between groups leads to spontaneous responses from participants as well as producing a fairly high level of participant involvement.

The researcher gathered a considerable amount of qualitative data during the interviews; the focus groups were used in the initial stages following the interviews to hone the data gathered. However, one of the weaknesses of using focus groups is the reliance on the interaction within the groups, never knowing whether or not this would be mirrored in individual behaviour. For example individual decision-making may alter compared with group influence (Janis, 1982).

This was experienced in the first focus group, where the researcher felt that certain individuals dominated the group and consequently the proceedings became slanted towards particular fields of expertise. The next group addressed this situation by concentrating on areas omitted from the first focus group. In total two focus groups were held and overall the results were a good source of data for the research.

2.9.2 Project steering group

Throughout the duration of the research project the research team and steering group would meet for meetings every three months. Following the formal aspects of the meetings the remaining time was used as "mini" focus groups. The focus groups discussed the research as it stood at the time, or from questions proposed by the author.

2.10 Questionnaire Design

Following the interviews and the focus groups a postal questionnaire was sent to selected individuals within the construction industry. To accomplish the highest possible response it was essential that the questionnaire was sent to suitable individuals and that the format was concise and focused to the project requirements.

The selection of the questionnaire respondents was facilitated by an article in *Building* (1999) magazine, which identified the top 250 consultants, 100 architects, 100 contractors and 75 engineers based in the UK. The questionnaire followed a similar pattern to the interviews, using the steering group as a source of information for contacts in addition to those identified through the *Building* article. The steering group reviewed the contact list to ascertain whether the companies were relevant to the research topic and in addition to supply contact names of professionals within the companies.

Hague (1993) claims that the questionnaire is one of the most important aspects in research and is one of the basic building blocks of market research, but for the purpose of this research it was used primarily for verification purposes only. The rationale behind this thinking was that enough quantitative data had already been obtained and any further quantitative data would be of no added benefit. However the respondents had the opportunity to add their comments and thoughts on associated issues.

2.10.1 Types of Questions

The questions are either open or closed. Closed questions have a set number of responses predetermined by the researcher while open questions allow the respondent to answer in full, with very descriptive answers (Fellows, 1997). Following the open format of the interviews and focus groups it was decided that the questionnaire should take the closed alternative.

Questions can also be qualitative or quantitative. On deciding the types of question to be asked the type of information required must be considered. If the results required are of a numerical form then the data will be quantitative and can make use of descriptive statistics. If the question requires detailed answers then the data will be largely qualitative, although parts may well become quantified (Cooligan, 1994).

The previous methods of data collection (Interviews and focus groups) had been predominantly qualitative. Therefore in order to validate this data it was felt that the questions needed to be of a quantitative nature.

2.10.2 Choice of Answers

Because closed questions were to be used the response answers were relatively easy to choose. The most common method of obtaining results is by the Likert scale. This provides various scales of agreement or disagreement to a given question, usually with a 5-point or 7-point scale (Fellows, 1997). The questions followed the 5-point scale.

2.10.3 Pilot testing the questionnaire

Prior to distribution there was a need to pilot test the questionnaire, to judge that the questions were clear and concise and that a pre-determined time for answering could be established.

The questionnaire was pilot tested on people within the Civil and Building Engineering Department of Loughborough University, the project steering group and friends of the researcher who have no association with the construction industry; this achieved an unbiased opinion on the questions. The significance of these three different groups is as follows:

- Civil and Building Engineering Department; Knowledge of the construction industry and methods of research but have limited knowledge of managing cladding
- Steering Group; Experts cladding and construction process but limited knowledge of research methods
- Friends; Limited knowledge of construction and research methods but provided a check on comprehension and clarity of the questionnaire.

The final questionnaire can be found in Appendix A.

2.10.4 Questionnaire categories and percentage returns

In total, 165 questionnaires were sent out to industry. From them 64 were returned, which gave a response rate of 38 percent. Table 2.1 shows the percentage of the returned questionnaires and their categories. The responses have been split into the following five categories, after each category is the number of responses received from the 165 questionnaires (Pavitt and Gibb, 2002).

Discipline	Number sent out	Number returned	% returned	% of responses
A	B	C	D (C/Bx100)	E (C/64x100)
Cladding Contractors	45	14	31	22
Cladding consultants	29	14	48	22
Designers/ Architects	39	14	36	22
Principal contractors	32	15	46	23
Systems designers	19	7	37	11
Totals	165	64	n/a	100

Table 2.1: Breakdown of questionnaire responses

2.11 Data Analysis

Following the data collection the next step is to analyse the data. The preferable approach is to consider, evaluate and plan the analysis in a similar way to planning the whole research project (Fellows and Liu, 1997). Geddes (1968) advocates the method of:

- Survey
- Analyse
- Plan

2.11.1 Interview analysis

The interviews were the starting point for the data collection following the literature search. The main source of data collection during the interviews was a matrix. A matrix is essentially the 'crossing' of two lists, set up as rows and columns to see how the two interact. The choice of data entry into the matrix cells are critical issues in qualitative data analysis. The conclusions drawn from a matrix can never be better than the quality of the data entered.

The test of any matrix is what it helps you understand from its content (Miles and Huberman, 1994). Furthermore they indicated that there are set rules of thumb for matrix analysis, these include;

- Quick scan- where scanning the rows and columns to see what initially becomes apparent. Then verify this through a more careful method.
- More generally, any early conclusion typically needs confirmation, checking and verification.

The primary purpose of the matrix was to gain outline information on interface management then hone the findings, the researcher followed the quick scan method enabling the main points to be discussed further in the focus groups. Furthermore Simister (1995) pointed out that one of the problems inherent within the richness of interview data is that analysis is impractical without a reduction in the form of data.

2.11.2 Focus groups analysis

In total two focus groups were held, full analyses of the results are shown in chapter 5 data collection and analysis. Morgan (1998) states that "*analysis of focus group data is different from analysis of data collected through other qualitative methodologies.*" Therefore it was necessary that the focus groups were thoroughly planned. Morgan further stated that there are four basic steps for focus groups:

- Planning- anticipating the major decisions that need to be made.
- Recruiting- having the right participants.
- Moderating- taking part in the discussions, at minimum good questions are required.
- Analysis and reporting- making sure the data is neither too complex nor too simplistic.

Planning for the analysis phases takes into account the scope and purpose of the project as well as the reporting of the results (Krueger, 1998). It was agreed within the project steering group that the information gained from the focus groups would be specific problems and solutions for cladding interface management and these would be validated by means of a questionnaire.

2.11.3 Questionnaire

The questionnaire was the quantitative data collection method following the qualitative methods. Fellows and Liu (1997) state that "*essentially, quantitative*

approaches involve making measurements by collecting data. The approach is built upon previous work which has developed principles, laws and theories of the particular research project."

Therefore the author built upon the data collected in the interviews and focus group to formulate the questionnaire. Its purpose was to validate the findings. According to Eaton (1998) this type of survey represents an efficient method of collecting data of a general nature and allowing statistical analysis to be performed.

To statistically analyse the data it was decided to use a computer aided package, the *statistical package for the social sciences* (SPSS), which is possibly the most widely used and comprehensive statistical program in social sciences (Bryman, 1997).

The great advantage of using a package like SPSS is that it enables the user to analyse quantitative data very quickly and in many different ways. Furthermore it provides the opportunity to use more complicated and often applicable statistical techniques that probably would not be used (Bryman, 1990). The SPSS results are shown in the chapter 5 and Appendix B.

2.12 Case studies

Following the interviews, focus groups and questionnaire the author carried out five case studies. The purpose of the case studies was to allow the author to observe "live" projects and to see how the interfaces are actually managed within a project. This also acted as validation of how the industry works.

Yin (1981) describes case studies as an empirical enquiry that investigate contemporary phenomenon within a real life context in which multiple sources of evidence are used. Furthermore he observed that a case study does not require control over behavioural activities. Also it is an ideal method of obtaining a clear insight into the complexities of a working project (Voyatzaki, 1996).

2.12.1 Case study design

It is acknowledged that one of the most important advantages of case study research lies with the opportunity it affords for a holistic view of processes (Gummesson, 1991) and a multiple case study approach is generally seen as more rigorous than a single case study approach (Yin, 1994). The multiple case study approach also enhances result generalisation, allowing the researcher to

make comparisons between the studies (Bryman, 1989). Therefore it was decided to use multiple case studies, in total five projects were chosen, drawn from various projects involving the project steering group companies.

The observation role of the researcher in case studies can vary. Robson (1993) claims that observation seems pre-eminently the appropriate technique for getting at 'real life' in the real world and described two basic methods of observation; participant and observation. Furthermore Ackroyd and Hughes (1992) describes four roles of observation from participant to complete observer. These are given in Table 2.2.

	Role	Description
1	Complete participant	The role in which the observer becomes a fully fledged member of the group under study, any research purpose being concealed.
2	Participant as observer	Both researcher and subjects are aware of the fact that theirs is a fieldwork relationship.
3	Observer as participant	Involvement with subjects is deliberately, or for a number of practical reasons, kept to a minimum.
4	Complete observer	Requires investigators to insulate themselves from any social contact whatsoever with the subjects.

Table 2.2: Participant observation roles (Ackroyd and Hughes, 1992)

The author chose the role of observer as participant. This method was chosen because the author had collected sufficient data from the previous methods of data collection.

2.13 Framework development and validation

The completed research produced a framework tool for improved management of cladding interfaces. This is covered in detail in chapter 4, CladdISS. The aims of the framework were;

- To show how problems can arise if "Best Practice" is not used on a project.
- To show the user how the cladding interface management process can be improved by using the framework.

The framework has been divided into 3 sections:

- 1 Project phases
- 2 Programming
- 3 Specialist Cladding Contractor & Workpackages

The main aspect of the framework presents a process map which identifies significant cladding interface management actions and decisions in a project, from its inception through to demolition and decommission. The process map is based on the process protocol (Cooper *et al*, 1998).

The framework stresses the need for the research, as ultimately a failure to address interface issues will:

- Reduce productivity
- Reduce quality
- Increase waste
- Increase costs for design, manufacture, installation, and the building life cycle

2.13.1 Validation

It is important to be sure of the validity of the research and the framework. It makes sure that there is confidence in the research findings. This was achieved by trialling CladdISS within the construction industry, during this time the recipients were asked to complete a questionnaire on the relevance and impact of the research. In total the framework was shown to 32 experts in the construction industry.

The validation questionnaire had two parts:

- General impact of the framework
- Specific impact of the review points

Listed below are summary findings from the questionnaire, complete results are shown in section 6.4:

- The majority (82%) thought the management information was useful.
- The majority (87%) thought CladdISS was a useful tool for the production of cladding on a project.
- 63 percent of the people surveyed would use CladdISS after seeing the presentation.
- CladdISS is easy to use and navigate.

2.14 Summary

The methodology for this thesis has been structured using guidelines from the research project proposal (CladdISS) and methods developed by the researcher. The chapter has defended the selection, planning and execution of the research design.

Essentially the methodology adopted a qualitative approach for the data collection with the interviews, focus groups and case studies. However, it used a quantitative method for validation with the questionnaire.

Chapter 3 Literature Review

3.1 Introduction

Chapter 1 introduced the research explaining the aims, objectives and the justification. Chapter 2 described and discussed the methodology. This chapter provides a review of published literature that helped determine the research objectives.

The literature review is an integral part of any research. It is important to assess whether the researcher has achieved sufficient and relevant knowledge from present and past publications. The literature review must be critical and therefore demonstrate that "the writer has studied existing work in the field with insight" (Haywood and Wragg, 1982). The researcher also gains a good insight into the subject and obtains a perspective from previous researchers while reviewing the literature.

It is widely accepted that a major problem within the construction industry is fragmentation (Latham, 1994; Kwakye, 1997). Unlike other manufacturing industries there is distinct separation between design, manufacture, and installation of the products. Over the years the need for integration has been identified. In the 1960's the Emmerson report highlighted the problem stating that "*in no other industry is the responsibility for design so far removed from the responsibility for production*". In more recent years "Rethinking Construction, 1998" (the Egan report) presented recommendations for change within the construction industry.

One initiative was for greater integration within the construction process. The reason for the fragmentation can be attributed to divisions within the professional disciplines and the prototype nature of construction (Rowlinson, 1987). However it not just the UK that has a fragmented construction industry, this has also been identified in the US construction industry (Sanvido and Medeiros, 1990).

An example from the cladding sector is offered by Pietroforte (1995) who identified "a stone veneered facade results from the contribution of several trades that assemble materials and components which need to be coordinated in

order to achieve a successful assembly and erection performance. Stone erectors tend to specialise depending upon the type of supporting system. The contractors assemble the wall in conjunction with window erectors" (interface management). The fragmentation of the industry poses challenges within the building façade particularly the development of the purchasing strategy.

This chapter identifies the resources used finding the literature and summarises the key findings; this also provides a background to managing construction interfaces and cladding issues. This chapter has eleven main headings based upon the following key word search; cladding, interfaces, design, procurement, communication, specialist contractors, supply chain management, buildability and workpackages:

- **Historical development of cladding within building architecture**
- **Implementation of cladding to the construction industry**
- **Cladding of buildings**
- **Construction design**
- **Buildability**
- **Specialist contractors and workpackages**
- **Procurement processes within the construction industry**
- **Management and process changes within construction**
- **Supply chain management**
- **Interfaces within the construction process**
- **Current research for improvements within construction**

3.2 Sources of Literature

The literature review is based on information gained from a variety of resources, namely:

- The Loughborough University Library (Pilkington)
 - . OPAC Database (books and serials).
 - . CD-ROM Database (Ante, Bids Compendex, Citis, Eevl)
 - . Internet.
- The Nottingham Trent University Library.
- PhD. Construction Project Management thesis.
- CWCT Library.
- Architectural Cladding Association Library and Videos.

All the above resources have enabled the author to achieve a good understanding of the written and recorded publications on the research topic. This is an ongoing process throughout the whole duration of the research from October 1998 until September 2001. Any publications or reports released after these dates related to the subject area are therefore not included in this thesis.

3.3 Historical development of cladding

Before the different cladding types are discussed it is necessary to consider two concepts that have influenced the evolution of this form of construction. First there was the development of frame construction, and second the introduction of systems prefabrication (Brookes, 1985).

3.3.1 The Frame

The first building with a structure of iron was the Menier factory in Paris, which was built in 1871-2. The Menier factory had an external skin made of non-loadbearing panel infills. However it was in large American cities such as Chicago in the later part of the 1800's that the steel frame structure acquired precedence in growth with the use of panel and frame construction (Brookes, 1998).

3.3.2 Advantages of frame construction

This 'new' form of construction brought two main advantages, firstly a potential for greater floor space than masonry construction. Secondly, and possibly the greatest significance of this form of construction and the affect on cladding as it stands today, the whole weight of the building can be supported by the frame. With these advantages there was a large swing in favour of this type of construction in America, in particular, the Chicago skyscrapers. One of these was the Scott department store 1899 which used an exposed frame with large glass panels (Brookes, 1998). Rowe (1956) commented "the frame has been the catalyst of architecture, but one might notice that it has also become architecture, that contemporary architecture is almost inconceivable in its absence".

The primary drive for the development of framed structures was not technology but economics. Developers were starting to realise that load bearing walls were using space that could be utilised for rentable space (Friedman, 1995). In Britain as well as America there were examples of industrialisation and prefabrication in the nineteenth century with the spectacular Crystal Palace in London, built for the Great Exhibition of 1851. Here the designer Joseph Paxton was required to produce a building which could be manufactured and erected very quickly (nine

months elapsed between the completion of the sketch design and completion of the building) and which could be dismantled and relocated elsewhere (possibly the first fast track project). The design culminated in a glass façade fixed to an exposed frame structure made of iron and timber (Macdonald, 2001).

3.3.3 Implementation of cladding in the construction industry

Nkado (1992) described cladding as "all activities necessary to render the building watertight and weathertight, including external walls, roofing, windows and external doors".

In the nineteenth century a manmade cladding material, terracotta, was one of the first materials used to clad brick buildings. Furthermore it was used more and more on steel and iron framed structures (Taylor, 1992).

The most common types of cladding used in the construction industry are non-loadbearing, often panel formed, in conjunction with a structural framework. The use of cladding has been influenced strongly by the building form. Firstly there was the development of frame construction, followed by the introduction of systems of prefabrication. From this, component parts of a building can be fabricated in a builder's yard or workshop facilities prior to their assembly on the actual construction site (Brookes, 1998).

The development of the early curtain walls endeavoured to find a thinner exterior wall. Early skyscrapers such as the Chrysler and Empire State buildings developed the metal skinned spires, with a thin metal skin and a backing of brick (Friedman, 1995).

Cladding was introduced with the idea of quicker construction, but the main concept and realism of the design is that of standardisation. Cladding predominantly is made of standard parts and designs. Standardisation aids the architect's development of a method in design, to implement constructional methods that will both relate to a known pattern of behaviour in use, and function more efficiently (Brookes, 1985).

3.4 Cladding of buildings

3.4.1 Different cladding types.

There are many types of cladding systems. It is important therefore that there is a comprehensive understanding of the different systems designed and manufactured before the management aspects can be addressed. Furthermore, there are three different cladding categories given from different organisations, each with a different emphasis. Listed are the three descriptions;

- Structure (CIRIA)
- Materials (Brookes)
- Systems (CWCT)

The building structure can be separated into two areas as a starting position, these are:

- **Walls in non-framed structures** (load bearing construction, load bearing walls)

This consists of load bearing units, which include brick, concrete block, and stone –and are not really cladding at all.

- **Cladding in framed structures** (framed construction, non-load bearing cladding)

The non-loadbearing cladding is the emphasis here. Claddings in buildings, often in panel form are mostly used in conjunction with a structural framework configuration (Brookes, 1983). These are slightly more complex in design and assembly and are separated into four main divisions;

- 1** Small units framed; masonry cladding on concrete/steel frames, masonry cladding on heavy steel frame, lightweight and masonry cladding on timber frames, and lightweight and masonry on light steel frame.
- 2** Large lightweight units on framed buildings; metal, steel, and aluminium, glassfibre reinforced cement, glassfibre reinforced polyester, fibre cement, metal faced proprietary composites, curtain wall overcladding including rainscreen.
- 3** Large heavy units framed; concrete panels, and in situ concrete.
- 4** Structural glazing, (CIRIA, 1992).

However Brookes (1983) stated that cladding can be separated into six main subdivisions based mainly on the materials used. These being precast concrete, glass reinforced panels (GRP), glassfibre reinforced cement, profiled metal and asbestos cement, sheet metal, and curtain walling.

CWCT categories cladding as;

- Profiled metal systems
- Curtain wall systems
- Precast concrete cladding
- Small panels requiring support from a backing wall (Rainscreen)
- Masonry (not included In this thesis)
- Fully supported copper or lead sheet (not included In this thesis)

From the previous classifications it is clear that there are numerous types of cladding and different materials used in their production. The CWCT categories are used to structure the following cladding sections. The majority of the information has been extracted from their technical notes.

3.4.2 Curtain walling

It is often said that this is the most used cladding type within the UK construction industry at present. This is a form of lightweight non-load bearing cladding which forms a complete envelope around a building or structural frame (Chudley, 1994).

The curtain wall generally consists of a grid system, either horizontally or vertically, complete with infill panels. In low-rise buildings the framing could comprise of a wooden grid but as a rule, especially for high rise construction, an aluminium alloy is normally employed for the grid material. There are three methods of constructing a curtain wall system. They are as follows:

- Stick System
- Unitised
- Panellised

With all three methods of erection the infill panels are usually made from glass or aluminium.

- The *stick system* consists of a prominent site erection process. With the frame (the stick) being constructed from the exterior of the building, generally off scaffolding. The frames are normally extruded aluminium protected by anodising or powder coating, but maybe cold-rolled steel or aluminium clad with PVC-U (CWCT, 2000). The infill panels are then secured to the grid. To make the structure "weathertight" against the elements, the

final structure will be sealed using silicone based mastic with access made possible from a cradle or a cherry picker. Figure 3.1 shows the general arrangements of a typical stick system assembly.

- The *unitised system* comprises narrow storey height units of steel or aluminium framework, glazing and panels pre-assembled off site in a factory environment. At site assembly mechanical handling is required to position, align and fix the units onto site fixed brackets which are attached to the floor slabs or the structural frame (CWCT, 2000). Figure 3.2 shows the general arrangements of a unitised system assembly.

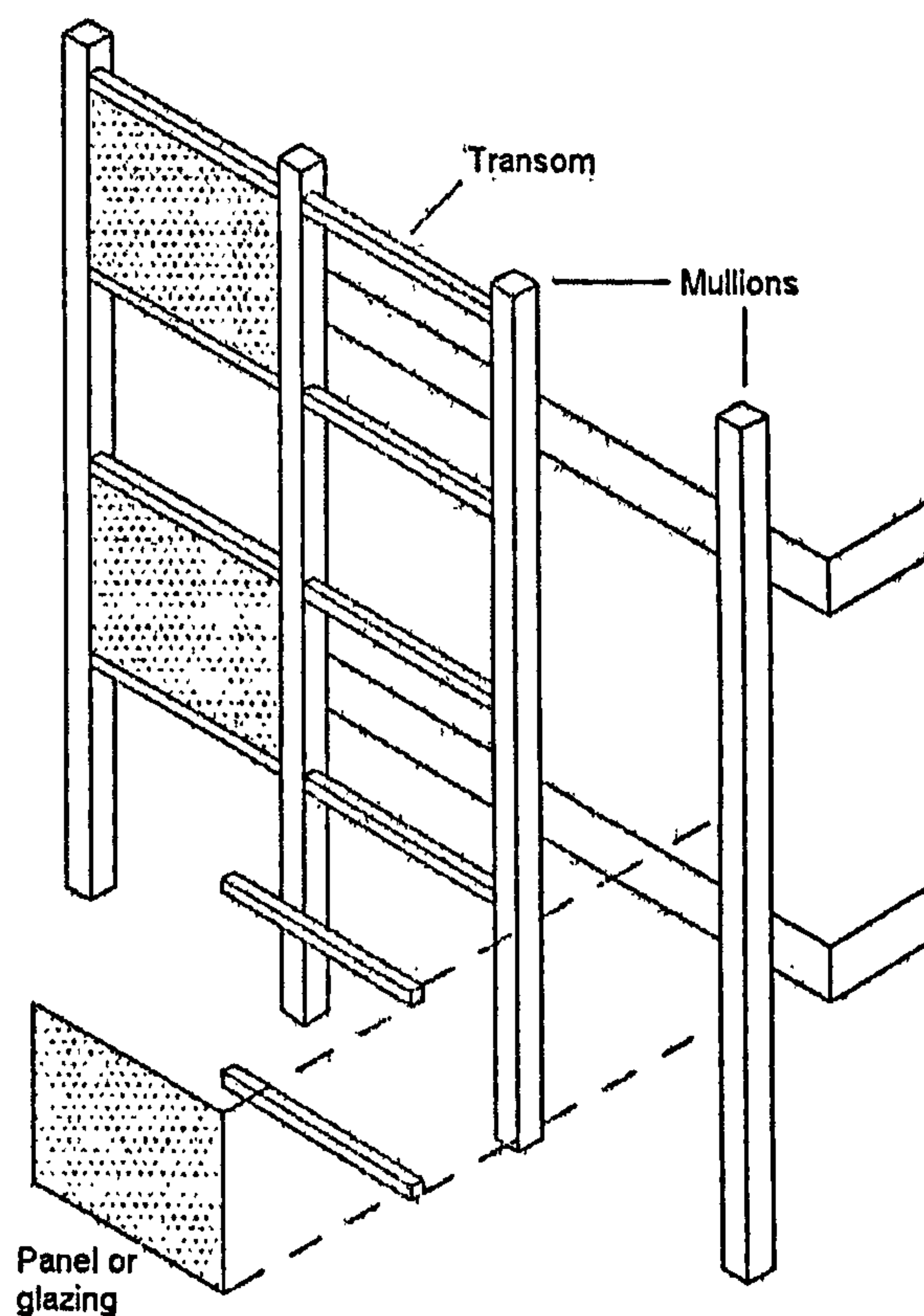


Figure 3.1: Curtain wall stick system (CWCT, 2000)

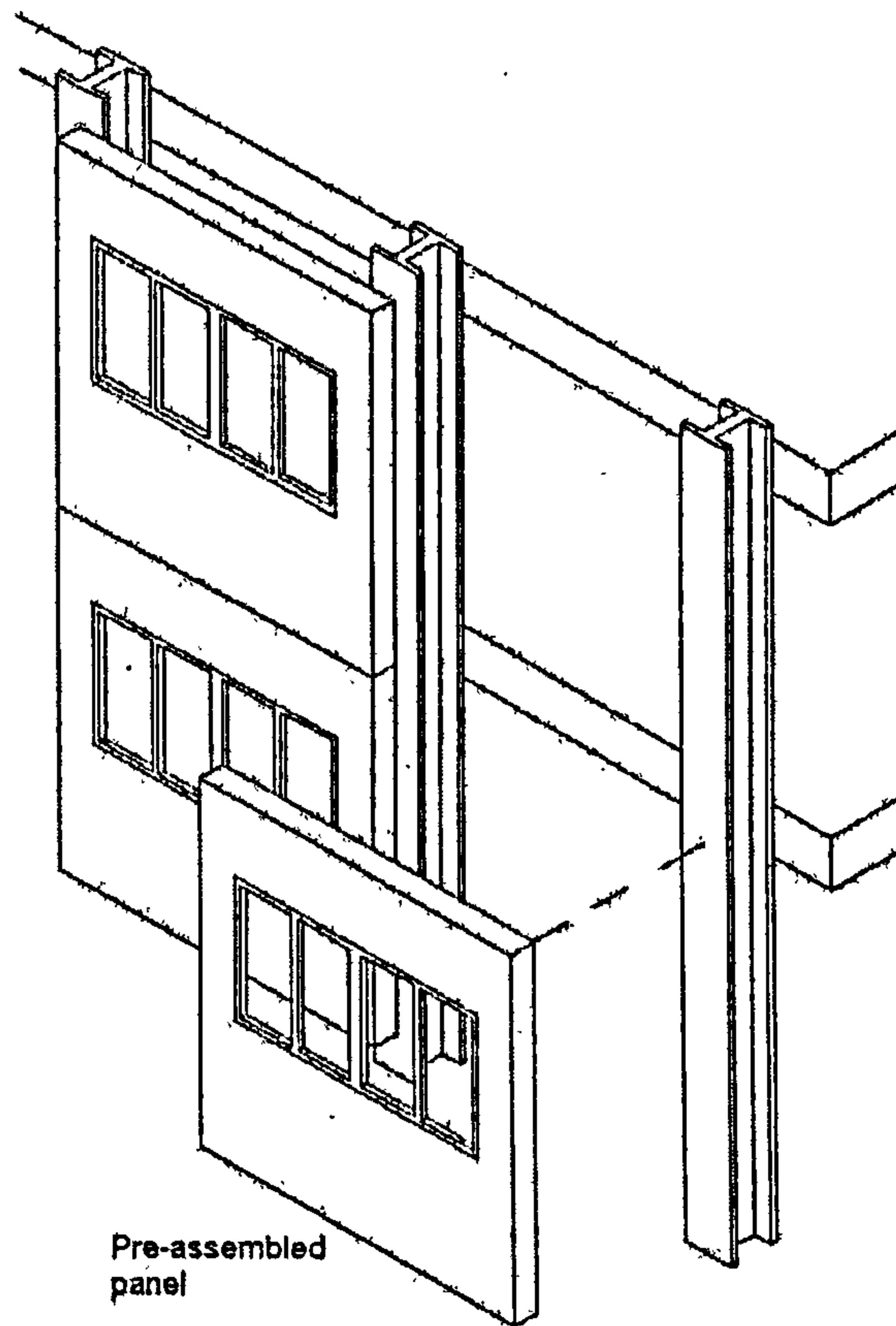


Figure 3.2: Curtain wall panelised system (CWCT, 2000)

- The *panellised system* is bolted together in an arranged sequence on pre-installed brackets, the panels are bay width and storey height thus the panels themselves form the grid. Generally with this method of installation the construction work can be carried out from the inside of the building, thus eliminating the need for scaffolding. Like the stick system the final application is that of the sealing mastic. Figure 3.3 shows the general arrangements of a panellised system assembly.

The unitised and panellised systems are a far quicker method of site erection. Both methods have their advantages associated with the high levels of potential prefabrication off-site. The stick system has the advantage of being smaller and involving easier components to handle, however compared with the unitised and panellised method, the site erection time can be far longer (Brookes, 1998).

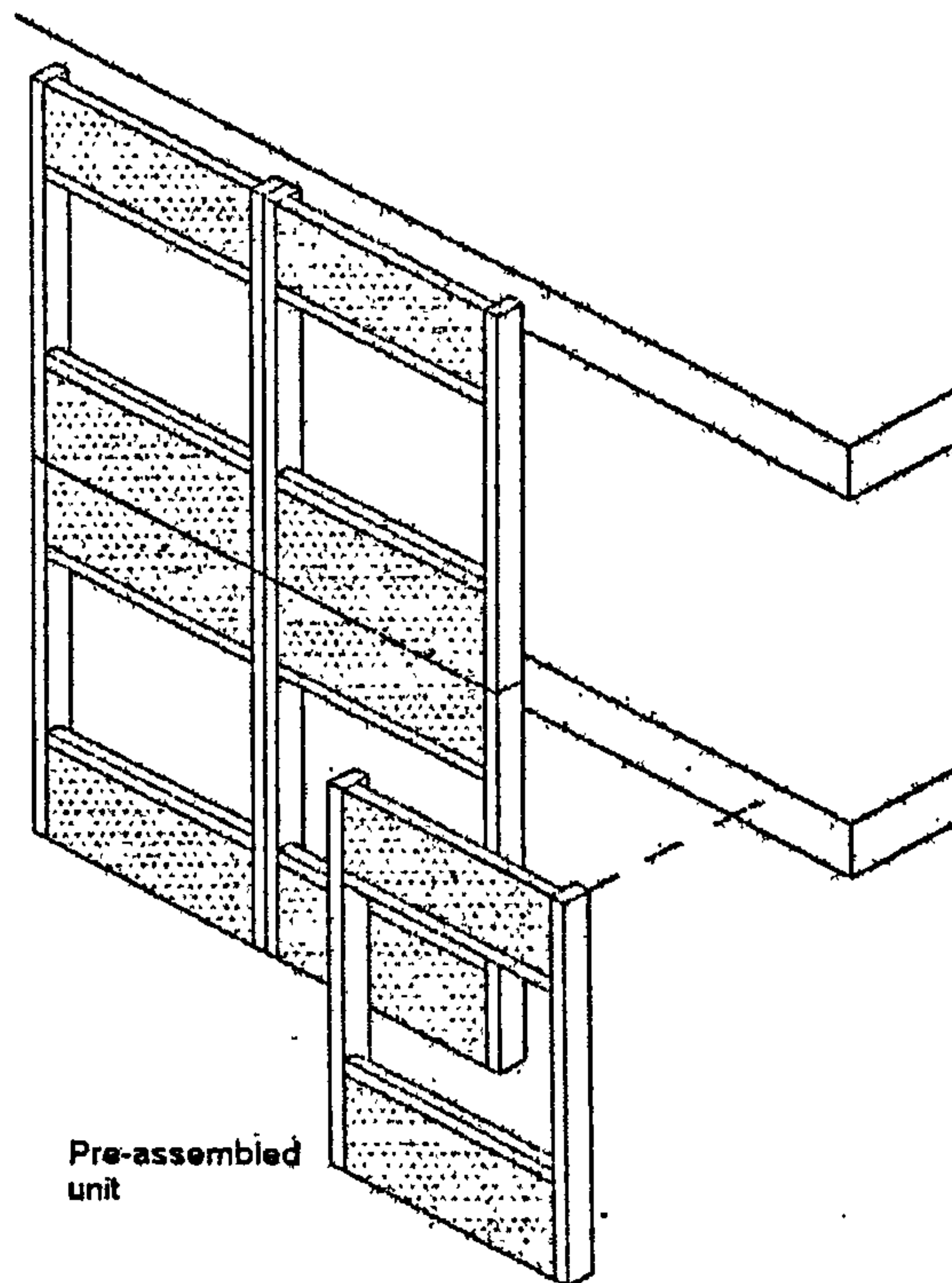


Figure 3.3: Curtain wall unitised system (CWCT, 2000)

3.4.3 Glazing systems

Over the last few years there has been a dramatic increase in the use of glass for curtain walling. Systems such as suspended glass and structural glazing are becoming very prominent, as well as Pilkingtons "Planar" system. Many of the systems are using laminated toughened glass. There are two main types of glazing systems, which broadly come under the same umbrella as curtain walling though they are systems in their own right. These are:

- Structural sealant glazing
- Structural glazing

Structural sealant glazing is a fairly recent development based on curtain wall. The structural support system is similar to the mullion and transom system of stick system curtain wall. However, the glazed panels are prefabricated units of a single unit size. The panels incorporate an extruded aluminium substructure with the glazed panel bonded to it with a sealant adhesive. The panels are then mechanically fixed up to the carrier system. The joints between the panels are sealed via either a site applied silicone seal, or on the more sophisticated systems, an EPDM or similar gasket.

The finished system has no capping pieces, a fully flush external face, and any opening lights have the same appearance as the fixed lights - due to the mechanical fixing which can incorporate opening light brackets. The manufacture of the prefabricated elements has to be carefully controlled to ensure the sealant adhesive bonds properly with the glazing and the aluminium substructure.

Structural glazing is a facade system more commonly known as Planar, due to the original Planar fitting by Pilkington. Glazed panels, either single glazed, toughened, laminated or double glazed are supported on point fittings, tied back to either the primary structure, or to a secondary structure. There are several types of fittings:

- Standard bolt
- Simple countersunk bolt
- Stud assembly
- Patch plate fixing
- Enhanced countersunk fixing
- Articulated bolts

The primary variation between the bolt types is in the accommodation of movement (as opposed to the patch plate fixing which has a slightly different method of operation). The articulated bolt will allow rotational three directional movement where as the standard bolt will allow little movement.

The bolt fittings are located along the edges and at the corners of the glazed panels (the number depending upon the size and weight of the panel) and are fixed back to the structure. The joints between the glazed panels are sealed with a silicone sealant (or similar), which will accommodate variation (CWCT, 2000). Figure 3.4 shows the general arrangements of a structural glazing assembly.

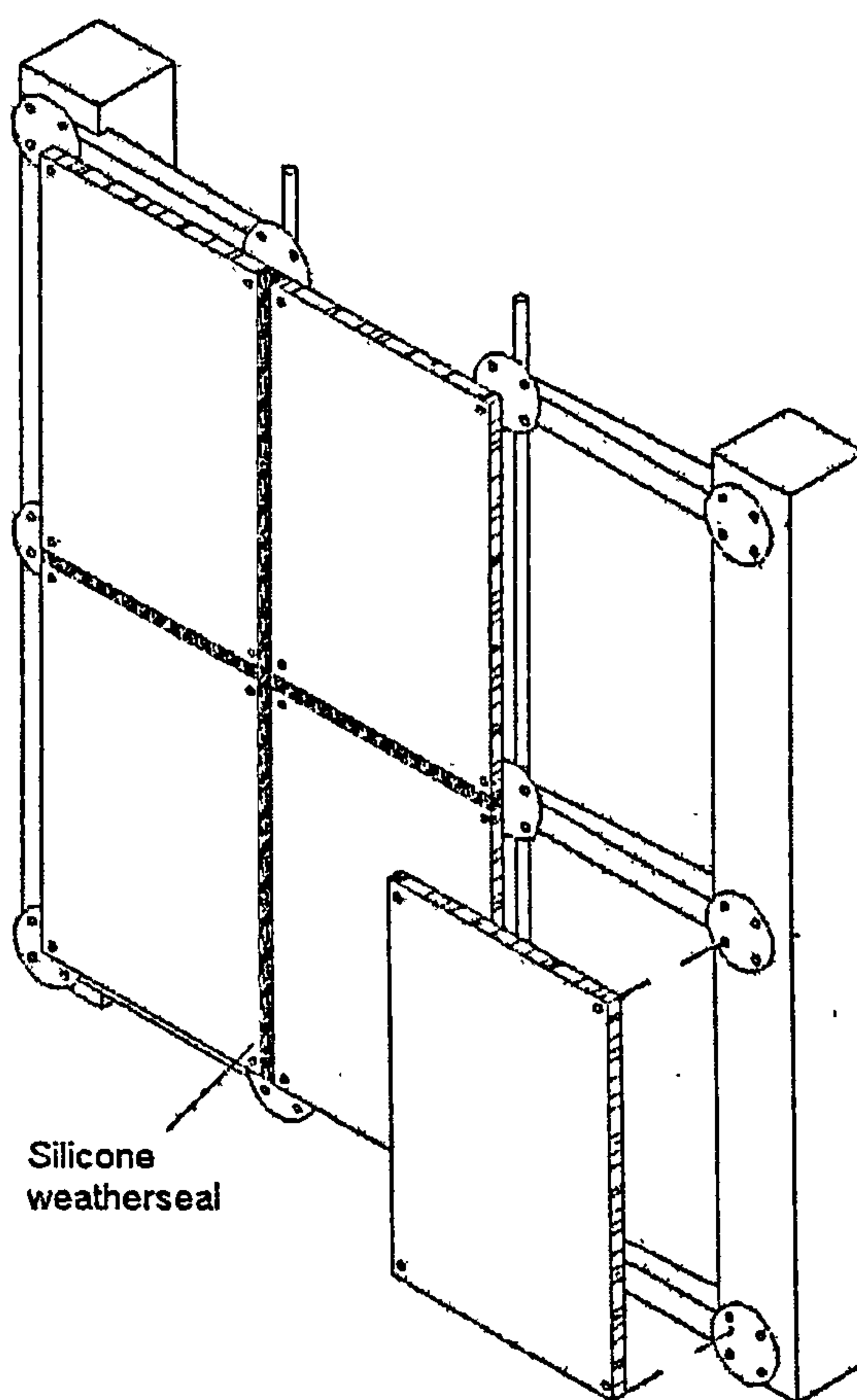


Figure 3.4: Structural glazing- bolted assembly (CWCT, 2000)

3.4.4 Concrete cladding

Concrete cladding can be separated into two elements;

- Precast concrete; where the concrete is coloured and has a surface texture applied to it
- Reconstructed stone; where there are two methods of application; wet – cast reconstructed stone and semi-dry reconstructed stone (Dawson, 1995).

However, there is often a problem defining the differences between the two types. A view is that any piece of precast cladding, structural or otherwise which is manufactured to resemble natural stone should be identified as reconstructed stone (Taylor, 1992); therefore from this point onwards concrete cladding will be referred to as precast concrete. Concrete cladding by its mere name suggests that weight will be a factor in the design. Pre-cast can be used as both loadbearing and non-loadbearing methods of cladding, but the most common is the non-loadbearing.

Pre-cast cladding came into its own in the 1950s and 1960s when there was large amount of concrete construction being carried out, especially with the erection of high-rise buildings. The three main advantages of using pre-cast over in situ concrete are:

- Speed of erection
- Freedom from the need of shuttering on site
- Better quality of finish and concrete strengths, due to the controlled environment of factory assembly (Brookes, 1998).

There has been a decline in the market in recent years for the installation of pre-cast cladding. This is due to an industry trend, where it is thought by some architects that concrete is no longer aesthetically pleasing. The majority of the installation now features around city centres, especially where projects need to resemble their surroundings.

The size of the pre-cast panels will vary, dependant on many aspects, typically in design and the site itself (for any weight restrictions). The panel heights generally are a storey height, with a weight restriction of about seven tonnes but are often less. This is for lifting purposes and installation.

Lorries transport the panels to site either horizontally or vertically. Whenever possible, on arrival at site, the panels are lifted straight into their final position by means of a crane. The panels are secured to the structure by means of pre-fixed anchors, and can be either top hung or supported from the base (in a similar fashion to the panellised curtain walling). As with the curtain walling systems the final operation is to "silicone" mastic the panels in order to achieve watertight joints (Brookes, 1992).

3.4.5 Metal cladding

3.4.5.1 Profiled metal Cladding

The PSA (1979) states that there are three types of profiled metal cladding, these can be defined as:

- Sinusoidal
- Symmetrical trapezoidal
- Asymmetrical trapezoidal

However figure 3.5 shows that the two trapezoidal types are virtually the same but the geometry of the profiling varies. The panel is an insitu construction incorporating an inner lining and spacer purlins with an outer sheet. The inner lining and spacer purlin may be replaced with a combined element.



Sinusoidal



Symmetrical trapezoidal



Asymmetrical trapezoidal

Figure 3.5: Profiled metal profiles (Brookes, 1998)

The lining and purlin are fixed back to either the primary structure or a secondary structure, with the outer sheet fixed through to the purlin. Insulation is commonly located between the purlins. The profile of the panel will accommodate a certain level of thermal and differential movement in the outer sheet, reducing the stress on the direct fixings.

The simplest form is a single un-insulated skin supported on cladding rails spanning between the main structural columns. For most buildings it will be necessary to incorporate insulation and this can be accommodated by using two

skins of metal sheeting separated by a spacer bar and with insulation in the resulting cavity (CWCT, 2000), as shown in Figure 3.6, as an alternative to sheeting rails, liner trays can be used, which when clipped together act as horizontal rails, normally at 500mm centres (Brookes, 1998).

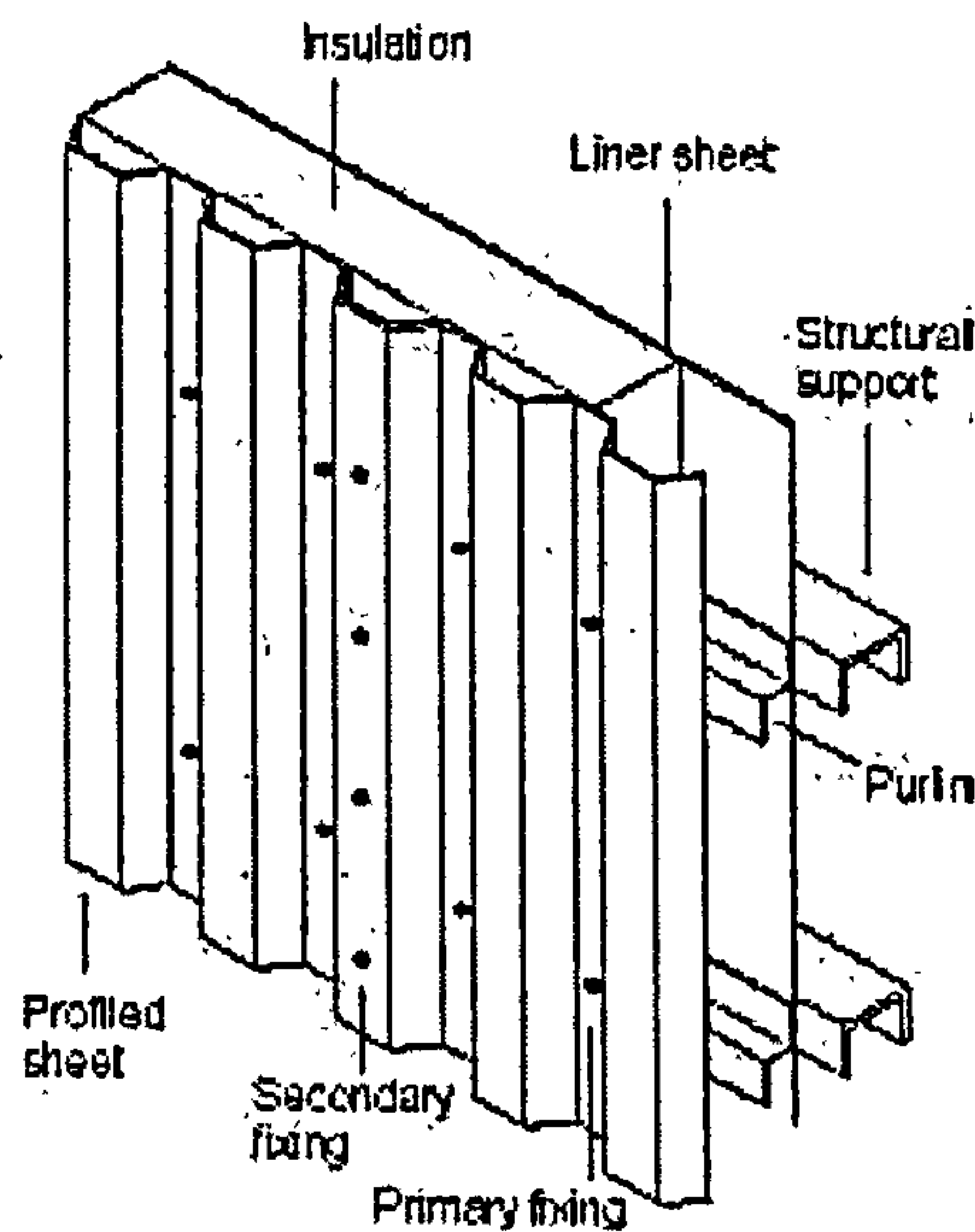


Figure 3.6: Site assembled profiled metal cladding (CWCT, 2000)

3.4.5.2 Composite Cladding

The use of composite materials in the construction industry has become more and more common. Cladding panels can be produced using laminating or foaming manufacturing methods. This is an increasingly popular form of cladding for industrial and commercial buildings (Stacey, 1997). Le maison du Peuple at Clichy, by Prouve, completed in 1939 was an early example of the use of metal composite cladding.

Composite panels are basically formed by two thin sheets of metal which are held together by a lightweight core of insulation, to which they are bonded, shown in figure 3.7 (Brookes, 1994). Composite metal panels are formed from two sheets of metal (steel or aluminium usually) bonded to a rigid insulation core. The panel thickness is in the range of 50-120mm, and the length (dependant on manufacturing method) is up to 12000mm. The panels are fixed back to either a support structure or the primary structure, depending on the panel size, structural bay width and expected tolerance range.

The joints between panels will vary from system to system, but some form of integrated assembly is to be expected. Many of the systems available incorporate a mated interface assembly, requiring a specific erection sequence, and it may prove difficult to replace single panels.

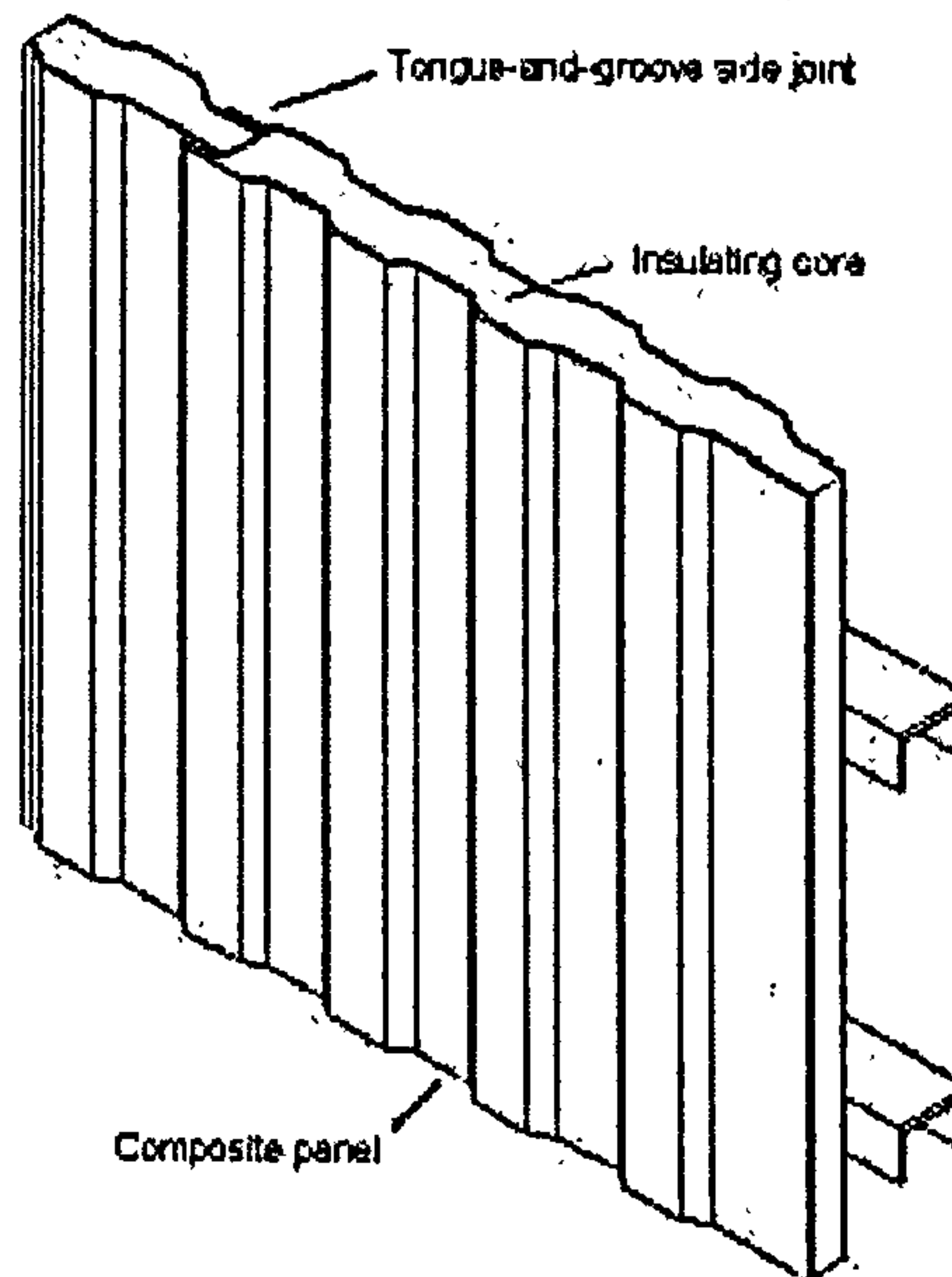


Figure 3.7: Composite panel with tongue and groove joint (CWCT, 2000)

3.4.6 Rainscreen cladding

Anderson and Gill (1988) stated that the development of the rainscreen cladding concept started in the 1950s and 1960s in North America and Scandinavia respectively. Rainscreen cladding has in recent years gained popularity in the UK, primarily because the open joints between the panels provide sharp straight lines (Grech, 2000).

Rainscreen panels can be constructed from a variety of materials, both for the external element and the carrier system. The typical features of rainscreen cladding are;

- A outer skin- the panel
- An air gap
- An insulation layer
- A backing wall

The principle of rainscreen may employ pressure equalisation to ensure the envelope integrity. The outer layer acts primarily as a water barrier, with open joints between the panels. The cavity located behind the outer layer, equalises the pressure differential between the outside and inside of the panel face, thus preventing excessive water penetration by capillary action. The cavity is backed by an airtight barrier and incorporates a drainage system for any water ingress. Some of the more sophisticated rainscreen panel systems incorporate the air seal and drainage channel as part of the support structure, as an integrated assembly (Grech, 2000). Figure 3.8 shows a typical assembly of a rainscreen system.

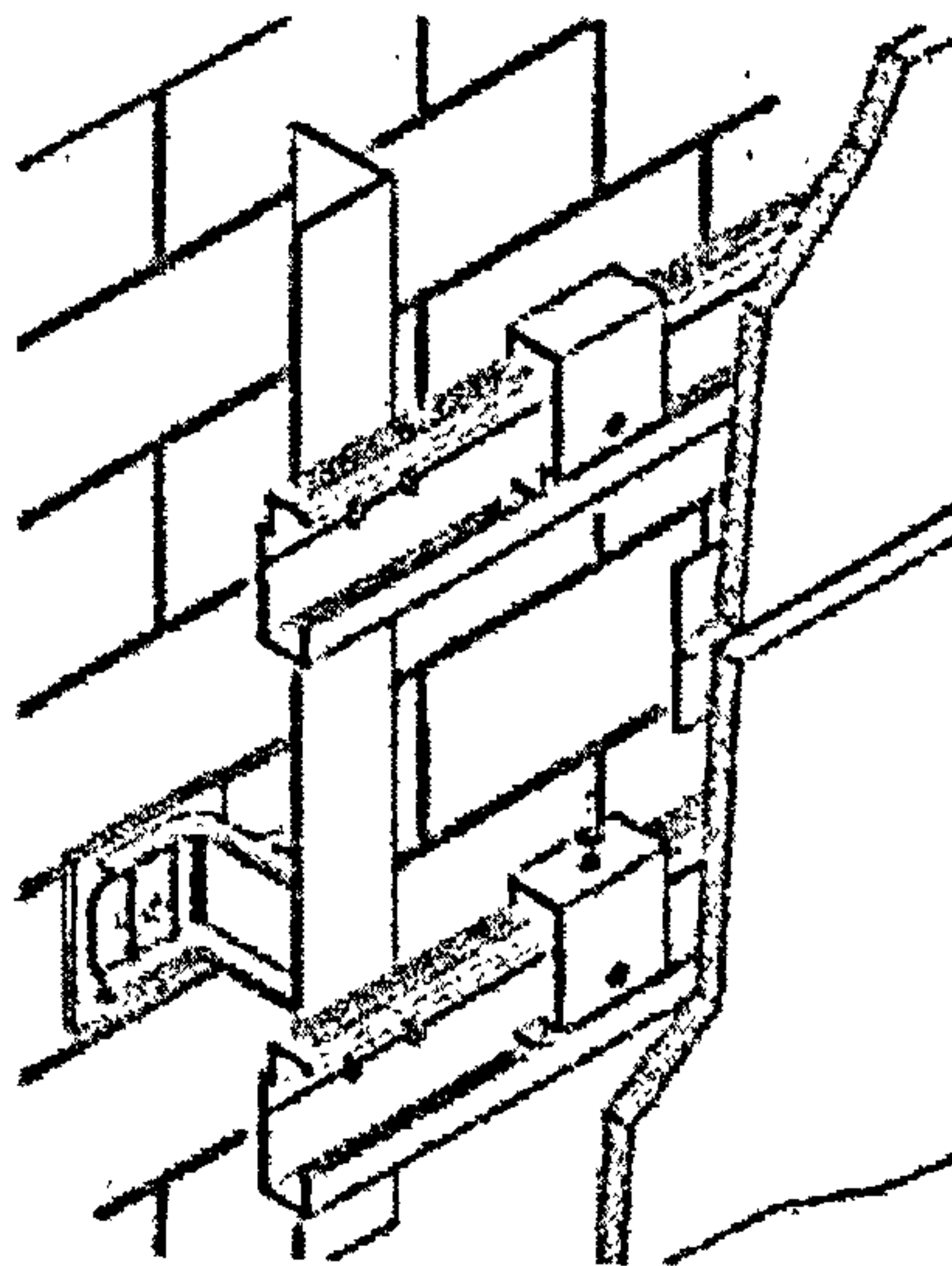


Figure 3.8: Typical 3-D view of rainscreen cladding (LSC, 2000)

3.4.7 Solar and Photovoltaic

Two recently completed projects; Duxford International Business Park, Sunderland and the Alfa-Laval site, London has used such methods. The idea behind these projects is for them to be used as benchmarks for the use of solar cladding in the UK (Macneil, 1998).

Also extensive research has been carried out on photovoltaics at the architecturally integrated facade at the University of Northumbria, Newcastle-upon-Tyne. The research has been conducted in unison with the university and Ove Arup (Shaw, 1997). However, the photovoltaic cells are merely incorporated in the external face of the cladding, therefore it really isn't a cladding type.

3.4.8 Manuals for cladding installation

There are several manuals written on the installation of cladding systems, often by the designers and fabricators themselves. The CWCT have published the "Standard Guide to Good Practice for Curtain Walling", which is an extremely useful manual for architects, designers, and installers for the installation of curtain walling systems.

The manual covers numerous aspects from; extrusions, performance criteria, testing, materials and components, finishes, quality, fabrication, handling and storage, installation and finally maintenance (CWCT, 1993).

3.5 Construction Design

Design means recognising the constraints of the law, the agreed budget and the requirements of the clients brief. Furthermore, it is also a creative process that involves both analysis and synthesis (RIBA, 1998). The design requirements for a project can be classified as the known and anticipated physical needs for the internal environment and the external surroundings of the proposed building, down to the smallest conceivable detail (Salisbury, 1997).

The design phase of a project can be classified as three stages (C, D and E of the RIBA plan of works) outline proposal, scheme design and detail design (RIBA, 1998) (see section 3.12.1). With the design configuration and features becoming firmer at each stage. The extent of the design team will vary depending upon the procurement route taken by the client (see section 3.11). For instance, with the traditional method, during the design process the architect is normally working in isolation, far removed from the principal contractor, whereas with design and build the architect or design team are very part of the construction process (Masterman, 1992).

3.5.1 Design management

The primary role of design management is to control the design activity and ensure that the project is delivered on time and within budget (Cook, P. et al, 1989). The RIBA (1998) practice management guide states that design management has four main stages of activity:

- Understanding; the brief, the site conditions etc
- General study; exploring the relationship of design elements
- Development; refining planning and design
- Communication; presenting solutions in appropriate form

Morris (1991) identified the need to consider and develop the client's requirements for a building adequately, involving the technical needs and general strategic planning and for the design to be managed firmly. Furthermore, the best and smoothest method of designing a project is to have them properly set up at the front end of a project where there is a strong constructive team spirit (Burton, 1992). In addition, Gray (1996) suggested integration with the client will achieve a flat organisation and therefore minimise communication failings.

3.5.2 Planning design

Planning the design is almost as important as the design itself. Planning involves the systematic determination of the specific form of the product. It can be achieved by a variety of planning techniques used by the client brief takers at the inception phase. Various techniques have been developed to aid the formation of ideas and provide good strong guidance to the design team (Pendlebury, 2000). Furthermore, Austin et al (1995) claimed that poor information and design planning are inextricably linked and argued that an improvement in design planning would facilitate the management of information flow.

Finally, Ireland (1985) stated that to obtain cost reductions and reduced construction times there needs to be efficient planning during design and coordination across the design-construction interface.

3.5.3 Detailed design (shop drawings)

The detail design or more commonly called, shop drawings' is the connecting link between design and construction. Due to the increasing complexity of today's construction process, shop drawings in recent years have been the subject of professional liability claims. Processing the drawings and ambiguous wording in the approval process are the principle source of dispute.

Most specifications state that the contractor (normally the specialist contractor) refrain from ordering materials until the shop drawings have been approved for construction. Therefore any delays in processing the drawings affect all the contractors' scheduling (Fisk, 1988). However the author, through experience (case studies, chapter 5) discovered that due to time constraints, the material supply and scheduling will continue if the shop drawings have not had final acceptance.

3.5.4 Cladding installation and responsibility

When it comes to the installation of the cladding on site problems can often occur. This is sometimes due to the nature of the design and not the installer's inefficiency. Listed are Illingworth's (1993) aspects that should be considered before the installation commences:

- Has sufficient expansion or compression been considered when designing heavy cladding?
- Can the cladding panels actually be installed (too big)?
- Accuracy of the structure must be maintained - floor to floor dimensions must be kept within tolerances (curtain wall can only work within certain tolerances).
- Tolerances and fixings - the fixings must be realistic for the structural form and for the installation process.
- Waterproofing the joints - inspection and installation.
- Touching materials must be compatible with each other.
- Has safe construction been considered?

Over recent years the facade has developed using new design and material technologies. Furthermore, so have the architectural expressions of designers (Kahn, 1992; Donaldson, 1987). The new technologies, in terms of design roles and procedures, can lead to lack of proper definition of design responsibilities, particularly those of the specialist contractors (Gray and Flanagan, 1989). This creates organisational inefficiencies and ultimately product failure if not adequately delegated. These are highlighted by the fast track nature of projects associated with modern construction (Pietroforte, 1995).

Furthermore, Rivard et al (1995) identified the lack of communication and coordination throughout the facade design results in sub quality solutions to the face design and ultimately inadequate performance of the facade. Cohen (1991) has identified that there is a splintering of responsibilities with cladding design with a separation of tasks occurring in design, analysis, construction, installation and maintenance.

In addition he stated that architects still typically design cladding conceptually, however the manufacturers fabricators and suppliers are responsible for the final detailing of the product. However, they are generally not qualified to establish and design for frame movement and the interaction between the cladding and

structural frame. Bell and Schwartz (1989) further endorsed this. Therefore there is a need for a structural engineer to be part of the process.

Due to the fragmentation of the cladding process, Brock (1991) suggested two actions. First, sole responsibility and effort is needed for the structural design and performance of the cladding. Secondly, specialist solutions are needed for specific categories: durability and integrity of the cladding materials and the design of the non-structural cladding and its interface with the frame.

Therefore, Pietroforte (1995) stressed that there is a need for established responsibility within the project. He also stated that *"the design process is becoming more and more fragmented; design becomes the negotiation of physical and organisational interfaces. Design integrity, so central to the architect's traditional role, risks losing its meaning if the need for managing design interfaces is not recognised and satisfied within the overall management plan of a building project"*.

Cohen (1996) concurred that the cladding design process in place today does not ensure that responsibility has been taken to oversee all aspects of the process completely, including architectural and structural design, detailing, fabrication and installation.

3.5.5 ADePT

With the growing importance for the effective design management that facilitates a coordinated design, the Analytical Design Planning Technique (ADePT) was developed. Adept was created by Newton (1995) as a flow model for the building design process that is subsequently analysed in a design structure matrix to produce a tool to assist in the management of complex multi-disciplinary building design projects (figure 3.9).

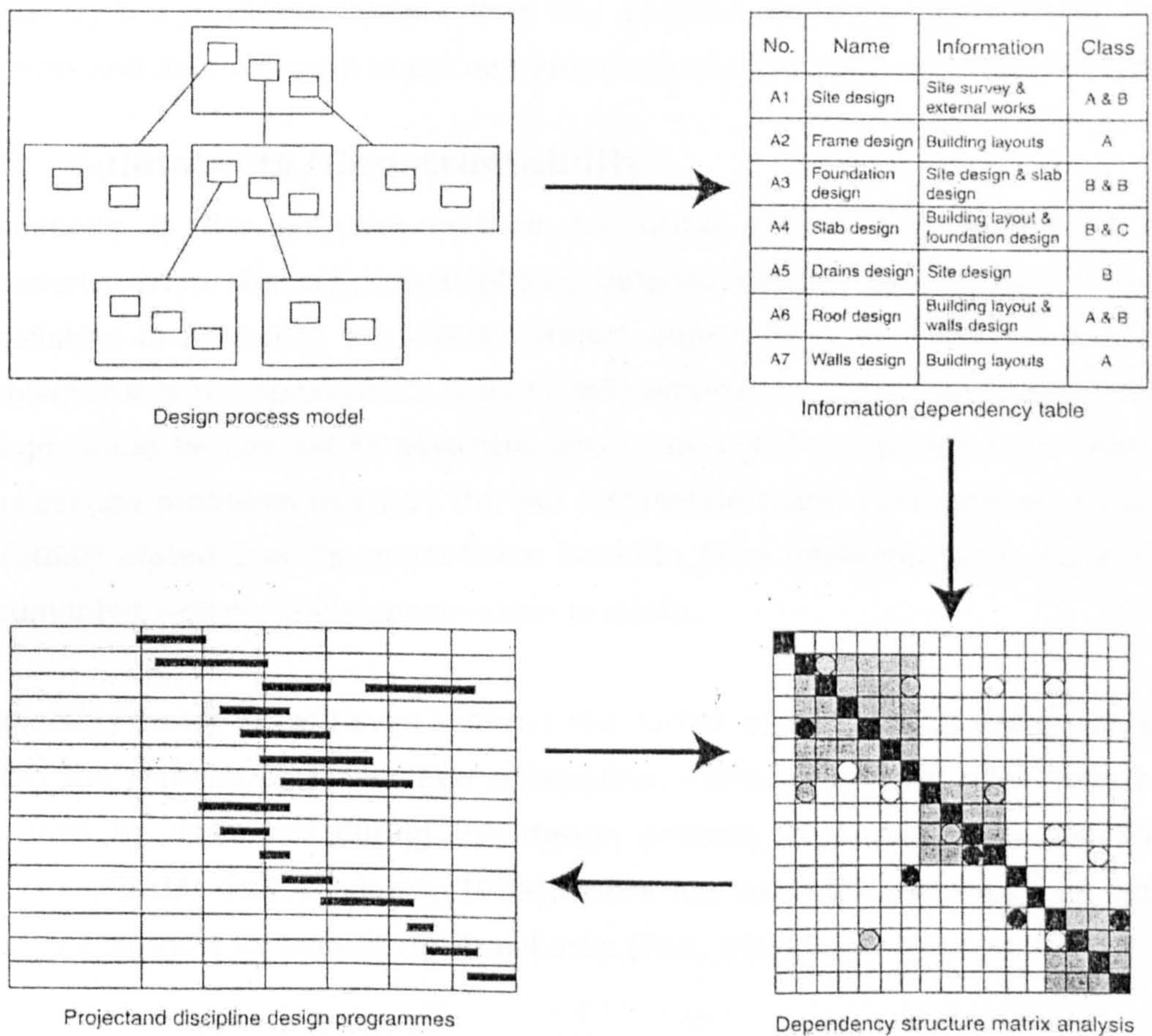


Figure 3.9: ADePT schematic approach

The ADePT technique, shown schematically in figure 3.9, offers an approach to design management that undertakes work in an iterative manner. It enables the works to be monitored on the development information allowing the design to be fully integrated (Austin et al, 1999). ADePT has three stages;

- *Model of the detailed stage of the building design process.*
Represents design activities and information requirements.
- *Dependency structure matrix (DSM)*
The data from stage 1 is linked by the means of the dependency table to the dependency matrix. This then arranges the activities with the objectives for optimizing the process sequence.
- *Design programmes*
This is a programme of design from the optimised process sequence.

However, the author considers that this process will only benefit large scale projects and its successful implementation into smaller scale projects is doubtful.

3.6 Buildability/Constructability

Buildability is the ultimate method for using construction knowledge and experience from the conceptual phase, detailed design, procurement and site installation in achieving the overall project objectives (CII, 1986). It can be a problem if it is not considered. Gray (1983) emphasised that the details within a design would be difficult to assemble and construct if the design team failed to consider the problems faced by the site installation team. Furthermore, Fisher et al (2000) stated that its quantifiable benefits from implementation have been documented well on many construction projects.

Buildability must be achieved without the forfeit of the overall design concept within the planned cost and time constraints. Although general rules have been assumed by designers during the design process to enable good buildability practice (CIRIA, 1983; Adams, 1989), there has been little research or figures available to show its benefits or drawbacks (Poh, 1997).

Furthermore, the nature of the building will relate to the complexity of the buildability, endorsed by Arditi et al (2002). Constructability of design is a subjective scale that depends basically on a number of interdependent project-related factors. Many design firms have a formal (explicit) constructability program that is launched as early as the conceptual planning stage of the project.

Through literature on constructability, Nima et al (2001) formulated 23 constructability concepts for use in a construction project starting from conceptual planning through to site installation. Within these 23 concepts are 3 subdivisions;

- Conceptual planning C1-C7
- Design and procurement C8- C15
- Field operations (site installation) C16- 23

C6 states that in order to accomplish the field operations (site installation) easily and effectively, major construction methods should be discussed and analysed in-depth as early as possible to direct the design according to these methods.

Constructability in construction is an area that is often overlooked or misunderstood. Constructability is the ability of an element to be constructed with relative ease. Often it causes problems because the designer of the element is solely a designer and has no, or very little, construction assembly experience. Therefore the aspect of interfaces between differing elements and constructability is never addressed (Pavitt and Gibb, 2002).

In a research project into "the use of visualization to communicate design information to construction sites," Ganah *et al* (2000) were trying to ascertain where the potential problem areas of design were and to investigate constructability problems that might arise during construction. They discovered the following information from an industrial survey:

- Interfaces between components of M&E services installations was the most common problem. It represents 67% for electrical installations, 64% for plumbing works, and 82% for mechanical installations.
- Cladding ranked high, here 75% of the total respondents experienced constructability problems at the interface between cladding components.
- In general, the most common problem was interfaces between components in all constructability areas. As many as 82% of the total respondents had experienced this problem.

Therefore, it shows that unless buildability is correctly managed early in the process and throughout the construction process it can have a detrimental effect on the interfaces and how they function.

3.7 Specialist contractors

The CIB in 1997 published a code of practice for the selection of subcontractors. This stressed the importance of subcontractors, and it was inevitable that principal contractors reassess their relationship with subcontractors. Some have done this by looking at cooperative approaches such as partnering (Mathews *et al*, 1996, Bennett and Jays 1998).

With the increased technological complexities of a project and building subsystems comes the need for greater care in the selection of the subcontractor. Often subcontractors are forced to try to avoid investment in specialised personnel. Integration of design, manufacture and installation for subsystems such as heating and ventilation needs high expertise, particularly if

the subcontractor has a number of construction projects in progress at one time. Subletting to secondary subcontractors generally is often the preferred solution (Sozen, 1998).

With the trend away from 'traditional lump sum, fixed price contracting there is a greater need for the specialist contractors to be involved in the process. This has brought about further problems especially at the interface between the mechanical and electrical services (M&E) design team and the M&E contractor. Klein (1998) gives the following reasons for these problems:

- "Insufficient and /or inadequate communication between the designers is often caused by inappropriate contractual arrangements or poor co-ordination of the various design inputs.
- Lack of management at interfaces and blurred divisions of responsibility.
- Little co-ordination of the design inputs.
- Procurement of specialist contractors' design - the basic defect in this system is that the specialist contractor is a de facto member of the design team but this is not properly (or not at all) reflected in contractual relationships, documentation or common terminology."

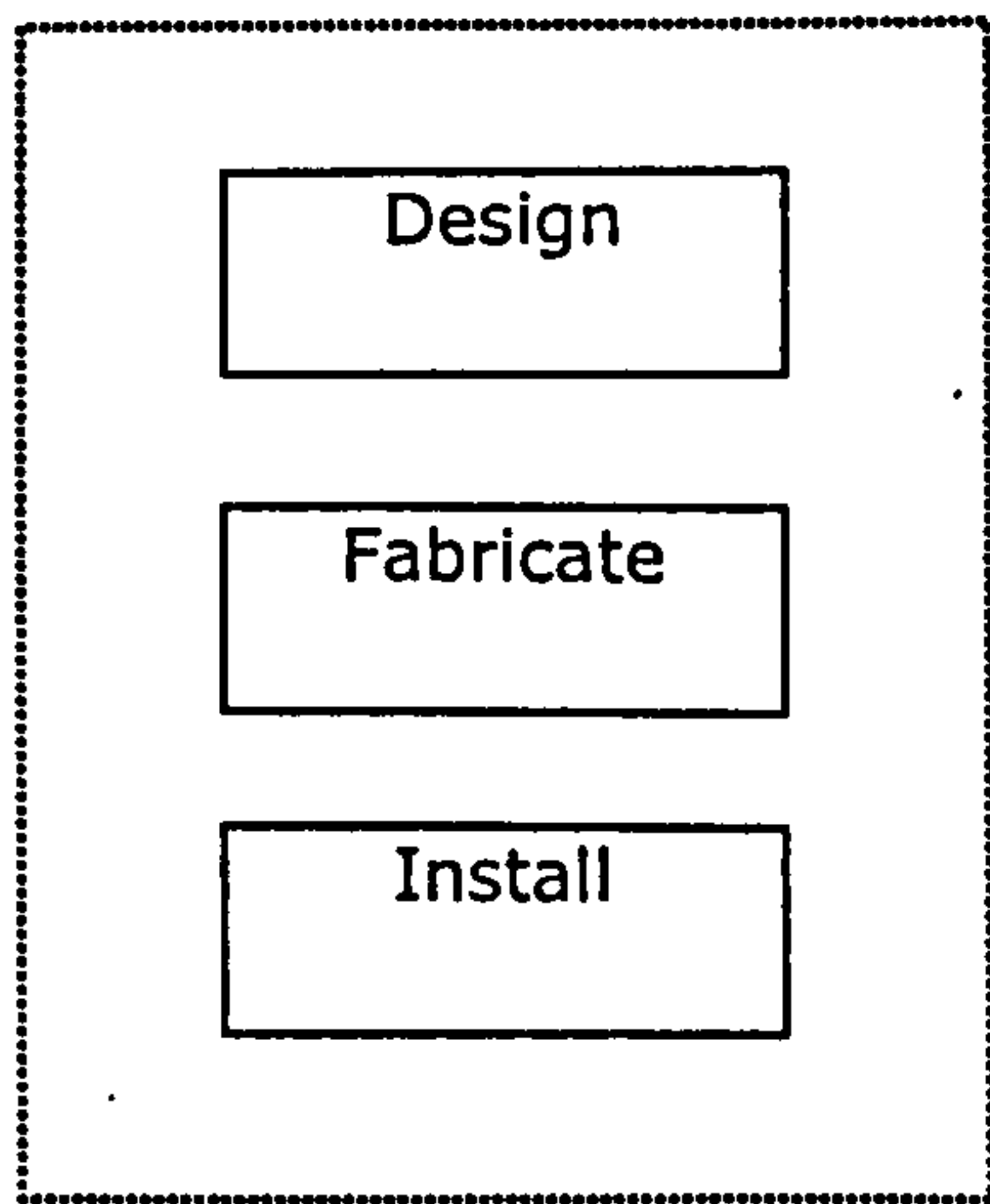
3.7.1 Mapping and quantifying the cladding subcontractor industry

The subcontract industry in construction comprises numerous companies ranging in sizes from international companies with turnovers in excess of £100 million to small companies operating in particular localities with £1 million turnovers or frequently much less. Therefore the successful procurement of a cladding project is completely dependent on the identification of suitable tenderers who have the necessary skills and resources, knowledge, capital and experience.

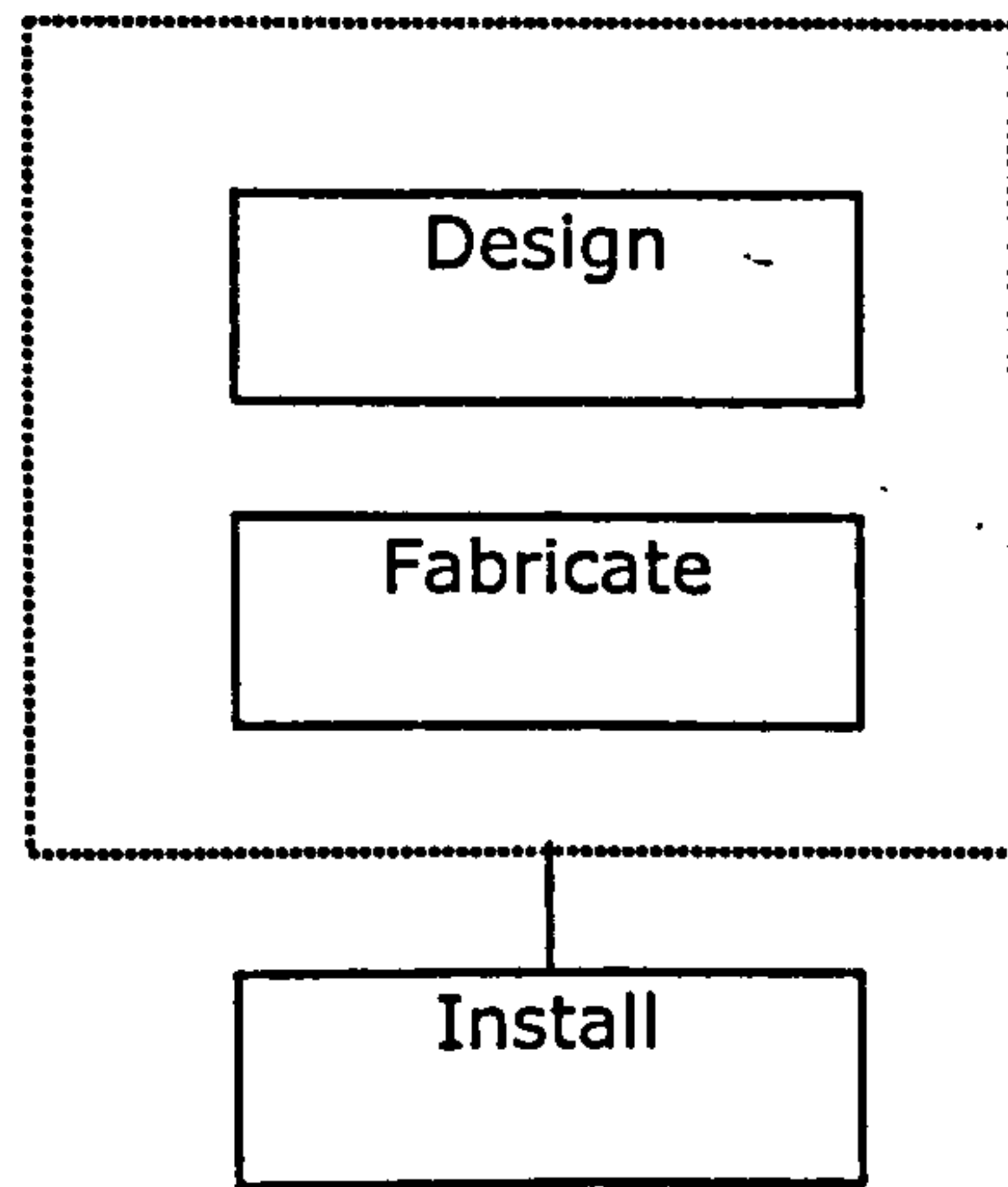
The cladding industry is frequently required to supply complex solutions to satisfy current architectural trends in the construction industry, the majority of the systems are semi-bespoke on every building. This is achieved via specialist contractors, all of which have different roles within the industry (Ledbetter, 1997). Therefore there is a need to understand the types of companies and specialist contractors that operate within the industry, especially as it is the specialist cladding contractor who enters into the contract for the project with either the client or the main contractor.

3.7.2 Types of Specialist Contractors

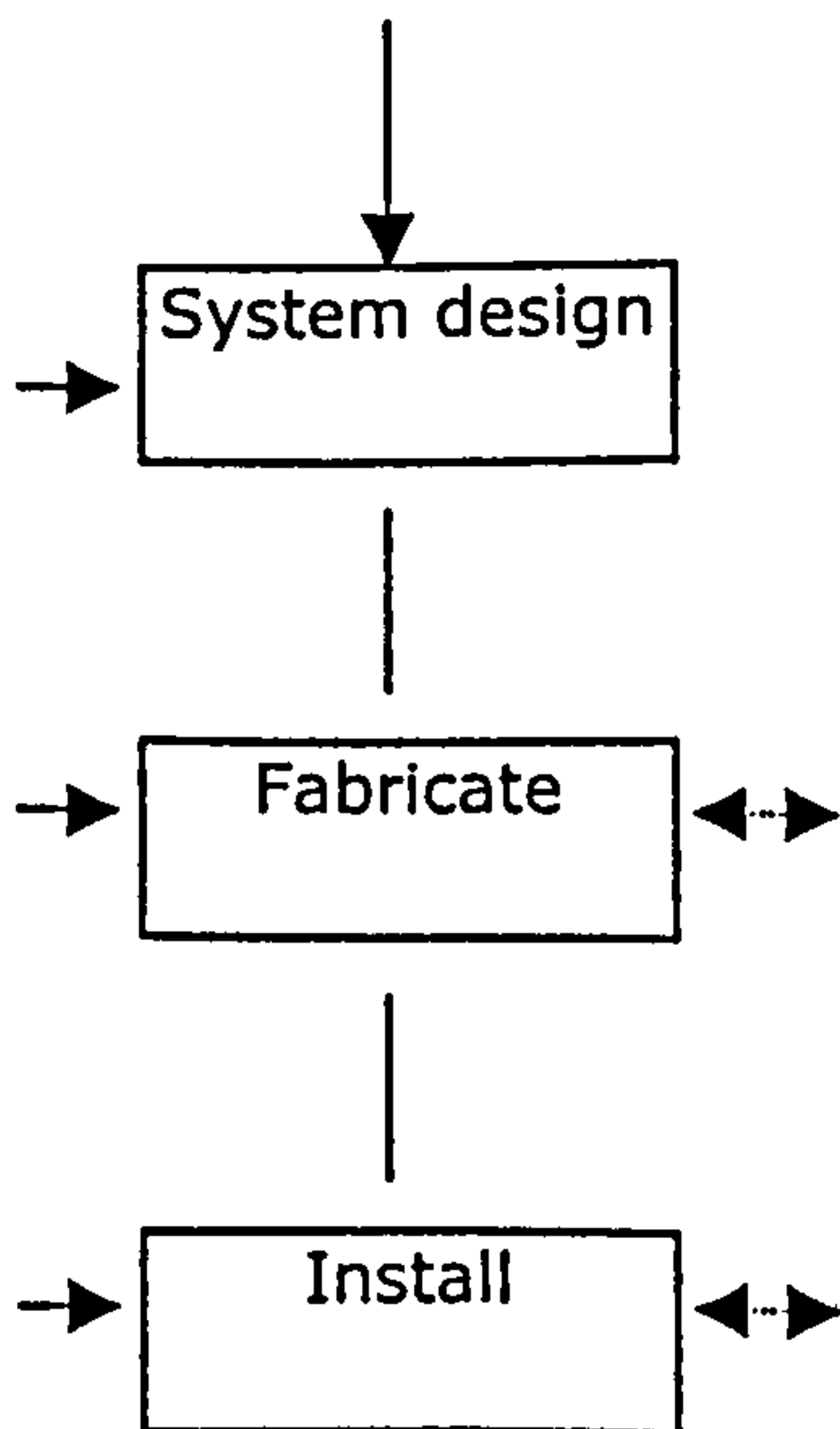
Typically the specialist cladding contractor is involved in many aspects of the delivery of a cladding system, this may include: system design, fabrication, installation, and component supply. A specialist cladding contractor may undertake all of the processes or be limited to just installation. There are four main types of specialist contractor in the cladding industry (Ledbetter, 1997), as shown in figure 3.10.



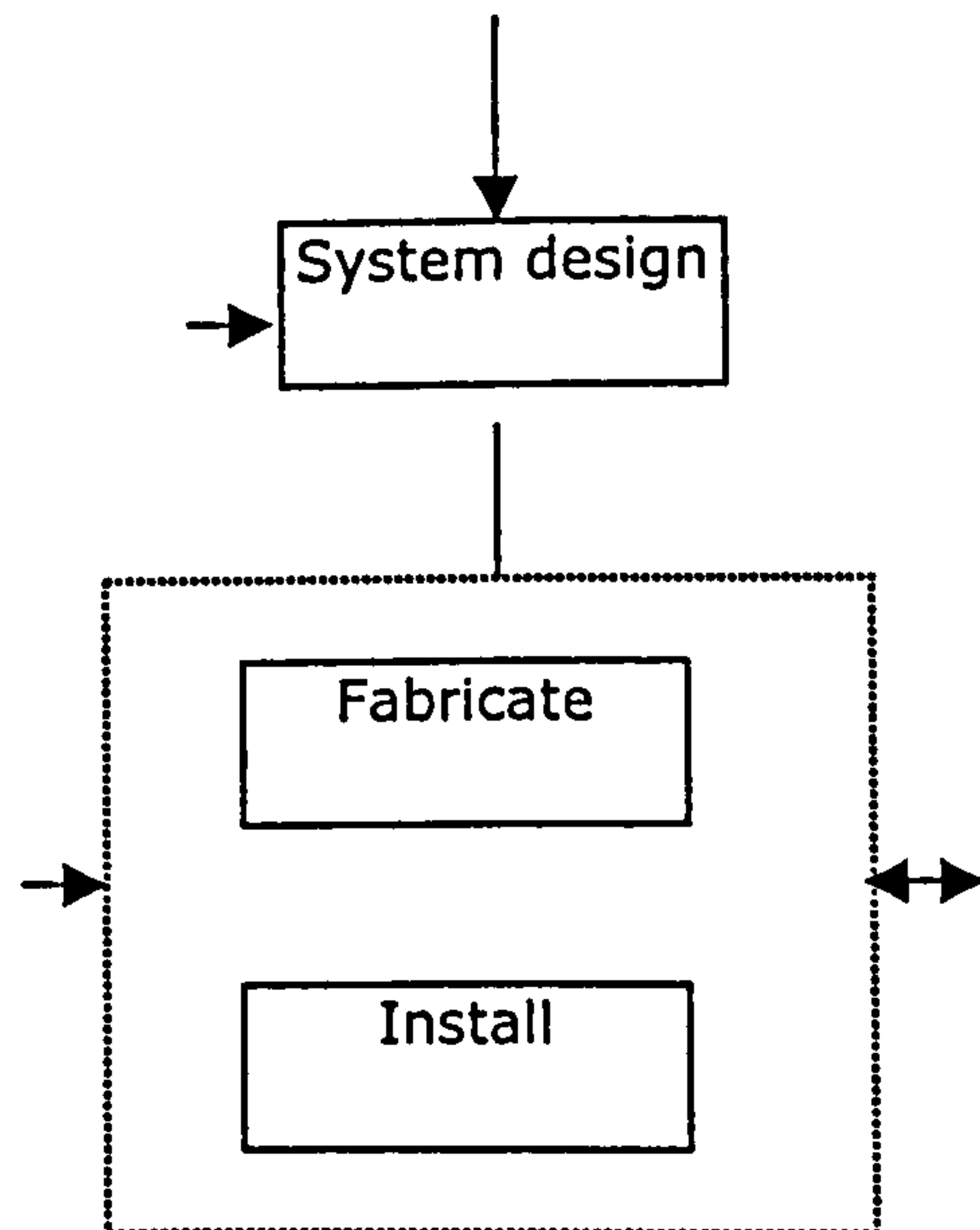
a) Fully integrated specialist cladding contractor



b) Integrated design/manufacture with sub-contract installation



c) Separate design/manufacture/install



d) Integrated manufacture/install by system fabricator

Figure 3.10: 4 types of specialist cladding contractor (Ledbetter, 1997)

- **Fully integrated specialist cladding contractor (FISCC)**

This is a company that manages the whole process including the extrusion of the aluminium and the finishing of the cladding sections. The only outside element will be the supply chain of raw materials such as glass and gasket components. The company will be responsible for all warranties and installation. There are few contractors who are capable of working this way.

- **Integrated design/manufacture with sub-contract installation**

This is a company that manages the design of the system and fabrication of the sections and like the FISCC is dependant on an outside materials supply chain. The installation will be sublet to an independent subcontractor, who may be responsible for the supply of fixings. Nevertheless the design/fabricator retains the contractual responsibility for warranties, including installation. The subcontractor will have a separate contract with the design/ fabrication company.

- **Separate design/manufacture/install**

In this scenario designers design a system, extrude the raw aluminium to stock lengths then finish them. The fabricator purchases the extruded lengths and fabricates them to the required size for a particular project. Subcontractors then install them on site. The supply of the aluminium and gasket components is the same as the FISCC but the glass is supplied to the fabricator. Before tender, the design team or the client may approach the systems designer for technical input on their systems. This information will be very "broad brush" until the system is specified.

- **Integrated manufacture/install by system fabricator**

This is virtually the same as the separate system except the fabricator will install the system without subletting. The fabricator is still contractually bound for the warranties and installation. This method gives the specialist contractor the greatest control for programming the project design and installation other than the fully integrated company (Pavitt and Gibb, 1999).

Once the system has been specified the major contractor has two options; either to go out to tender to their known fabricators or to a list of fabricators provided by the specified systems designer. The latter is the most common method. The fabricator will be contractually bound for warranties and installation to the major contractor. The fabricator and the systems designer will have a separate

contract between them for the supply of the extruded aluminium and the actual system design. Also the fabricator and installer will have a contract between them for the installed work.

3.8 Workpackages

Dreger (1992) states a workpackage is the smallest project measurable unit separate from others. It is a group of related operations of a relatively short period of time, assigned to a single organisation. The workpackage provides a very specific, definable output, often carried out by specialist subcontractors. It includes descriptions of;

- What is to be done
- How it will be measured
- When it is to be started and finished
- Cost
- Specific targets to reach, or deliverables to provide, at specific milestones in a project

It is very common in management procurement systems to use workpackages. Furthermore it is often common practice to break up the workpackages into smaller specialised packages. Therefore all workpackages that are subcontracted must be clearly identified (Harris and McCaffer, 2001).

However the division of work into specific workpackages sometimes has a detrimental effect on the design and construct process. When the project design is underway consideration should be made for subcontracting and workpackage contents. Tatum (1987) stated "the packaging and availability of design may not allow desirable work packaging or construction sequences". If the workpackages are inadequately coordinated then delays may occur. O'Connor *et al* (1987) agreed stating "poor works packaging can result in an excessive amount of interdependency amongst workpackages, thus increasing the likelihood of delays".

Furthermore, from a contractor's viewpoint; the increasing proportion of work on site is now undertaken by specialists as workpackages, the problem of getting the project constructed has increased in complexity because of the added interface issue between all the workpackages (Gray and Flanagan, 1989).

3.8.1 Cladding workpackages

Some forms of cladding are similar and may be the responsibility of a single specialist contractor. However most are widely dissimilar, such as the installation of windows into profiled sheeting, and require separate specialists to detail and install the elements on each side of the interface. Also entrance doors are often installed by a different contractor from the surrounding cladding.

Therefore there is a need to package the work and in doing so it is necessary to identify who is responsible for the cladding interfaces at the contractual boundaries. Some clients and main contractors have sought to appoint a package manager responsible for co-ordinating the work of a number of specialist contractors as shown (figure 3.11) using the construction management route of procurement (Ledbetter⁴).

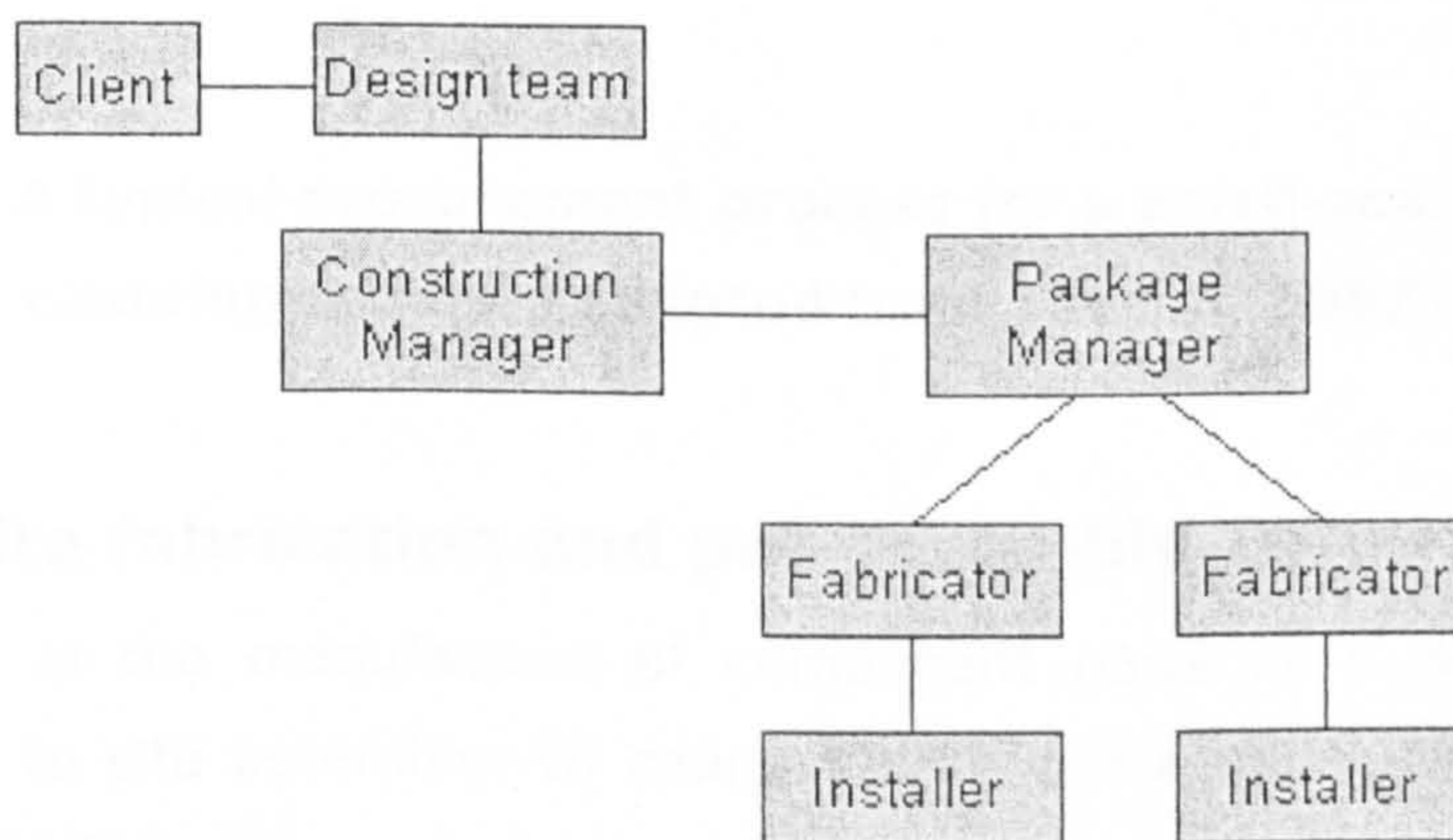


Figure 3.11: Example of cladding workpackaging

To be able to understand how the specialist contractor affects the cladding process there must be an understanding of their procurement role within the industry. Figure 3.12 shows how the specialist contractor may be involved in the sequence of a particular cladding system; in this case it is the production of a curtain wall system.

⁴ Unpublished PowerPoint presentation- Stephen Ledbetter, CWCT, Bath.

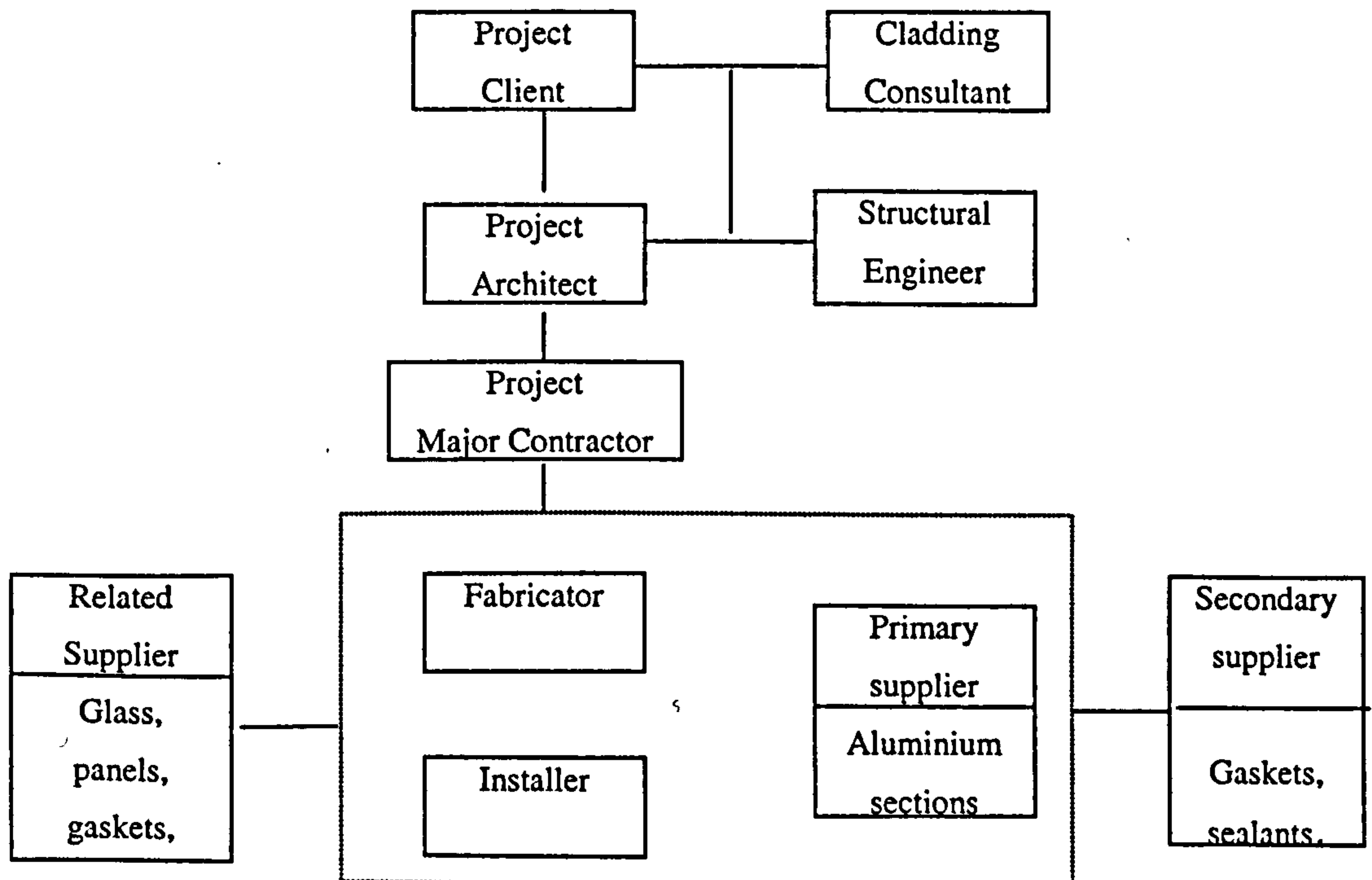


Figure 3.12: A typical procurement process for a small-scale curtain wall cladding system (Adapted from Layzell, 1997).

3.9 Off site fabrication and pre-assembly

Prefabrication is the manufacture of component parts of a building and its services prior to site assembly. Of course this is not a new concept. Ductwork manufacturers have been prefabricating their products for years and pre-packaged plantrooms are a common fixture on roofs in UK buildings (Smith, 1999).

Off site fabrication and pre-assembly are part of the broad spectrum of innovative contemporary techniques available to clients, developers and construction companies seeking greater cost-effectiveness in construction (Gibb, 1999). In addition Thomas and Sanvido (2000) state that "*component material management is recognised as an important component of effective project management.*"

The benefit of off-site fabrication is taking the construction site off the site. Gibb (1999) further stated that "*even the best-organised construction sites are fraught with problems and challenges both for managers of the construction*

process and the workers who do the actual work". Tatum (1986) emphasised that off-site fabrication increases quality, time and safety.

Both the Egan and Latham reports (sections 3.12.2) proposed a series of actions for improved productivity on construction sites; these include the use of off-site fabrication. Furthermore, Neale et al (1993) stated that "the benefits of effective use of off-site fabrication are;

- A better working environment in the factory
- Better works methods
- Access to work made easier
- Repetitive work planned with more certainty
- Semi-skilled operatives can be trained for a limited number of skilled tasks
- Reduced operative movement between tasks and at breaks
- Familiarity with materials and components
- More efficient sequencing of work by operatives
- Working methods can be analysed in detail to improve techniques
- Less damage by other trades
- More efficient use of site crange
- Easier to introduce specialist tools and techniques

However many differing terms have been used to describe pre-assembly and this was identified by CIRIA, (2000). Therefore definitions were developed to distinguish the categories of pre-assembly. Gibb (2001) produced the following definitions from close evaluation of contemporary applications;

- *Component manufacture and sub-assembly*
Sub assemblies e.g. door furniture and light fittings
- *Non—volumetric pre-assembly*
Assembled in a factory, which may include several sub-assemblies e.g. wall panels and structural sections
- *Volumetric pre-assembly*
Also factory assembled, but may include usable space e.g. toilet pods or plant room units
- *Modular building*
Similar to volumetric, but in this case the units form the building.

Thomas and Sanvido (2000) have identified, using three case studies, that unless correctly managed the subcontractor fabricator interface can have a significant negative effect on labour productivity of the subcontractor. Late vendor deliveries, fabrication or construction errors, and out of sequence deliveries plagued each of the three projects. This identifies that off site fabrication and pre-assembly has to be properly managed or the benefits can be reduced.

3.10 Managing procurement systems within construction

To be able to manage the interfaces within the procurement of the cladding process then there must be an understanding of the systems for management of the design and construction of building projects open to the client and the eventual contractor. These can be categorised into four distinct areas; separated and co-operative, partnering, management and integrated, (Masterman, 1992). Figure 3.13 shows the procurement option "tree" currently available.

This section introduces the four main procurement systems:

- Separate and cooperative
- Integrated
- Management
- Partnering

It has been suggested that there are four essential differences between the procurement methods, which are based on;

- The arrangements for assessing the cost of the building and identifying the principal contractor to be used
- The roles and the relationships of the specialist contractor used and their role within the design process
- The process structure adopted, involving the overlap of design and construction, the use of multiple prime contracts and the implementation of these.
- Details of and conditions of contract provisions for extensions of time for inclement weather, etc (Ireland, 1985).

Therefore the client or project coordinator has to consider these differences before deciding on the procurement option for the project.

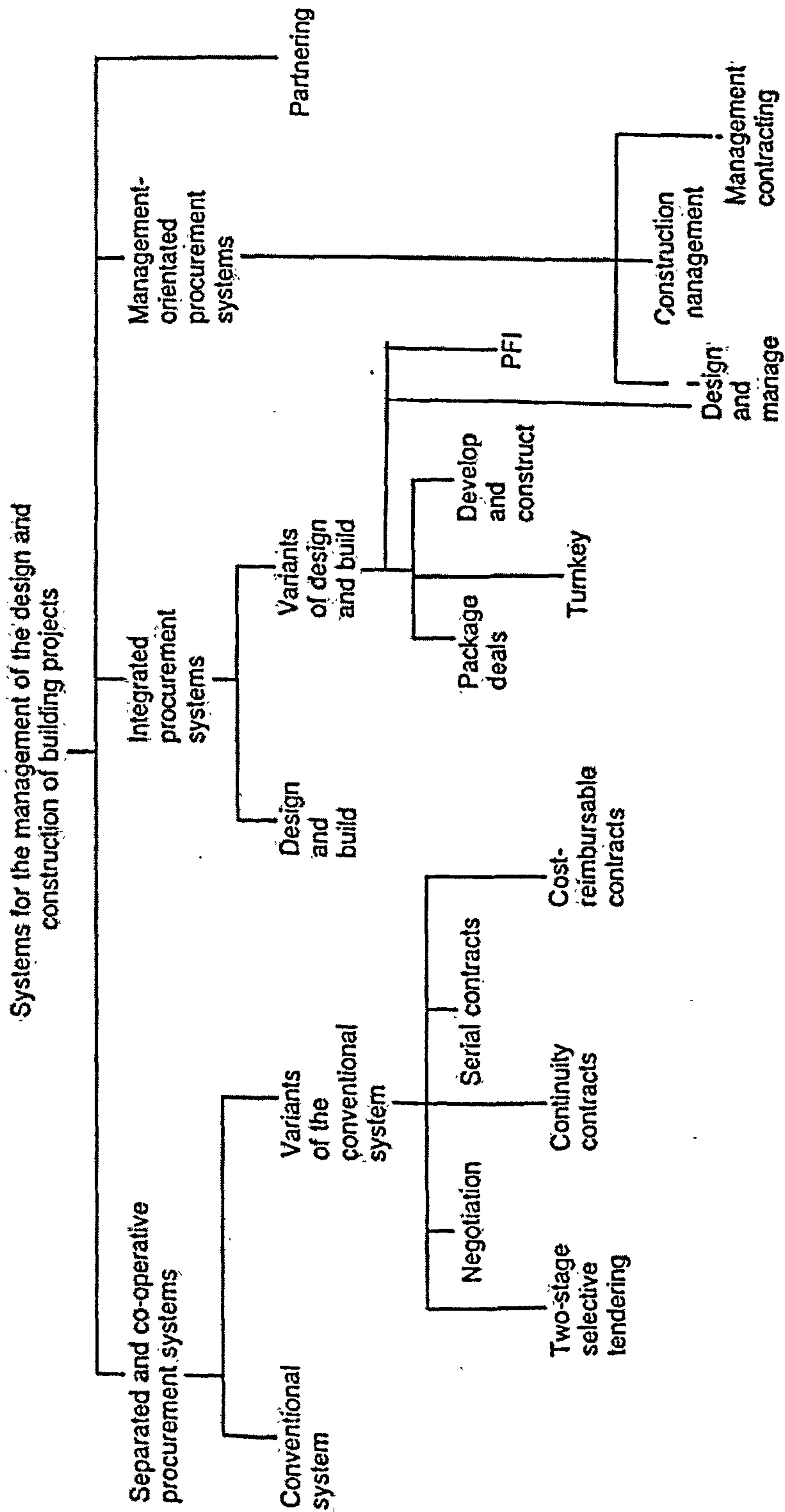


Figure 3.13: Procurement Option Tree (adapted from Perry, 1985)

3.10.1 Separated and Co-operative

This method of procurement is often referred to in the industry as the traditional method of procurement. Masterman (1992) maintains this definition dates back to the late 1700's when clients traditionally employed craftsmen, on an individual basis, under the supervision of a master mason, or surveyor and rarely an architect.

The traditional method can be interpreted as having two definite sections; design and construction.

Apart from the separated design and construction this method of procurement has four basic characteristics;

- 1 The project is procured in a sequential order
- 2 The design of the project is completed or virtually completed before construction on site is commenced.
- 3 The management of the project is divided between the client's consultants and the main contractor and there is little scope for involvement between the two party's activities.
- 4 Normally the client pays the consultants on a fee and expenses basis, whereas the contractor is paid for work completed on a measure or predominately lump sum premise.

The majority of clients have used the traditional method for the last 150 years (Masterman, 1992).

3.10.2 Integrated

This method of procurement incorporates the process of design and construction undertaken by one contractor. Therefore the responsibility of the activity is undertaken by one organisation, the building contractor. Similar to the separated and co-operative method in which traditional is referred to as the method of procurement, the integrated technique is misconstrued in definition, and the majority of the industry considers the integrated system as design and build.

The definition of integrated procurement contains three fundamental elements these are; the responsibility for the design and construction lies with one organisation, reimbursement is generally by means of a fixed, lump sum price and the project is designed and built specifically to the client's needs and specifications (Masterman, 1992).

Within the integrated procurement system the process can be broken down into sections. The NEDO document *Thinking about buildings* (1985) identified three categories;

Direct; where a contractor/designer is appointed after some judgement but without other competition from other parties.

Competitive; where the conceptual designs prepared by consultants to the client allow several contractors to offer designs and prices for the completed project.

Develop and construct; where the client's design team completes the concept design before asking contractors to develop the design in competitive tender, either with their own designers or employing the client's design team to complete the full design (Potts, 1995).

3.10.3 PFI; Private finance initiative

Private financing arrangements are fairly common in the construction industry, for example work for foreign governments where financiers such as world banks in conjunction with developers commonly undertake DBFO or BOOT projects. The major difference in the UK PFI lies in the sharing of risk (Harris and McCaffer, 2001).

The UK government launched the PFI scheme in 1992; its purpose was to change the way public sector capital projects are procured. Under this scheme the private sector (construction company) takes on the risk of finance, design, construction and facilities management of a project, in return the construction company receives payment linked to the deliverability and the effectiveness of the project. Figure 3.14 shows the typical asset procurement for PFI (Tiffin, 1998).

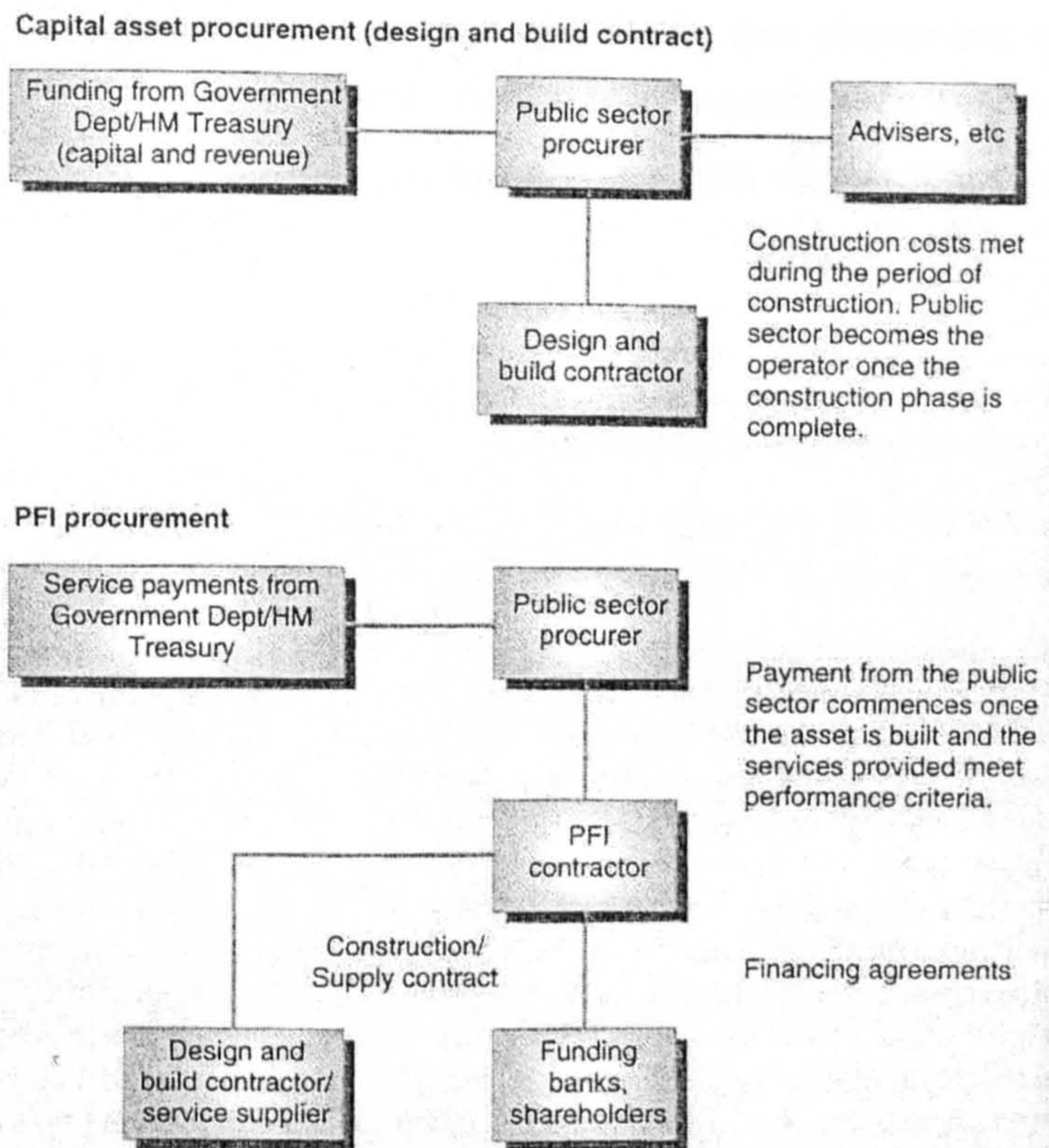


Figure 3.14: Typical asset procurement for PFI (Tiffin, 1998)

3.10.4 Management

Throughout the 1970's and 1980's there was a substantial increase in management oriented procurement methods in the UK, mainly as a result of clients requiring earlier completion and shorter construction times on their projects (Masterman, 1992). Carter (1973) stated that the introduction of management based procurement systems was due to three factors;

- 1 The diversity, complexity and standardisation of building techniques
- 2 The growing prominence of the subcontractor within construction
- 3 The growth in the size of projects, demands for shorter construction times and cost targets and for more and greater unified management within the construction process.

Under management procurement the contractor provides the client with a consultant service based upon a fee for co-ordinating the construction, managing and overseeing the project (Potts, 1995). The contractor places special emphasis on the integration of the management of both the design and construction.

There are three forms of management procurement; these are management contracting, construction management and design and manage (which possibly is

a hybrid of design and build), the first two being the prominent methods. The main difference in the three is the contractual relationship that is undertaken between the client, management contractor and the construction work package contractors.

3.10.5 Partnering

Partnering is a relatively new method of procurement but is being widely used by best practice clients in the public sector in a number of countries around the world mainly in Canada, the USA and Australia (ECI, 1997). With this approach many major clients such as Shell Oil, Proctor and Gamble and the U.S. government are adopting such arrangements. The arrangement aims at the advancement of trust and co-operation between parties rather than an adversarial relationship (Potts, 1995).

The Reading Construction Forum, (1995) defined partnering as *"a managerial approach used by two or more organisations to achieve specific business objectives by maximising the effectiveness of each participant's resources. The approach is based on mutual objectives, an agreed method of problem resolution and an active search for continuous measurable improvement."*

Partnering has come to the fore in the UK construction industry in recent years. The whole project team forms an alliance with the client with one common goal of procuring a project as efficiently and cost effective as possible. Partnering within the manufacturing sector has been defined as "a commitment by customers / suppliers regardless of size, to a long term relationship based on clear mutually agreed objectives to strive for world class capability and competitiveness (Partnership Sourcing, 1993). Evans et al (1997) identified and adapted research in the USA as follows:

- Information sharing and monitoring to support long-termism
- Co-ordination at multiple levels in the channel to achieve benefits/ synergies
- Joint planning to support long term co-ordination
- Compatible corporate philosophies important for long term co-ordination
- A product champion to lead the change
- Fair and realistic sharing of risks and rewards
- Speed of resource and information flow

They stated that these, in essence, are difficult interface management issues and would be more successful if a long term partnering agreement was implemented.

3.10.5.1 Forms of Partnering

There are a few different methods for co-operative working, however partnering can be classified as the following;

- **Strategic Alliances or Term Partnering**

These arrangements are a period of time rather than a single one off project.

- **Protect Alliances or Project-specific Partnering**

These arrangements are for the period of a sole project and the contract may be awarded competitively.

Both methods of partnering are extensively practised in the private sector. A variation of the latter is more suited to the public sector and is described as follows;

- **Post Award Project-specific Partnering**

The contract is subject to the normal competitive process, then, as suggested in the name, the partnering arrangement is entered into after the contract has been awarded. However the intent to partner must be prominent in the tender process (ECI 1997).

Successful partnering depends upon the relationship between the client and the contractor (Mosely et al, 1991). If parties become suspicious of the motives and the actions of others, the success of the project may be compromised (Drexler, 1999).

3.10.6 Procurement Summary

The method of choosing the main contractor to undertake the project must be determined at some time by the client, as this may dictate the manner in which the concept and detailed design is developed. For example with the traditional method the design team will develop the design whereas with design and build the client's design team may only prepare a brief and the design itself will be completed by the main contractor. Therefore the acceptance and decision of the procurement route chosen by the client must be decided as soon as possible in the process.

Each of the different procurement options will offer the client a different reason for that particular option, these are generally time, cost and quality, shown in Figure 3.15 is the 'procurement triangle' (Aqua, 1992).

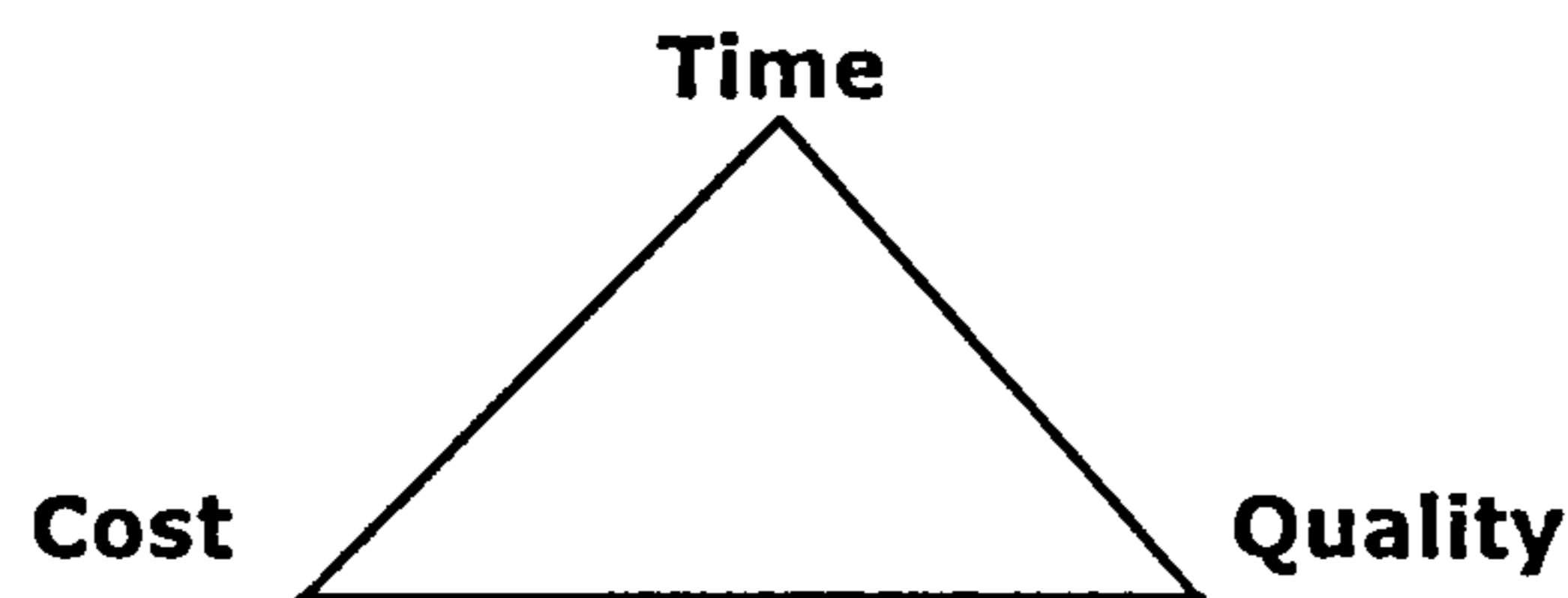


Figure 3.15: Procurement triangle

Therefore these three elements may be held in a particular balance as one of the elements may take precedence over the other two. However changing any one of the three elements will have an effect on the other two (Aqua, 1992). With this in mind the client will have to evaluate which element is most important. Furthermore the triangle is used for many comparisons not just procurement.

However, throughout the data collection period the issue of procurement route and its affect on interface management was constantly raised. Therefore the author validated the procurement effect in the questionnaire and the results are shown in chapter 5.

3.11 Management and process changes within construction

Throughout recent years there has been a need for change in construction not just in ways of building projects but the methods by which the projects have been developed. Government white papers and private sector development are addressing this. The researcher has reviewed some of the recent developments in this particular field.

3.11.1 Constructing the Team: The Latham Report

The Latham report was a government document intended to review and advise the industry on actions needed through out the industry to enable change. The final report *"makes recommendations to tackle the problems revealed in the consultation process. The review has been about helping clients to obtain the high quality projects to which they aspire. That requires better performance, but with fairness to all involved, above all it needs teamwork"* (Latham, 1994).

The Latham report has provoked a lot of interest throughout the construction industry following its release in 1994. The following key points have been established;

- The clients should take a greater lead in the project and government run projects should act as best practice to the industry
- There should be a better process for briefing clients
- Checklists should be developed within the design development and responsibilities process
- Failure of material flow to the site or design changes can lead to unmanageable situations. Designs should be frozen and fully developed before manufacture and site construction.
- Contractual arrangements between parties need substantial change
- There must be integration of the works of designers and specialists (Latham, 1994).

The report highlighted the need for 'specialist contractor' involvement in the design, but as the report commented often there is confusion on the term specialist. Cladding, and in particular curtain walling, was stated in the report as being a specialist trade. It commented further that curtain walling is a product orientated industry where the design input is responding to a performance specification, and where the skills of the specialist are in the quality, compliance, value for money and delivery of the product. This statement alone highlights the need for co-ordinated interface management within the industry.

3.11.2 Rethinking construction: The Egan report

Following the Latham report the government released the "Egan" report in 1998. John Prescott, the deputy Prime Minister formed the construction task force, which was chaired by Sir John Egan. The aim of the task force was to improve the quality and efficiency within the UK construction industry. The following key points have been extracted;

- There is a deep concern that the UK construction industry is under achieving, with low profit for contractors.
- Clients are dissatisfied with the industry's overall performance.
- The construction industry could improve quality and efficiency by using other industries techniques'
- There should be 5 drivers of change through the industry

- Committed leadership
- A focus on the customer
- Integrated processes and teams
- A quality driven agenda
- A commitment to people
- An end to competitive tendering and replace it with long term relationships
- There must be an improvement in management and supervisory skills

The Latham and Egan reports clearly indicate that there is a need for improvements in the construction industry. For greater efficiency to be achieved better processes have to be developed and many companies and universities are developing such processes. BAA (British airport authority's) have produced their own process map for generic projects, also with the aid of BAA Salford and Loughborough Universities are in the process of expanding their Process Protocol map.

3.12 Process Mapping

Process mapping and benchmarking are becoming widely used tools as methods for improved management, and their use in the construction industry is growing rapidly (Winch, 2001). Process maps can be broadly separated into two sections; true maps of what actually happens in the project set up and protocols in which processes are shown of what ought to happen (Winch, 1994).

3.12.1 RIBA Plan of works

The Royal Institute of British Architects introduced the RIBA plan of works to assist design teams working on large construction projects. It is a recognised procedural guide for complex construction projects in the UK. It is particularly relevant and useful when compiling a brief (Salisbury, 1998).

Figure 3.16 shows an overview of the RIBA plan of works, Salisbury (1998) states this displays the normal method of building up a brief through the various stages of a building project. It could be said that this method is too sequential, in particular with some of the procurement options used at present. Even the RIBA says the plan of works is fundamentally a work planning and co-ordinating tool that must be adapted to the particular circumstances and must never become a requirement imposing certain procedures (Salisbury, 1998).

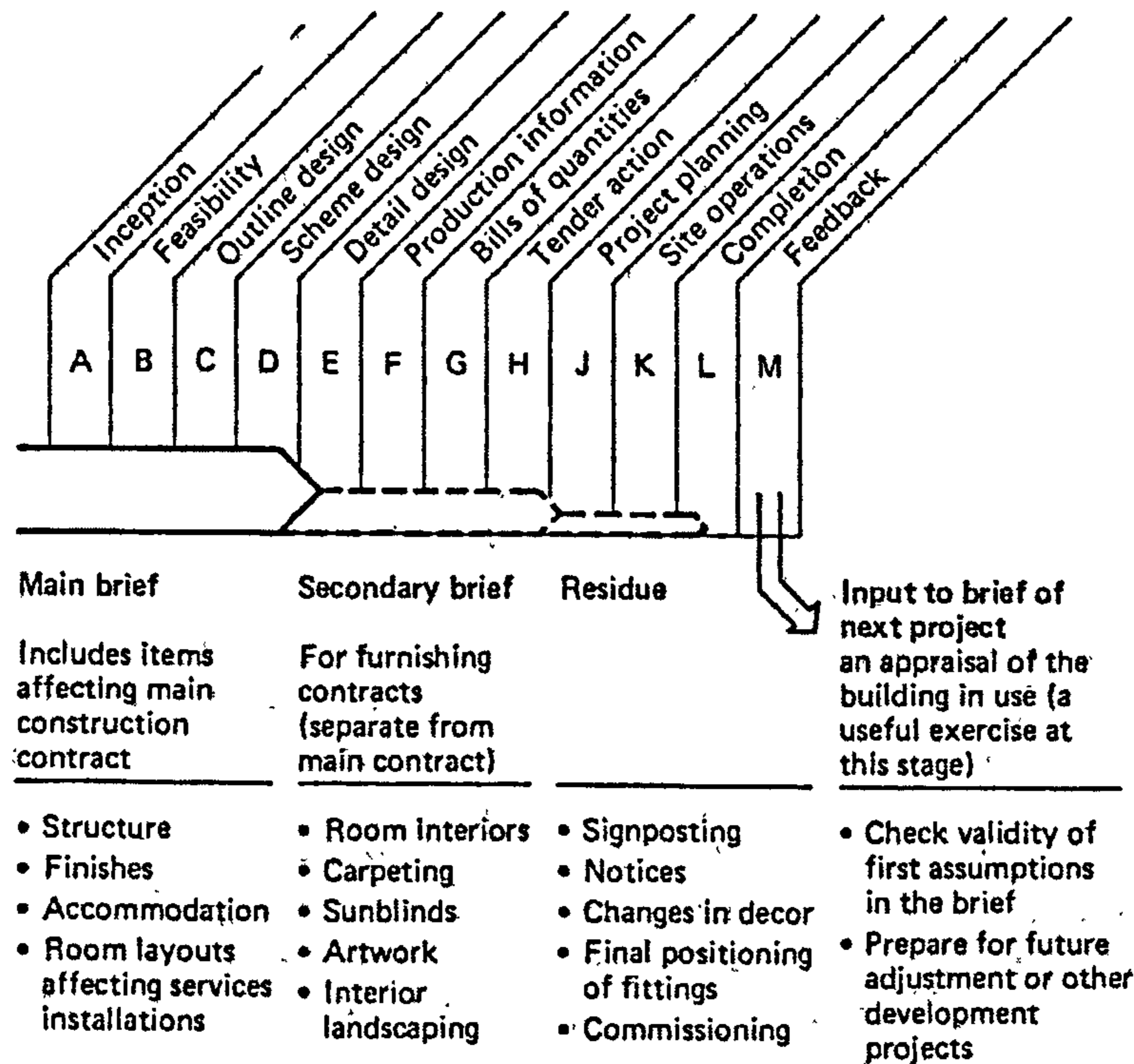


Figure 3.16: Overview of the RIBA Plan of Works (original)

3.12.2 The architects plan of work

The outline plan of works has become recognised throughout the construction industry. It was updated and approved by RIBA council in 1998 and provides the framework for construction activities.

The new plan of works is a substantial reworking of the original document to reflect changes in practices in legislation to include variants for design and build procurement and partnering arrangements (RIBA, 2000).

The document shows the work stages (A-L) for both a fully designed project and contractor's proposal (design and build). Figure 3.17 shows the work stages for the fully designed project. The contractor proposal section has the same work stages except the emphasis is on the contractor design rather than the conventional method of architect's feasibility and concept designs.

RIBA Outline Plan of Work 1998

The Work Stages into which the process of designing building projects, and administering building contracts may be divided. *(Some variations to the Work Stages apply for design and build procurement.)*

FEASIBILITY	<p>A Appraisal Identification of client's requirements and of possible constraints on development. Preparation of studies to enable the client to decide whether to proceed and to select the probable procurement method.</p> <p>B Strategic Briefing Preparation of Strategic Brief by or on behalf of the client confirming key requirements and constraints. Identification of procedures, organisational structure and range of consultants and others to be engaged for the project.</p>
PRE-CONSTRUCTION PERIOD	<p>C Outline Proposals Commence development of Strategic Brief into full Project Brief. Preparation of Outline Proposals and estimate of cost. Review of procurement route.</p> <p>D Detailed Proposals Complete development of the Project Brief. Preparation of Detailed Proposals. Application for full Development Control approval.</p> <p>E Final Proposals Preparation of Final Proposals for the project sufficient for co-ordination of all components and elements of the project.</p> <p>F Production Information F1 Preparation of production information in sufficient detail to enable a tender or tenders to be obtained. Application for statutory approvals. F2 Preparation of further production information required under the building contract.</p> <p>G Tender Documentation Preparation and collation of tender documentation in sufficient detail to enable a tender or tenders to be obtained for the construction of the project.</p> <p>H Tender Action Identification and evaluation of potential contractors and/or specialists for the construction of the project. Obtaining and appraising tenders and submission of recommendations to the client.</p>
CONSTRUCTION PERIOD	<p>J Mobilisation Letting the building contract, appointing the contractor. Issuing of production information to the contractor. Arranging site hand-over to the contractor.</p> <p>K Construction to Practical Completion Administration of the building contract up to and including practical completion. Provision to the contractor of further Information as and when reasonably required</p> <p>L After Practical Completion Administration of the building contract after practical completion. Making final inspections and settling the final account.</p>

Figure 3.17: The work stages for the fully designed project

3.12.3 The Generic Design and Construction Process (Process Protocol)

The Process Protocol was developed at the University of Salford (Sheath et al 1996). Recognising that current protocols, such as the RIBA plan of works, are predominantly driven by designers and the other deficiencies of current practices in the construction industry (Kagioglou 2000). Kagioglou et al (1998) adopted six basic principles for their Process Protocol;

- A whole project view
- Progressive design fixity
- A consistent process
- Stakeholder involvement/teamwork
- Co-ordination
- Feedback

The methodology behind the Process Protocol is to provide the basics allowing the range of organisations involved in a construction project to work together seamlessly. It also provides the footing for research and process development in construction. The Process Protocol aims to provide a framework for any generic construction project. The Process Protocol model consists of the following three major elements (Wu, 2001):

- **Process;** A set of activities undertaken by multifunctional team to produce information for other processes or deliverables. For example, 'establish need for project'.
 - **Deliverable;** As output of the process, deliverables represent documented project and process information, such as Stakeholder List, Statement of need, project brief, etc.
 - **Phases;** Essentially the model breaks down the design and construction process into 10 discrete stages, the 10 stages are identified within four major headings for the construction process (Cooper et al, 1998). Figure 3.18 shows the Process Protocol map.
- Pre-project
 - Pre-construction
 - Construction
 - Post-construction

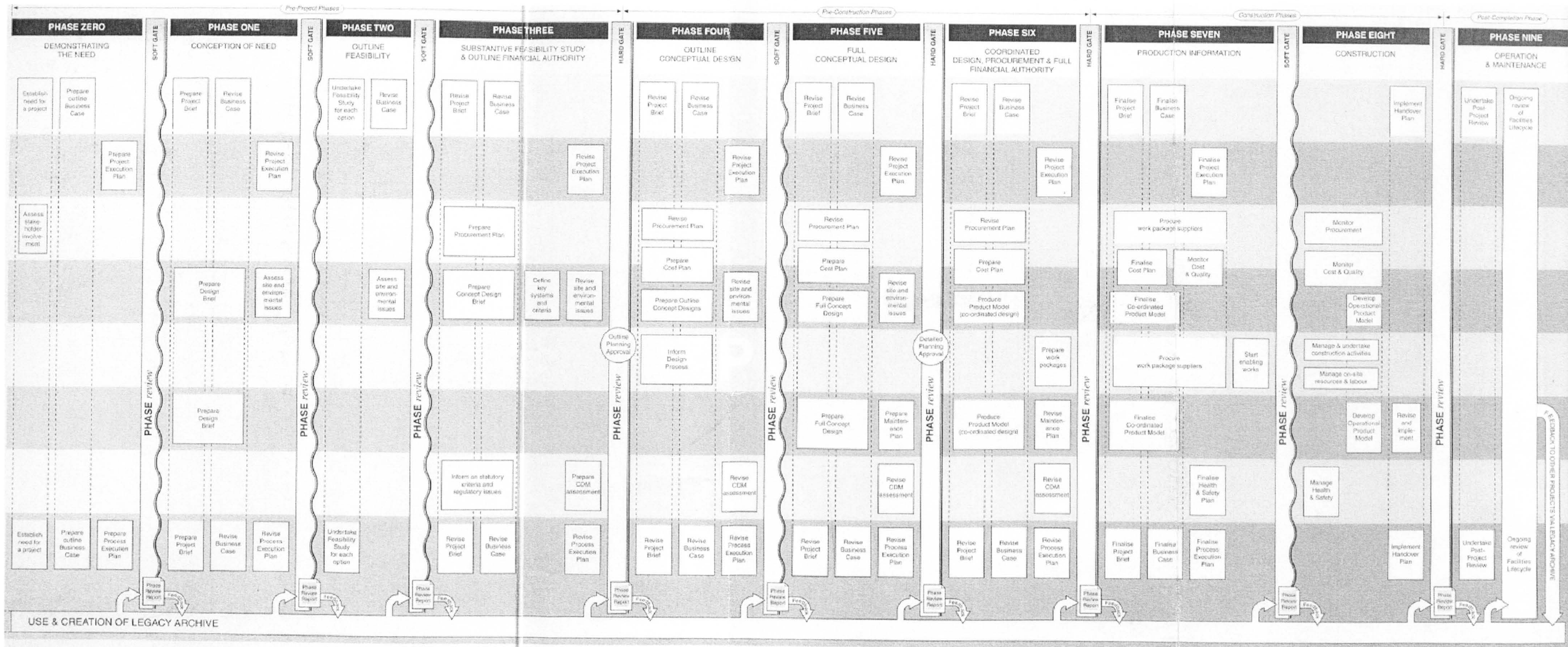


Figure 3.18: Process Protocol Map

The Process Protocol is based upon a number of key principles that have been taken from the manufacturing industry, which has a proven track record in recent years, which is one of the guidelines extracted from the Egan report. The process is managed by using stage gates (hard and soft) between the stages. The stage gates are managed by using multifunctional teams at each phase.

The stage gate approach is found in the manufacturing processes (Cooper, 1994). The idea behind the stage gates is they should be used as "walls" that need to be crossed in a project but are flexible enough without compromising the success of the project. The gates can be either hard or soft; the soft gates show the flexibility within the process (Cooper *et al*, 1998).

Soft gates provide phase reviews and illustrate the flexibility of the process whereby the activities that are not finished in time are noted and their significance to the project assessed. The project can continue enabling concurrent activities if required.

Hard gates illustrate the need for completing all the activities described by the process protocol before the phase review meeting.

3.13 Supply Chain Management

Another managerial process that has received attention from the construction industry in recent years is that of supply chain management (SCM), although the concept has been around for a long time in the manufacturing industry. Indeed, Forester (1961) referred to supply pipelines in much the same way that supply chains are referred to in current management philosophies.

However, it appears there is disparity on a definition of SCM. Fernie *et al* (1999) found that interpretations of SCM are based upon the contexts and purposes of the various exponents whether professional, industrial or academic. Furthermore, is SCM a management tool or technique or is it a label that encompasses a range of techniques and tools.

Stevens (1989) states the objectives of SCM as "*the supply chain is to synchronise the requirements of the customer with the flow of material from suppliers in order to affect a balance between what are often seen as conflicting goals of high customer service, low inventory investment and low unit cost.*"

However, an approach that best describes SCM e.g. from raw material to final use (Kochan, 1996) is demonstrated by Metz (1998) who describes SCM multi stages as replacements for single stage supply chains (figure 3. 19).

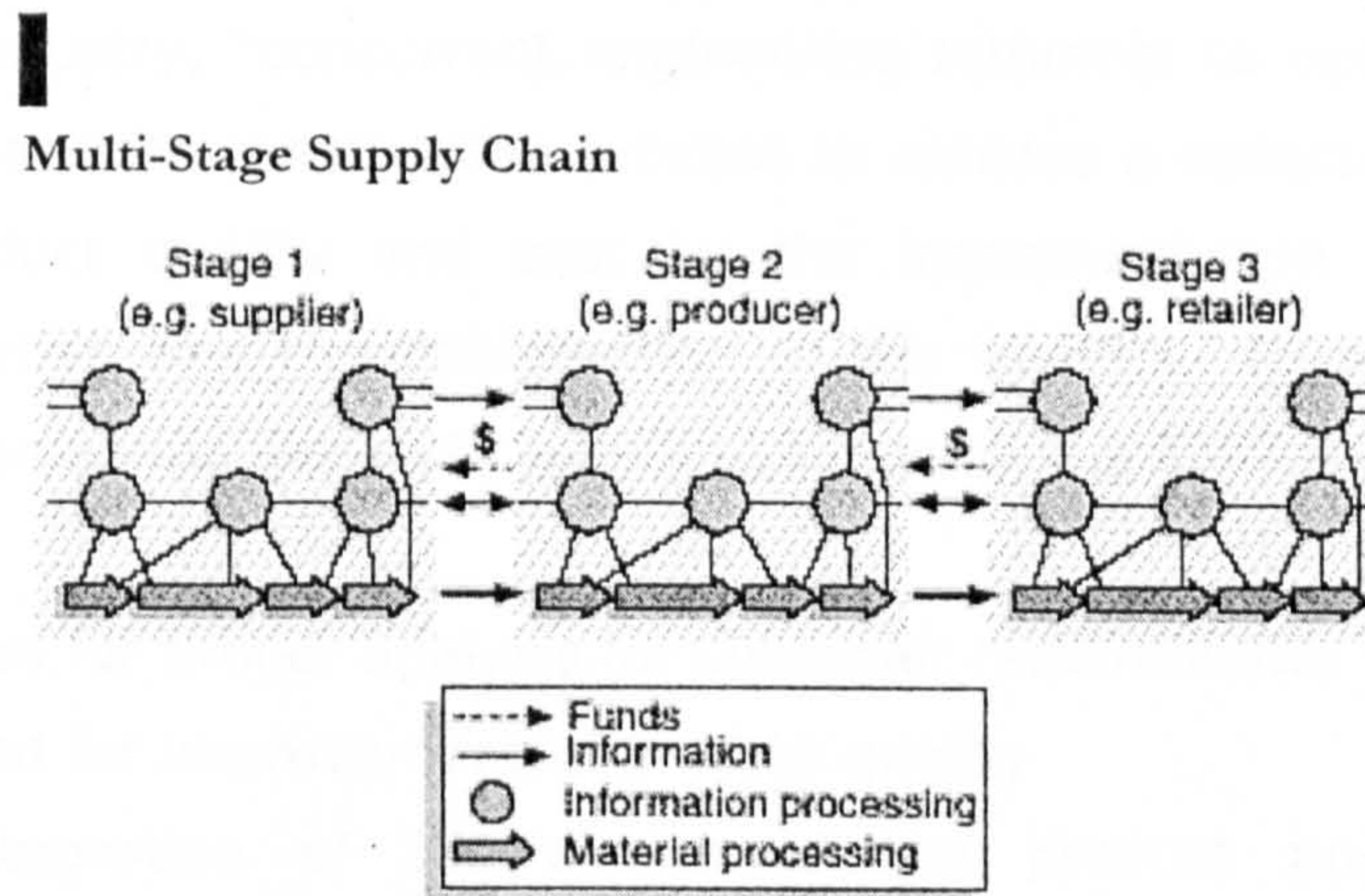


Figure 3.19: Multi stage supply chain (Metz, 1998)

The single stage supply chains can be used to present an organisation as a supply chain within itself. Therefore, it can be considered that the supply chain issues must be considered as both inter-organisational as well as intra-organisational (Fernie *et al* , 1999).

Nicolini *et al* (2000) stated the issues of interfaces and interdependence are exacerbated by the traditional method with its rigid approach between parties (client and principal contractor, designers and builders, contractors and suppliers) culminating in competitive procurement and commercial practices within the industries. Furthermore the limits of numerous activities at one time need to be reconsidered in order to prevent interface problems. He further stated the need for integrating the project at sub levels illustrating Lahdenpera's (1995) model "system unit procurement approach".

3.14 Concurrent engineering

Another approach that has identified the need for greater integration within the construction team from client to specialist suppliers is that of concurrent engineering. It focuses in on the use of information technology and various ideas and concepts taken from the manufacturing industry to integrate the myriad of aspects of the construction process (Anumba, 1995).

Concurrent engineering has sometimes been labelled simultaneous engineering or parallel engineering. The most popular definition is that of Winner *et al* (1988)

which state that *"it is a systematic approach to the integrated, concurrent design of products and their related processes, including manufacture and support"*.

Furthermore, Evbuomwan and Anumba (1995) stated that, in the context of the construction industry, "concurrent engineering attempts to optimise the design of the project and its construction process to achieve a reduction in lead times, improved product quality and cost by the implementation of integration in design, fabrication and the construction of the works". In addition they said concurrent engineering generally points to the following key issues;

- The need for proper analysis for customer requirements
- The need for improvement in product quality
- The integration of the design of the product and all associated manufacturing and assembly
- The consideration of life cycle issues which affect the product design and ultimately maintenance
- Resolution and management of conflicts in the early design stages
- Paralleling the design process.

Prasad (1995) compares concurrent engineering to sequential procedures; the comparisons are shown in figure 3.20.

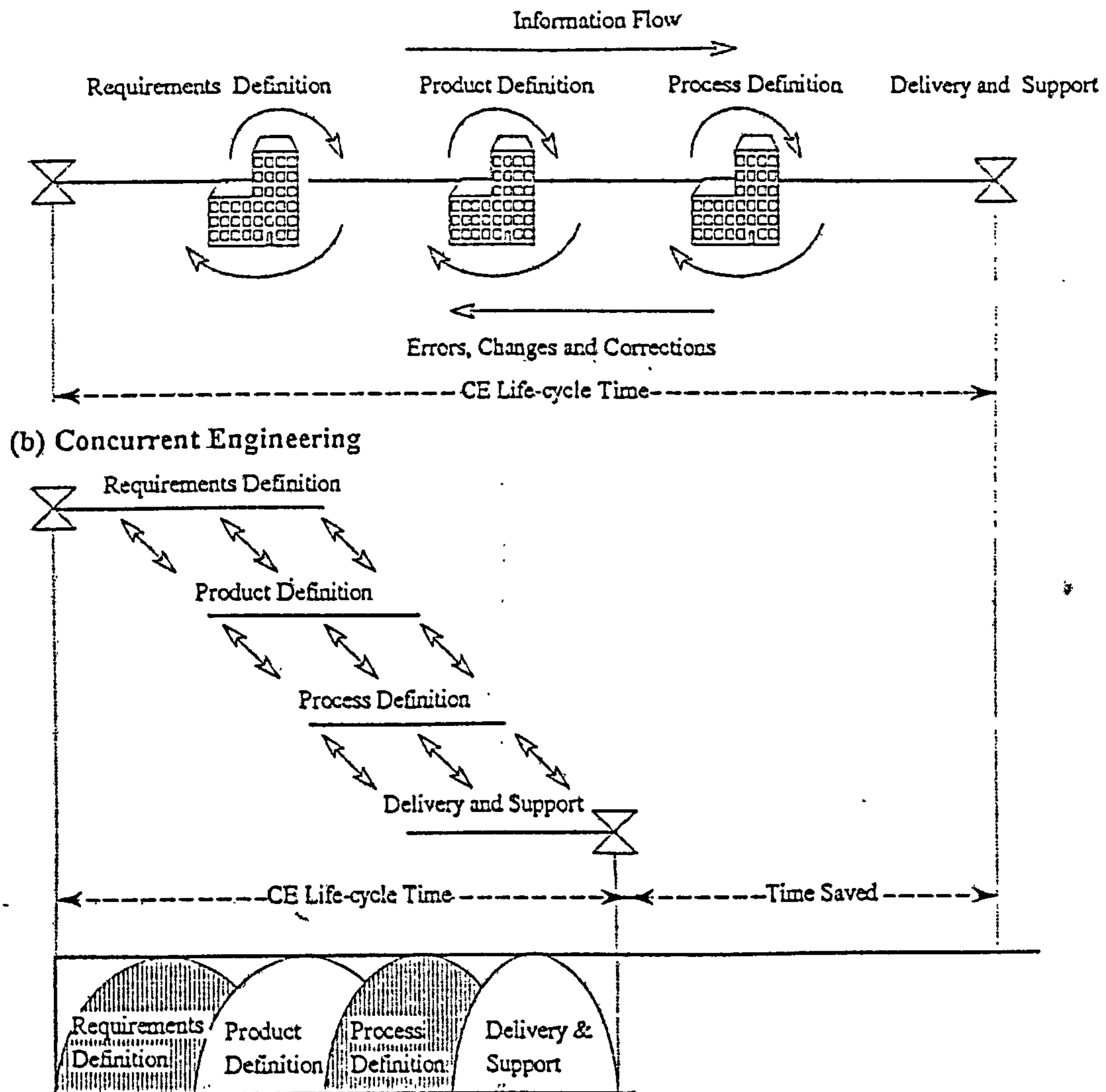


Figure 3.20: Concurrent v Sequential procedures Prasad (1995)

3.15 Interface Management

From the outset this thesis has stressed that there must be an understanding of interfaces and what they are. Gibb (1994) states that interfaces may be classified as the following types:

Physical interfaces, which are physical joints and connections between elements or components. These may be unavoidable or may be brought about by the intricacies of the detailed design.

Management or contractual interfaces, where the parcelling of work into discrete packages to suit logistics or design information availability creates interfaces between works by several specialist contractors.

Organisational interfaces, which are the interactions between the various parties involved in a construction project.

According to Rush (1985), there are five levels of physical interfaces;

- Remote: when two systems are remote from each other, they do not physically touch. (e.g. a curtain wall and an internal sunshade device)
- Touching: This relationship involves contact without a permanent connection between the systems. (e.g. surface conduit mounted on wall)
- Connected: This category applies when two systems are permanently attached directly to each other. (e.g. bed-head trunking mounted on hospital ward wall)
- Meshed: The meshed category refers to systems that interpenetrate and occupy the same space. (e.g. raised floor and under floor A/C system)
- Unified: When two systems are unified, they are no longer distinct. (e.g. masonry chimney and structure)

However the author acknowledges there are remote interfaces but the issue of the interface still has to be managed and potentially the fact that the interface is remote may cause greater problems.

Pavitt and Gibb (2002) have taken the three types further. Figure 3.21 shows how they can become interrelated within the project decision-making process.

Project Decision Making

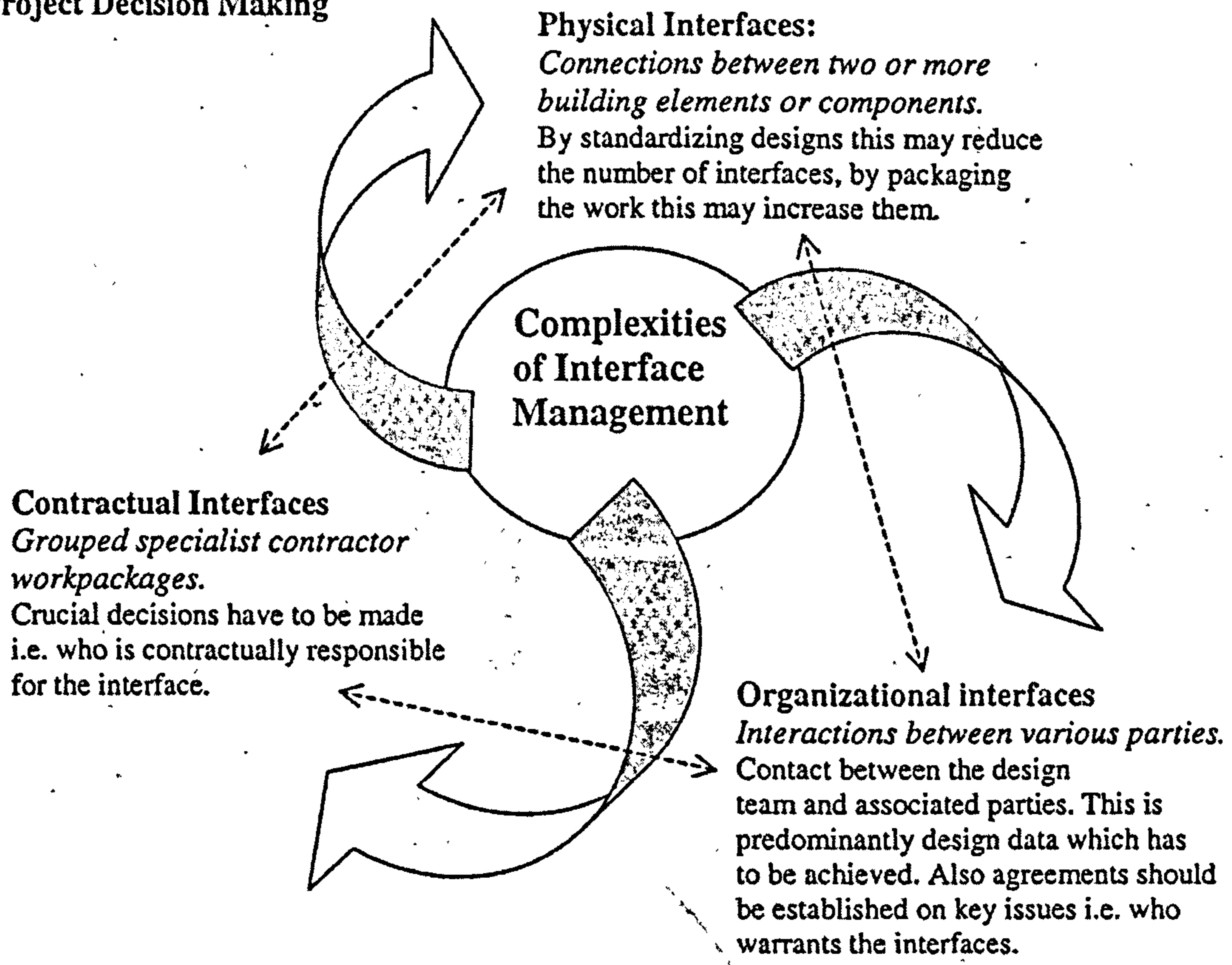


Figure 3.21: The relationships between the three interface types

3.15.1 Cladding interfaces

There are numerous construction interfaces but in the cladding sector there appear to be six main (see chapter 5 data collection) interfaces these are defined as;

- **Frame/cladding interface**

This is possibly the most complex interface. The cladding must be designed so that the frame can accommodate the cladding weight and differing panel sizes. This will vary significantly between cladding types.

- **Cladding/cladding interface**

This is an interface that brings together two dissimilar cladding types, whereupon the junction must be designed so the cladding types can accommodate movement and tolerance of each other and still maintain the integrity of the building envelope.

- **M&E Services/cladding interface**

This is an interface that details M&E works such as flues and louvres that may pass through or be connected to the cladding panels. Figure 3.19 shows a typical M&E /cladding interface.

- **Internals/ cladding interface**

This is an important interface, which concerns the internal design layout, especially the positioning of internal walls. It is possible that the cladding brackets will protrude into the building thus imposing a design restriction on the internal walls, floors or ceilings. Furthermore, the level of raised floors and suspended ceilings will impact on the cladding layout and visa versa.

- **Roof/cladding interface**

This is one of hardest interfaces to design and manage. This is because the interface involves more than two elements; frame, cladding and roof. Site management and programming for this is crucial, as the building is often required to be made water-tight as soon as possible. Thus three or four different trades have to work in a confined, organized and controlled sequence.

- **Secondary components/cladding interface**

This is an interface that is sometimes considered late in the process. It deals with the various features that are secured to the cladding, such as sun-shades, cleaning cradles, handrails, signs and flagpoles (Pavitt & Gibb, 1999).

3.15.2 Curtain wall connection to steel frames

One of the most common interfaces, cladding to frame, has been identified by the Steel Construction Institute in "*Curtain wall connections to steel frames*", (1992) which states the operation of fixing wall cladding to multi-storey steel frames is an activity on the critical path of a construction programme. Therefore the cladding connections have to be designed so that they not only have sound structural and physical properties, but also permit efficient and rapid erection. A distinguishing factor of good and successful cladding systems is that much of the preparatory work (lining and levelling) is carried out in advance of the erection, and therefore will not affect the critical path.

Many cladding support systems have used this philosophy successfully in the UK, managing the interfaces between the frame and the cladding. However in recent history there are examples, sometimes in relation to major projects, of needless

programme overruns arising from the cladding installation. These are often attributable to poor detailing of the designs and therefore should be avoidable if consideration of buildability and tolerances are taken at the early stages of design (Ogden, 1992). Ogden's research stated that certain aspects must be considered when designing cladding systems and associated erection procedures and can be divided into three areas;

- **Pre-design;** Zoning areas, recognition of tolerances and co-ordination of the professionals involved with the whole process must be considered
- **Design;** All components within the cladding system should be designed to achieve optimum performance. This should include the fixings, frame and panels to allow for all of the movement associated with cladding
- **Installation;** Effective installation procedures must be considered at concept design stage throughout the development programme.

3.15.3 The importance of interface management

Sundgren (1999) found, during a literature review, benefits from successful product variety creation, one key factor stands out: the importance of key subsystems and interfaces. These key subsystems may constitute a product platform with robust and standardised interfaces from which product variety can be created easily. Although the importance of having a platform with robust interfaces seems apparent, not many studies have investigated and captured its creation.

The above research, though taken from the manufacturing sector further emphasises the lack of interface management literature and highlights the importance of its development.

Gibb (1995) followed up his previous research by concluding several points on the importance of interface management:

- Problems on complex construction projects become concentrated around the interfaces
- Contractual arrangements sometimes exacerbate interface problems - either too many individual contractors or too much unfamiliar work managed by one specialist contractor
- Different trades have different cultures - with different attitudes to tolerances, damage and interface responsibility

- Failure to give adequate consideration to both physical and contractual interface will lead to poor co-ordination on site, contractual conflicts and potential future problems with the works
- A positive, proactive and open attitude to interfaces from all parties should improve constructability and productivity on site

3.15.4 Interface Problems

Al-Hammad (2000) observed that the success of a building project depends upon proper coordination, cooperation and communication between the construction parties. He further added that if interface problems occur amongst the construction parties, these will have an adverse effect on the completion and quality of the projects. In a survey of construction companies he found that there were 19 key interface problems these 19 have been subjectively divided into four general categories: financial, contract and specifications, environmental and other common interface problems, such as poor quality of work and lack of management supervision.

These four categories clearly indicate Gibb's three interface areas especially the organisational and contractual interfaces.

Interfaces between cladding and the six areas (mentioned previously in section 3.13) often cause problems in their production. One example of this is the cladding to services interface where, in many instances services are designed to avoid the cladding (Gibb, 1997). Often this is not possible, a typical interface is shown in figure 3.22 which shows cladding interfacing with pipework.

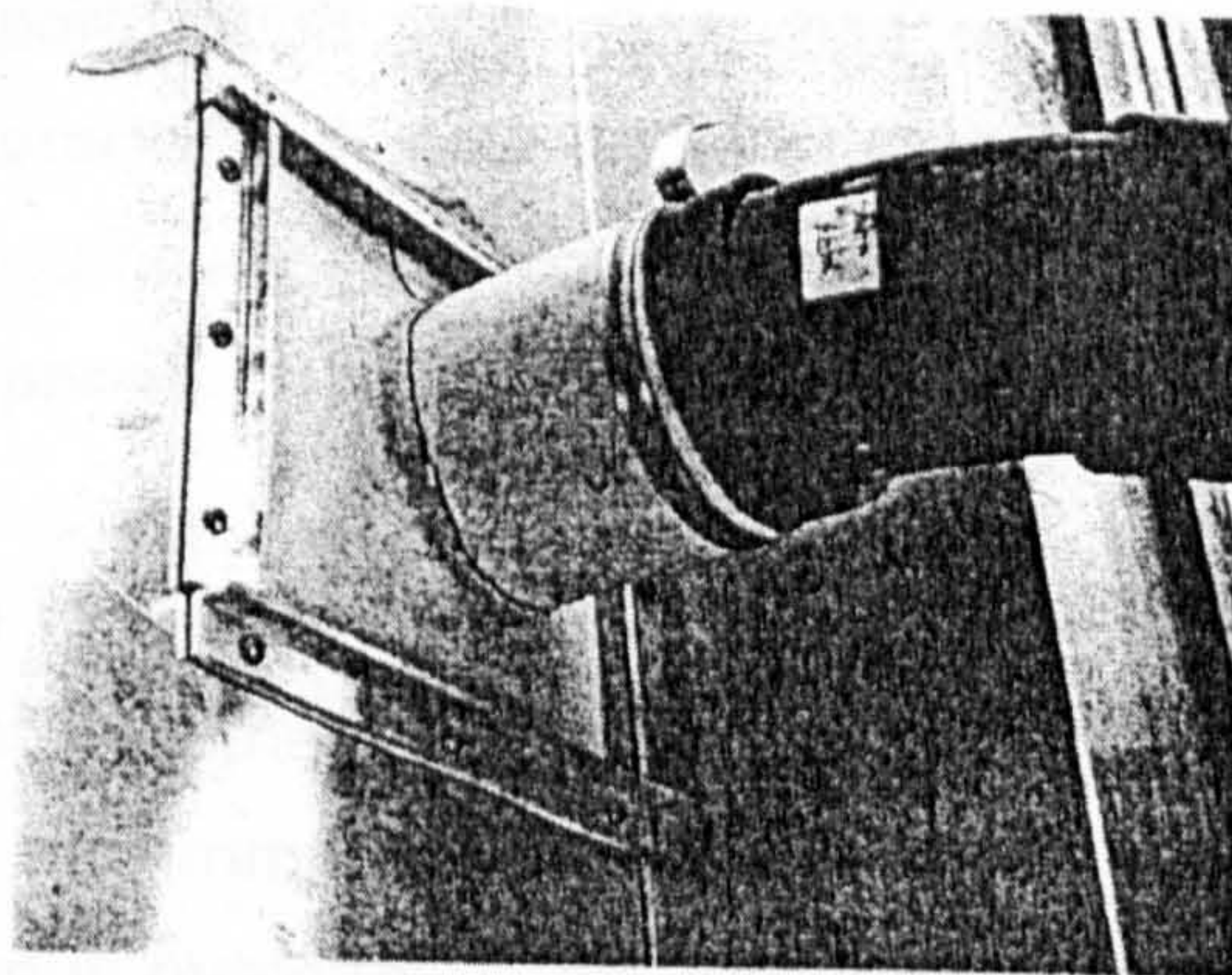


Figure 3.22: Cladding to pipework interface

Gibb (1997) stated this was rated as a very significant interface mainly due to the complexities of weathering the penetrations and co-ordination of services within the area available in the cladding section.

Problems arise as although the interface was indicated on the original scope drawings, at that stage the extent of the ductwork, in particular the size and position, had not been determined. Therefore the exact design of the penetrating interface had to follow the detailed design of the building services. This meant that other aspects of the cladding design had to proceed, leaving the interface design until much later.

3.15.4.1 Quarry Hill, Leeds

The Mopin system (a system based on a lightweight structural frame, steel sections encased with insitu concrete (Morris, 1978) was chosen for 938 new flats at the Quarry Hill slum clearance project in 1935 (final completion was in the 1940's due to the war). There were several differences between the original Mopin system and the one used at Quarry Hill, it is not clear whether these changes were due to statutory requirements or design changes by the architects. One unexplained aspect was the critical change in the fixing method of the precast concrete wall panels. The new fixing device entailed in part rolled mild steel angles approx 60mm x 600mm x 6mm with welded on mild steel brackets.

The first problems were seen when a number of the cladding panels were found to have become displaced and were in danger of falling from the structure. After remedial work had been conducted on the panels an independent survey was carried out. It found that either actual or incipient failure had occurred to the cladding fixings. The report found that water had penetrated through to the cavity and corroded the brackets. This was due in part to the joints between the panels failing because insufficient allowance had been made for expansion and contraction between the panels (Morris, 1978).

The principle here is the interface between cladding to structure, especially the allowances for movement and the actual cladding to structure fixings. It is out of the author's expertise to comment on the design change of the brackets but it clearly shows the disastrous outcome if the bracket fails. Emphasised further by Ransom (1981) who states "*some cladding defects are caused by movement between the cladding and its background; by failure to allow for the inaccuracies*

inherent in construction; by inadequacy of the fixing and jointing methods used; and by premature failure of sealants” (implying poor interface management).

3.15.4.2 Anonymous project

This project was used by Harrison and McCampbell (1991) as an example in “Problems in roofing design”, where the author uses examples from projects where roofs have caused problems in design and consequently defects on completion. It gives the observations of the project, recommendations and finally design principles.

Observation; Massive leaks were occurring at the interface between a low wall, high wall and roof. The architect had not detailed this particular interface but left it to the site labour to resolve the situation. Unless the differing trades were not directed to perform in accordance with the other trades, then probably the trades were not working at the same time.

Recommendation; The designer must specify that the roof is put on first and the remaining trades then install their work. The cover flashing should then be installed following the completed work.

Design principle; Don't leave design decisions to field personnel.

This particular example was aimed at the small building market, but the principle can be related to any building project. The interface should have been detailed before site installation. However the author has doubts over the recommendations, it may be possible to install the roof first, but the sequencing of the interface is the essential point.

3.15.5 Cladding Defects

Rivard et al (1995) stated that *“it is estimated that building envelope failure accounts for more than 50% of building deficiencies. Since these failures are usually not life threatening, they escape the attention of the general public.”* Furthermore, Waring and Gibb (2001) stated *“the UK curtain walling industry has been criticised for its inability to deliver cladding systems that are both well considered in their design and defect free upon installation.”*

Waring and Gibb (2001) conducted a survey on reasons for cladding failure, in particular, curtain walling. The survey identified the following five categories as the most frequent problem for failure:

- Weathertightness (30%)
- Tolerance and fit (16%)
- Buildability (15%)
- Durability (8%)
- Maintainability (7%)

Furthermore, the principles of weathertightness, tolerance/fit and buildability (60%) of the failures were attributed to problems at the interfaces. It was identified that whilst curtain wall may be bespoke or standardised, interfaces need to be designed individually for each project. In addition, where the cladding is bespoke, the interfaces are considered at an early stage, since they are integral to the design. However, with standard systems the interfaces are hardly ever considered due to standard manufacturing details.

Furthermore, Cohen (1991) commented, "*one of the main causes of cladding failures can be found in architectural education and practices. Without the introduction of principles of engineered cladding into education, failures will continue to happen*". In other words, it appears that failures are due to designers not having enough knowledge of systems or cladding types they are detailing.

The UK cladding centre (CWCT) published a standard and guide to good practice for curtain wall in 1993. A document intended to offer advice to all sectors of the construction industry on the installation of curtain wall systems. It was criticised by some for not offering prescriptive design advice and steers clear of design principles to the disappointment of some including Chevin (1993).

3.16 Research for improvements within construction

In a report for the DETR, Shove *et al*, (1995) claimed that the British cladding industry appears to be falling behind its European rivals. Most cladding systems have a poor reputation in terms of weather tightness and performance, making suggestions that there is potential for innovation and improvement.

The consensus view is that the industry faces a set of issues that can and should be studied to develop a generalised, relevant knowledge base. This view is summarised in a report from the BRE relating to cladding development, in which it stated "*the mission for the research at BRE will be to establish and advance the basis for the design of cladding systems. The disparate functions of cladding*

systems will be considered within a complete engineering frame work with advances in design founded on a proven and reliable knowledge base" (BRE, 1995).

3.16.1 Innovation within the cladding industry

Shove *et al* (1995) carried out research into cladding innovation stating that the innovation within the cladding sector is widely thought to be the responsibility of architects. Innovations are tried firstly on new expensive projects, and then applied on less prestigious projects with little or no effect.

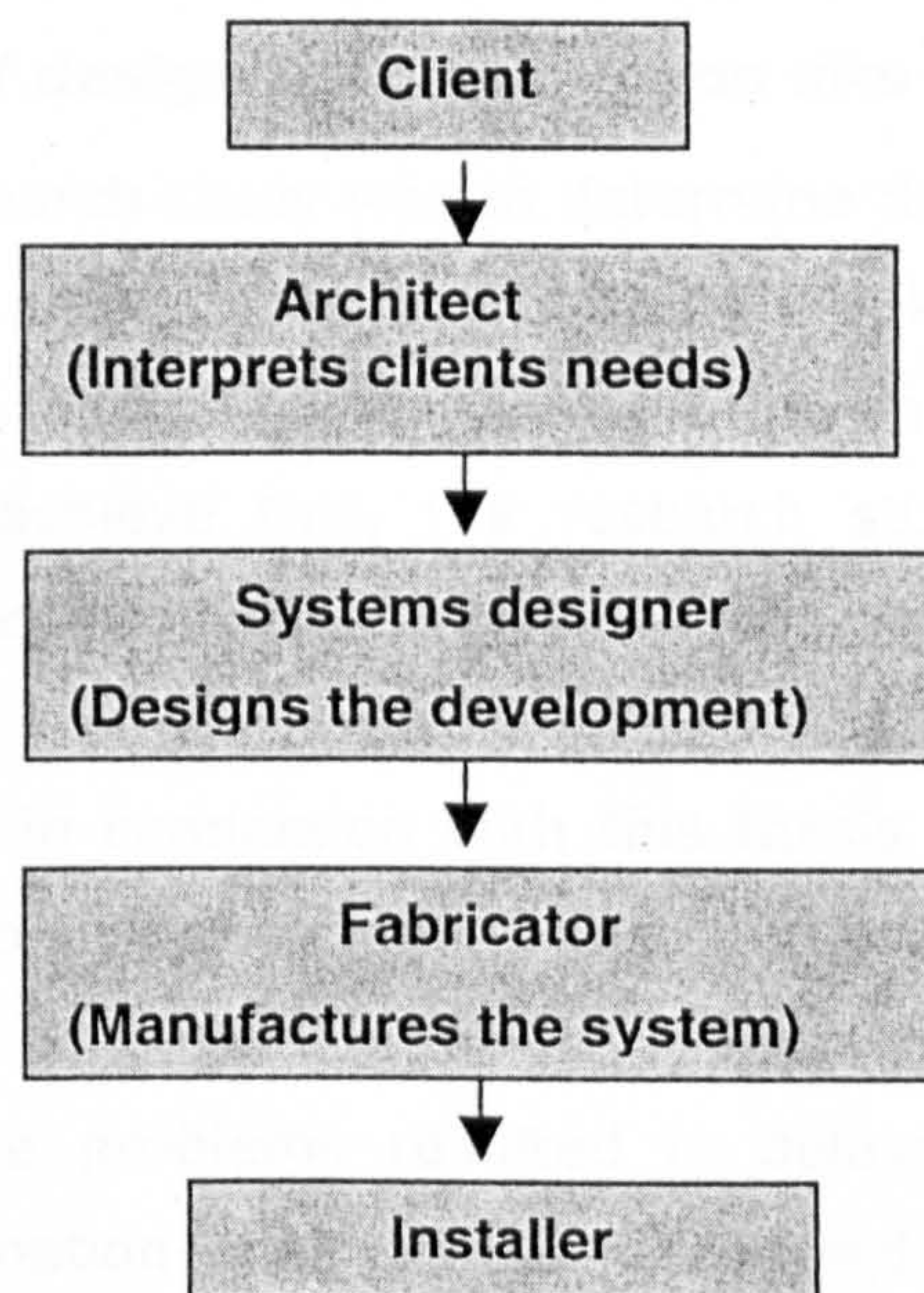


Figure 3.23: Client to installer progression (adapted from Shove, 1995)

Figure 3.23 shows a linear sequential process. Shove also states that the industry assumes linear influence through the process (i.e. client to architect, architect to systems designer, system designer to fabricator, fabricator to installer) and also a linear influence for larger more complex projects to smaller, simpler projects.

Shove highlighted that there was an untapped potential for innovation within the industry. However, Shove found that, in practice, there was no real evidence of this linear influence. Decisions appear to be influenced by individuals and organisations as matrices rather than linear progressions.

3.16.2 Attempts to solve problems

Within the construction industry research has been carried out and is on going to develop methods for increasing quality, productivity, and defects. Some of these research projects have been implemented and prompted by the government papers mentioned earlier (e.g. Latham). The researcher has tried to identify work that is related to the cladding sector or principles that could be implemented into the cladding process. Taywood Engineering has carried out several research projects in recent years, two of the projects cover influences within design productivity and zero defects.

3.16.3 The influence of design on construction site productivity

The objectives of this research study was to determine the changes necessary to the construction industry design process in order to make significant reductions in both operational and capital costs as well as improving the quality of completed projects. To achieve this, the research studied influences of the design process on the productivity of the construction (Wilson, 1997).

This research concluded, in connection with this thesis that problems occur at the interfaces between building elements and trades. Many of the problems resulted from the lack of consideration of tolerances on the accuracy of construction. Most of the problems resulted in delays and additional costs. Responsibility for co-ordination must be clearly defined and specific individuals must be given the responsibility for each interface.

Also the research further concluded that there must be simplified design within construction. Facades were often too complex and not standard. This led to reduced productivity and extra costs rectifying the added complexities. In other words there should be simplified designs by standardising materials, dimensions and arrangements (Wilson, 1997).

3.16.4 Towards a zero defect construction culture

This research carried out by Taywood Engineering was to identify critical construction process factors that can eliminate defects. Through the use of workshops and case studies the research examined the construction industry enabling an understanding for its success or failure in delivering zero defects. It particularly looked at the cladding industry in which constantly changing procurement routes are described as a supply web rather than a linear supply chain. A major quality improvement could be gained by developing a

standardised procurement process with a better understanding and control of the supply chain process (Masat, 1998).

The study found that trade contractors, particularly cladding contractors, who had to input design knowledge were not involved early enough. Invariably the structure was being fabricated by the time that these contractor requirements were understood and implemented in the design process.

Part of the study focused on understanding the process of procuring and supplying the cladding system. Stating *"the specialist cladding subcontractor is situated at the interface between the construction and manufacturing industry. From this position, it has to reconcile the design and specification with available components, the fabrication process and site erection. Therefore the role covers three separate processes"*:

- Component design
- Facade design and fabrication
- Installation

"Only a few of the largest companies undertake all three parts of this process".

In the section of the report: guide to improved performances, it stated under the heading of "Interfaces" three factors;

- The responsibility for the design of the interfaces between the specialist contractor components must be clearly defined at an early stage
- The arrangement of the flow of information and products between the companies in the supply chain needs to be managed
- A non-confrontational approach or "total teamwork" is required to ensure that the client receives the desired standard of building.

3.16.5 CWCT seminars and workshops

CWCT is an independent resource centre for all those concerned with the design, manufacture, construction and maintenance of building envelopes. Members include clients, developers, architects, engineers, consultants, main and specialist contractors, manufacturers, suppliers and other research and testing organisations.

The Centre was founded in 1989 in response to growing technical problems being experienced with cladding. The Centre is involved in three main activities:

research, education and training and publication. The Centre studies technical and process aspects relating to both glazing and cladding. This includes windows, glazing screens; curtain walling, slope glazing, rainscreen facades, overcladding, reinforced concrete, GRP and GRC panels (www.cwct.co.uk).

3.16.6 CIMclad

Integration of the processes involving design, manufacture and installation of cladding systems has the potential to improve business in the cladding sector. This potential is being explored by a research project entitled "Computer Intergrated Manufacture of Cladding systems (CIMclad)". This is an UK industry led initiative investigating the feasibility of improving the efficiency and competitiveness of the cladding sector through the development of a standardisation and integration framework for computer- integrated manufacture of cladding systems for building projects (Agbasi et al, 2001).

The projects initial focus is on Rainscreen cladding, which serves as a pilot for the wider cladding sector. The initial focus of the research is the interface between scheme and detail design. The project is split into five workpackages with the following objectives;

- To establish the potential for process improvements through standardisation of procedures and more efficient use of IT
- To consolidate and state more formally a set of standard performance specifications for layered cladding walls
- To develop a product model to support the major aspect within the specification, design, manufacture and construction of layered cladding walls
- To implement and test these concepts via fast-track implementations and industrial deployment of standard object-oriented CAD technology
- To propose a road map for the cladding sector as a whole to realise computer integrated design manufacturing in the context of wider development within the construction industry (Agbasi et al, 2001)

3.17 Literature Summary

The literature review has produced some interesting literature on cladding, management, design and processes within construction. However there is very little written specifically on interfaces, particularly on how they should be managed. This shows the need for the research and its outcome. However the key lessons from the literature are;

- The construction industry is very fragmented in its approach, which causes problems from design through to installation.
- Literature on cladding and interfaces is very scarce. Principally there are two main sources of literature for cladding; (Brookes and the CWCT) and one for interfaces, (Gibb).
- Planning the design can be as important as the design itself, if this is properly planned cost reductions and reduced construction times can be achieved.
- The link between design and construction; the shop drawings; if not correctly managed can cause disputes and time delays.
- The responsibility for a construction task is rarely detailed early enough, especially in the cladding sector.
- Buildability is an opportunity to use construction knowledge, however if it is not properly considered it can produce problems in installation.
- The role of the specialist contractor is becoming more and more prevalent in construction, however their role within the process will depend upon the procurement option.
- There are four main types of procurement options. All offer different values to a project, however it does appear that the traditional option offers the least in terms of benefit to interface management.

In addition there is constant reference to the way construction project teams operate, especially in their fragmented approach from design through to site works. There are constant citations for better integration within the process, from inception through to completion, particularly from the specialist contractors. This can only improve interface management.

Chapter 4 CladdISS

4.1 Introduction

Chapter 1 introduced the research explaining the aims, objectives and justification. Chapter 2 described and discussed the methodology. Chapter 3 provided the review of published literature that helped determine the research objectives. This chapter explains the funded research project entitled CladdISS "a standardised strategy for window and cladding interfaces". It explains how CladdISS came into existence, the methodology behind the research and its final deliverables.

4.2 The Research Project

The CladdISS project was developed following two research projects on cladding, these being the "testing methods for construction interfaces" and the CWCT survey for the cladding industry commissioned by the department of the environment (DOE). Both of these projects identified the need for investigation into construction interfaces in particular for cladding elements.

The £307,000 research project was 50/50 industry/government funded through the LINK scheme, Meeting Client's Needs through Standardisation (MCNS). This scheme was jointly funded by the Engineering and Physical Sciences Research Council (EPSRC) and the Department of the Environment, Transport and the Regions (DETR).

Industrial partners in the project included: architect Brookes Stacey Randall; the Centre for Window and Cladding Technology (CWCT); structural engineer and cladding consultant Ove Arup; airports client BAA; contractor HBG construction; contractor and cladding test house Taylor Woodrow; precast cladding supplier Trent Concrete; curtain walling supplier Kawneer; and consultant the Building Performance Group. These companies formed the steering group for the research.

4.3 Aims of CladdISS

The aim of the research was to facilitate a cultural change in the cladding sector of the construction industry. It was considered that this would be achieved by enhanced management of the design development process particularly concentrating on the technical and management aspects of construction interfaces.

- Technical aim;
To develop a strategy for standardisation of cladding interfaces by collating appropriate standardised, technical details for different cladding types and their relevant interfaces, with particular emphasis on buildability.
- Management aim;
To develop a strategy for mapping a process between scope design, detail design, fabrication and installation of the different cladding types and other building elements.
- To benchmark best practice requirements for contractual arrangements, performance testing, design development, tolerances, warranties and interface responsibility producing a strategy for improvement.

4.4 Objectives

There were three key objectives for the project:

- To produce a strategy for appropriate standardisation of cladding interface design.
- To produce a strategy for interface design process improvement.
- To demonstrate that effective interface consideration is essential for improved design, manufacture and construction of building elements.

4.5 Research method and resources

The research was undertaken by a research team from Loughborough University. The team was led by Alistair Gibb a senior lecturer at the University and two research assistants, Gary Sutherland (RA 1) and Trevor Pavitt (RA 2), the author of this thesis. The research was aided by the expert guidance from the industrial steering group. This covered both technical and managerial aspects

RA 1 was employed to "broadly" investigate the technical issues and RA 2 the management guidance, however there were areas of crossover between the two aspects. The following explains the phases of the research in terms of method.

The research was conducted over three years, RA 1 was employed for the first two years and RA 2 was employed for the last two years. Therefore the second year of the research both RAs were employed simultaneously allowing cross-fertilisation between the two researchers. RA 1 spent the first eighteen months of the project based at Brookes Stacy Randall (part of the steering group) an architects' practice specialising in cladding design. The rationale being to provide the RA access to live and historic projects thus forming the foundation of the technical aspects of the research. The final six months were spent at Loughborough University working in parallel with RA 2. In addition both RA's were retained for a further 12 months under the EPSRC's research assistant's industrial secondment (RAIS) scheme.

4.5.1 Research Associate A (Gary Sutherland)

Literature review: This was based upon previous projects with the aid of the steering group and their companies. Information from other sectors of industry was also investigated to establish appropriate knowledge transfer into construction. The review was completed within the first six months of the project.

Generic detailing, component detailing, dimensional framework: Key details of main elemental types and construction were developed showing generic detailing to take account of means of construction and performance in use (e.g. weather protection). Component details were identified from Brookes' database and from other collaborators, including typical element drawings for location on a dimensional framework as required.

Historical case studies: These were identified and reviewed to support both the maintenance review and standardised detail collation.

Key industry focus groups: The steering group members were used as a source for key experts in the areas of the building envelope. The experts were used as a knowledge base for a series of workshops. The focus groups developed a standardisation strategy for cladding interface design.

Develop standardisation strategy: Using the outcomes of the focus groups and other work a strategy for standardisation of cladding interface design was developed and incorporated into CladdISS. As described in section 4.5 - CladdISS strategy.

4.5.2 Research Associate B (Trevor Pavitt)

This section describes the author's input to CladdISS. The full comprehensive methodology for the thesis is documented in chapter two.

Evaluate process implications: This operation included a further literature review and close liaison with RA A to ensure that process implications from the technical study were incorporated and interrelated. Furthermore collaboration with other researchers on other projects including the existing IMI project management of detailed building design at Loughborough and the Taywood/CWCT work described in the literature review (chapter 3).

Semi-structured interviews with key industry practitioners: As with RA 1, RA 2 used the steering group as a source for industry contacts. From these and other contacts developed during the formative stages of this project a list of 40 key industry practitioners was established. These practitioners were interviewed using a semi-structured format comprising a limited number of open-ended questions.

The interviews explored these questions and other related matters. The interview process was field tested on members of the steering committee prior to the main interviews, this was to establish the length of the interviews and to make sure the content was in keeping with the research topic.

Process industry focus groups: Two workshops, involving industry practitioners were convened to discuss the process aspects of cladding interface design and construction. The focus groups explored the key issues raised by the research work to date and in particular the interviews.

Questionnaires to verify key issues: A questionnaire was used to verify the essential issues arising from the focus groups and interview findings. In total 165 questionnaires were sent out to industry, 64 of these were returned. The results were incorporated into CladdISS.

Develop process strategy: Using the outcomes of the above mentioned sections a strategy for standardisation of the process of cladding interface design and construction has been developed and has been incorporated into CladdISS. The process map has proved to be the focus of the management section of the research.

4.6 CladdISS Strategy

The following text is taken from the introduction to the CladdISS CD.

CladdISS is an interactive CD ROM software tool that provides a strategy for optimising technical and management aspects of cladding interfaces. CladdISS is targeted at all disciplines associated with the building envelope especially;

- **Designers/Architects:** making sure their design decisions do not compromise the interfaces.
- **Engineers:** making sure the cladding design is considered when designing the structure and all critical interfaces.
- **Construction Managers/Project Managers:** making sure that they manage and coordinate the interfaces to improve the project outcomes.
- **Specialist Cladding Contractors:** making sure their workpackages interface effectively with other workpackages.

4.6.1 Why Use CladdISS?

Failure to address interface issues will:

- **Reduce productivity**
- **Reduce quality**
- **Increase waste**
- **Increase costs for design, manufacture, installation and the building life cycle**

CladdISS addresses these issues through four distinct steps:

Step 1 Review of interface management strategy: review the process for managing the interfaces; actions required at different project phases (process map), programming implications for cladding interfaces and specialist cladding contractor and workpackage information.

Step 2 Identification of cladding types and other building elements.

Step 3 Classification of interface profiles.

Step 4 Consideration of key issues and actions.

4.6.2 Step 1: Review interface management strategy

The first stage of the interface standardisation strategy reviews the process for managing the cladding interfaces. The aims of the management section are;

- To show the user how problems can arise if 'best practice' is not used on a project.

- To show the user how the cladding interface management process can be improved by using CladdISS.

The management section has been divided into 3 sections:

- **Actions required at different project phases**
- **Programming implications**
- **Specialist Cladding Contractor and Workpackages**

Actions required at different project phases are the key to managing the cladding interfaces. The aim of the process map is to make the user aware of crucial management issues when procuring cladding interfaces in line with a generic cladding process.

CladdISS presents a process map that identifies significant cladding interface management actions and decisions in a project, from its inception through to demolition and decommission. Table 4.1 shows the stages in the CladdISS process map that are based on the process protocol (Salford, 1998). In total there are twelve phases. At the end of crucial phases within the process are review points, six in total.

The CladdISS review points advise the user that before progression to the next stage the review point outcomes must have been established within the project team. The information in CladdISS has the ability to be mapped onto other project processes if necessary.

Phase 0	Demonstrating the need	
Phase 1	Conception of need	CladdISS review 1
Phase 2	Outline feasibility	
Phase 3	Substantive feasibility and outline financial	CladdISS review 2
Phase 4	authority	
Phase 5	Outline conceptual design	CladdISS review 3
Phase 6	Full conceptual design	CladdISS review 4
Phase 7	Co-ordinated design, procurement and full	
	financial authority	
Phase 7a	Production information	
Phase 8	Manufacture Construction	CladdISS review 5
Phase 9	Maintenance /facilities management	CladdISS review 6
Phase 10	Demolition/Decommission	

Table 4.1: Project Phases

As an example table 4.2 shows the CladdISS actions required in phase 2: Outline feasibility.

Main Project Process Protocol Actions & Decisions	Phase 2 Outline Feasibility Feasibility study for each option Re-assess site and environmental issues Revise business case
Cladding Process CP Actions & Decisions	Consider off site pre assembly. Obtain specialist contractors input. Consider environment issues (e.g. noise, dust) Develop outline planning constraints for aesthetic appearance. Consider on site storage capacity. Consider implications of cladding panel size (e.g. crantage). Consider the need for specialist cladding contractor input for cladding supply chain. Consider if on/ off site testing is applicable. Ensure requirements are included in the cost build up.
Interface Management IM Actions & Decisions	Consider cladding interfaces with other elements and systems. <i>* Note* "Increase in cladding types and building elements will increase interface complexity."</i> Consider compatibility between different systems/elements (e.g. precast on light steel frames).

Table 4.2: Phase 2 of the CladdISS Process Map

Programming implications displays how cladding projects are generally programmed; highlighting the difficulties that often arise. CladdISS emphasises the need for improved programming and planning for cladding interfaces, stressing failure to consider interfaces will lead to problems in design, installation and throughout the lifecycle of the building.

CladdISS compares two approaches for programming cladding interfaces and demonstrates their significance as follows:

- **Traditional Programme**

This section shows the progression of a typical construction project using the "traditional" procurement route. Highlighting the fact that if this route is followed, crucial aspects of the cladding production will often culminate in added costs and site installation problems to the project. Listed below are the key reasons for these added costs and installation problems.

1 One or more of the interface elements will be in manufacture before another element has been fully designed, this will mean assumptions will have to be made for:

Loads

Cladding fixing zones

Movement

Manufacturing and installation tolerances

2 Material compatibility of different elements may be overlooked

3 The interface responsibility may not be clearly defined

4 Buildability between the elements may not be adequately considered

5 Sufficient specialist contractor information may not be available thus compromising the design.

- **CladdISS Preferred Programme**

An improved construction programme suggests methods for a programming process for more effective management of the cladding interfaces. The programme is interconnected with the CladdISS process map and also provides information on lead times for cladding elements. This is important because some cladding systems have lead times as long as thirty-seven weeks, among the longest in construction (France, 1993). Figure 4.1 shows the preferred programme.

Shown are grey markers and lines which indicate an exchange of information between the parties. This will facilitate the optimum project solution. The information will normally be provided by the specialist contractors to the design team. The type of information will increase over the initial design phases, when required by the design team (represented by the tapered line). CladdISS advises the user to consider the different procurement options that allow specialist contractor involvement at the early design stage. Finally it shows a planned interface management process giving an example of a project with details of its benefits.

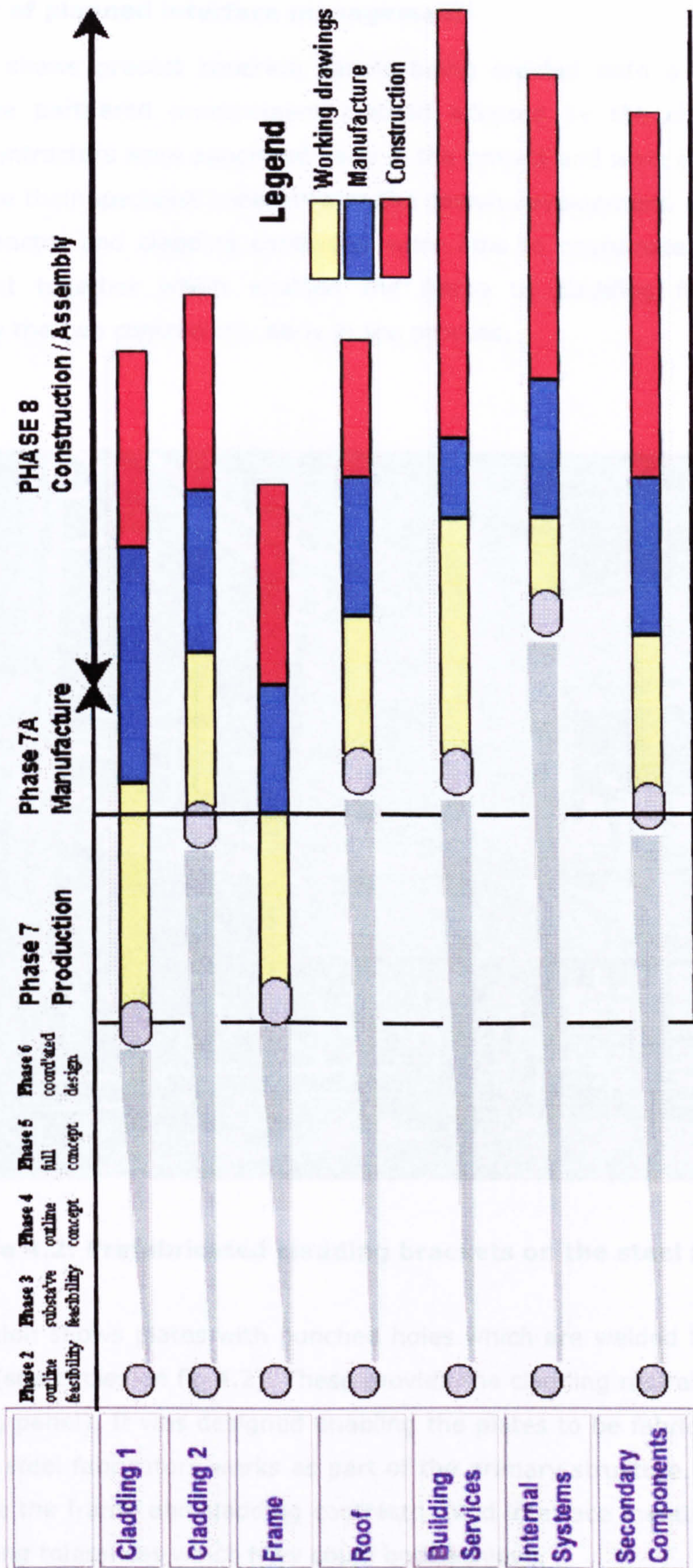
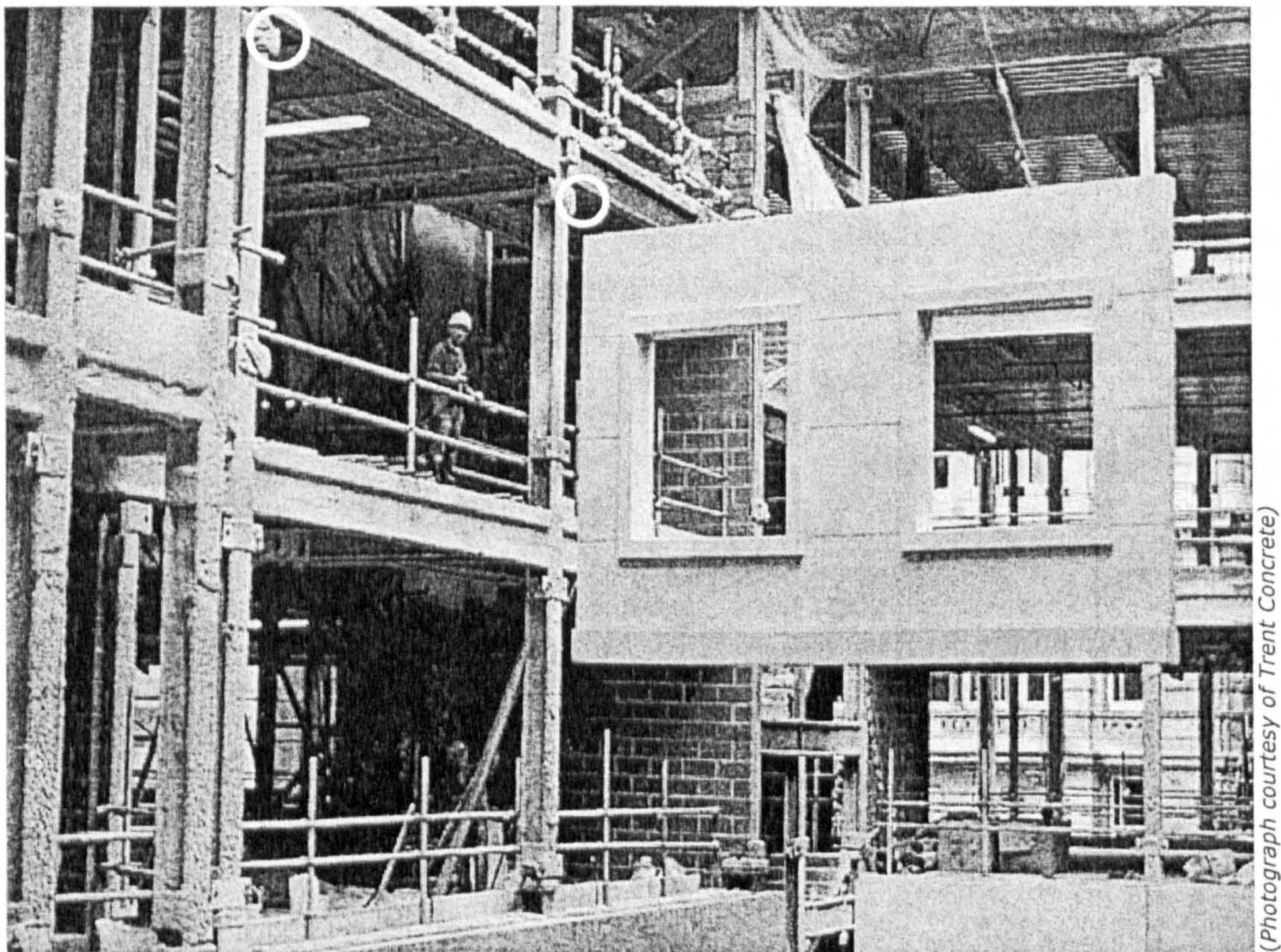


Figure 4.1: The improved construction programme

- **Benefit of planned interface management**

Figure 4.2 shows precast concrete panels being erected onto a steel frame. Through the partnered procurement method adopted by the client the key specialist contractors were appointed early in the project and were therefore able to contribute their specialist knowledge to the design development. Also both the frame contractor and cladding contractor were able to coordinate their design development together which enabled the frame to cladding fixings to be designed by the two contractors, early in the process.



(Photograph courtesy of Trent Concrete)

Figure 4.2: Prefabricated cladding brackets on the steel frame

The illustration shows plates with punched holes which are welded to the frame stanchions (see circles on fig 4.2). These provide the cladding restraint fixings (4 per cladding panel). It was designed enabling the plates to be fabricated in mild steel at the steel fabricators works as part of the primary structure. At the early design stage the frame and cladding contractor held interface meetings to agree manufacturing tolerances which they could both achieve.

Once this was finalised the fixing to the frame (which is often problematic) was straight forward, as the tolerance adjustment was eliminated by allowing larger holes in the brackets.

The normal methods of restraint fixing are post applied to the frame. Because these are not part of the structure, the restraint fixings have to be in stainless steel and have to be bolted to the frame which has a time element and often the frame has to be site drilled. On this project, replacing the fixings with mild steel plates saved approx 2% of the cladding contractors overall costs.

Specialist Cladding Contractor and Workpackages explains the types of specialist contractors and their role in procuring cladding packages.

Typically the specialist-cladding contractor is involved in many aspects of the delivery of a cladding system, this may include: system design, fabrication, installation, and component supply. A specialist-cladding contractor may undertake all of the processes or be limited to just part of the process.

Ledbetter (1997) identified that there are four generic types of specialist cladding contractors, CladdISS has taken this further and adapted the four types by the introduction of material supply and project design and detailing. Figure 4.3 shows the four types of specialist cladding contractor adapted by CladdISS. Following that is a description of the their different formats;

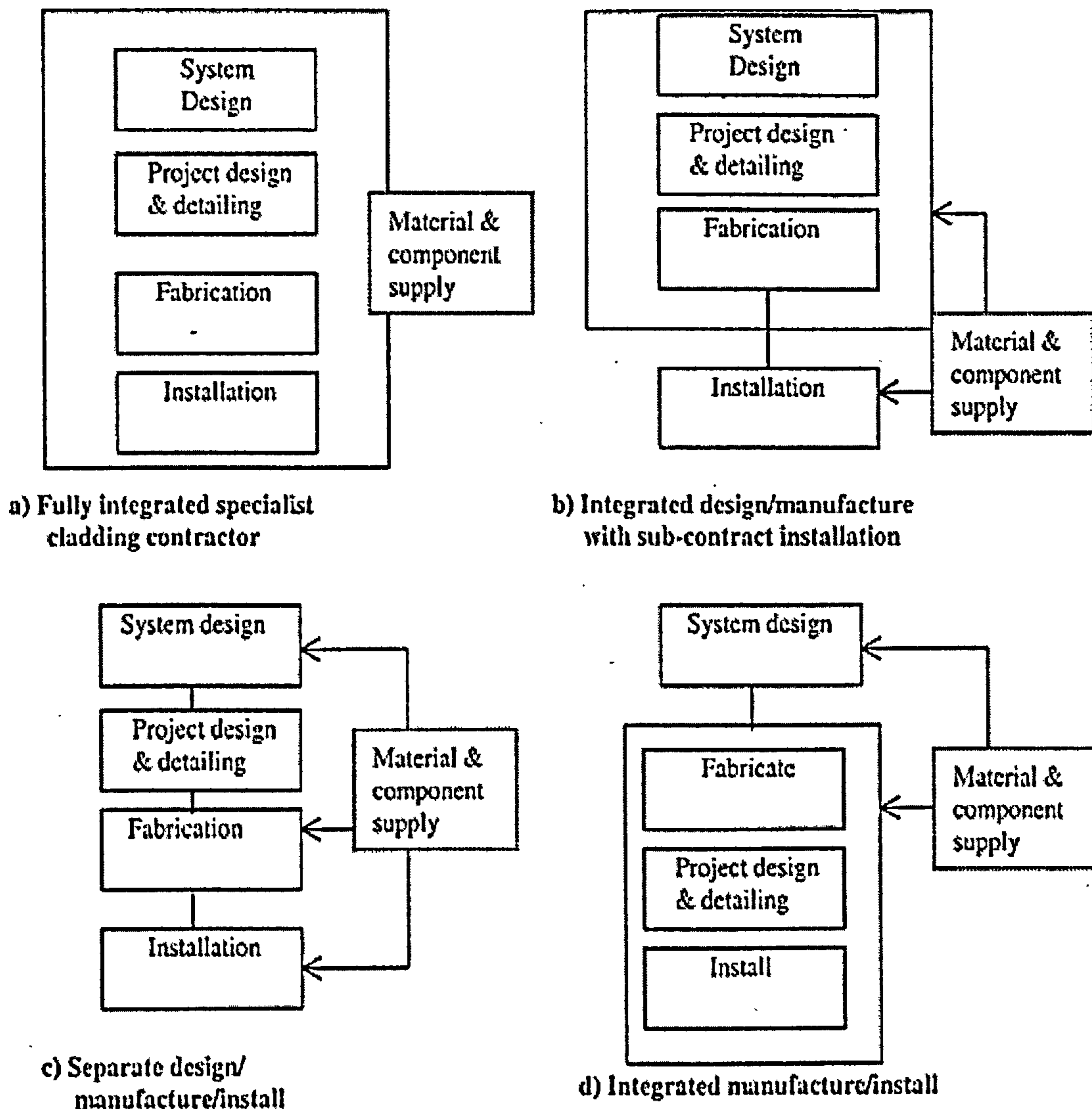


Figure 4.3: The four different types of specialist cladding contractor adapted for CladdISS (adapted from Ledbetter, 1997)

From the four types these can be placed into two broad categories:

(A) Integrated specialist cladding contractor

(BCD) Collaborative specialist cladding organisations. Here the fabricator (or occasionally the installer) will enter into a contract with the client or contractor, but the project design/detailing may be carried out by themselves or by others, the installation will be invariably sublet in some form.

- **A Fully integrated specialist cladding contractor (FISCC)**

This is a company that undertakes the whole system design, project design/detailing, fabrication, installation and the finishing of the cladding sections. The finishes will vary from cladding type to cladding type, for instance

with aluminium curtain wall, the finish can be anodized or powder coated. The only outsourced element will be materials such as glass and gasket components. The company will be responsible for all warranties and installation. There are few specialist contractors who are capable of working this way.

- **B Integrated design/manufacture with sub-contract installation**

This is a company that undertakes the design and fabrication (cutting and machining) of the system and like the FISCC is dependent on an outsourced materials supply chain. The installation will be sublet to an independent subcontractor, who may be responsible for the supply of fixings. Nevertheless the design/fabricator retains the contractual responsibility for warranties, including installation. The installer will have a separate contract with the design/fabrication company and will guarantee the installed work.

- **C Separate design/manufacture/install**

This occurs where the system company designs a system, extrudes the raw aluminium to stock lengths then finishes them. The fabricator purchases the extruded lengths and fabricates them to the required details for a particular project. Separate subcontractors then install them on site. The supply of the aluminium and gasket components will be provided by independent supplier's dependant on their own supply chain.

Before tender, the design team or the client may approach the systems designer for technical input on their systems. This information will be very "broad brush" until the system is specified. Once the system has been specified the major contractor has two options; either to go out to tender to their known fabricators or to a list of fabricators provided by the specified systems designer. The latter is the most common method. The fabricator will be contractually bound for warranties and installation to the major contractor.

The fabricator will have a separate contract with the systems designer for the supply of the extruded aluminium and the actual system design. Also the fabricator will have a contract with the installer for the installed work.

- **D Integrated manufacture/install by system fabricator**

This is virtually the same as the separate system except the fabricator will install the system using in-house teams, without subletting. The fabricator is still contractually bound for the warranties and installation. This method gives the

specialist contractor the greatest control for programming the project design and installation other than the fully integrated company.

- **Detailed design and detailing**

Typically, for traditionally procured projects, a design team, working for the project client will produce a concept design for the cladding. This will usually include elevation layout drawings. The project design team will probably have discussed the concept with a number of system companies. The concept will then be used as the basis for a tender negotiation with the specialist cladding contractor. This may involve a two-stage tender.

The successful specialist contractor will then work up the concept into a detailed design, usually requiring the project design team's approval. The specialist will then produce workshop drawings for materials procurement, fabrication and installation. In a few instances that project design team will develop the concept design and produce the detailed drawings before they are issued to the specialist (e.g. Portcullis House, Westminster).

Where a partnering approach is adopted for the project, the same steps are included, but the various parties will already have a partnering agreement for the work and therefore the tendering process is not required. In this way, it is easier to obtain early manufacturing and installation input into the process.

- **Material supply**

When procuring a cladding system it is essential that there is an understanding of the materials used and their supply times. For example a curtain wall system can have a long fragmented supply process for the aluminium. Furthermore the gasketry and hardware may all come from separate specialist suppliers.

Often the design team does not have sufficient understanding of material lead time's especially glass (identified in chapter 5, data collection). Therefore the material supply can be as important as the fabrication. The management strategy should be reviewed before progression to step two (Identification of cladding types and other building elements) because;

The **project design team** must be aware of critical interfaces in the project and make sure they are considered throughout the project design period.

The **principal contractor** must be aware of key issues and programming details between interfacing workpackages.

The **specialist contractors** must be aware of other interfacing workpackages (e.g. lead times, warranties and testing).

4.6.3 Step 2: Identification of cladding types and other building elements

The hub of the CD-ROM is the two-tier interface matrix (Figure 4.4) where the project team can identify the key interfaces to be considered. The upper tier covers interfaces between most of the UK's common cladding types for major buildings.

The lower tier covers the interfaces between key building elements such as cladding and the frame, roof, building services, internal systems (walls, floors & ceilings) and secondary components such as sun shades, cleaning equipment and handrails.

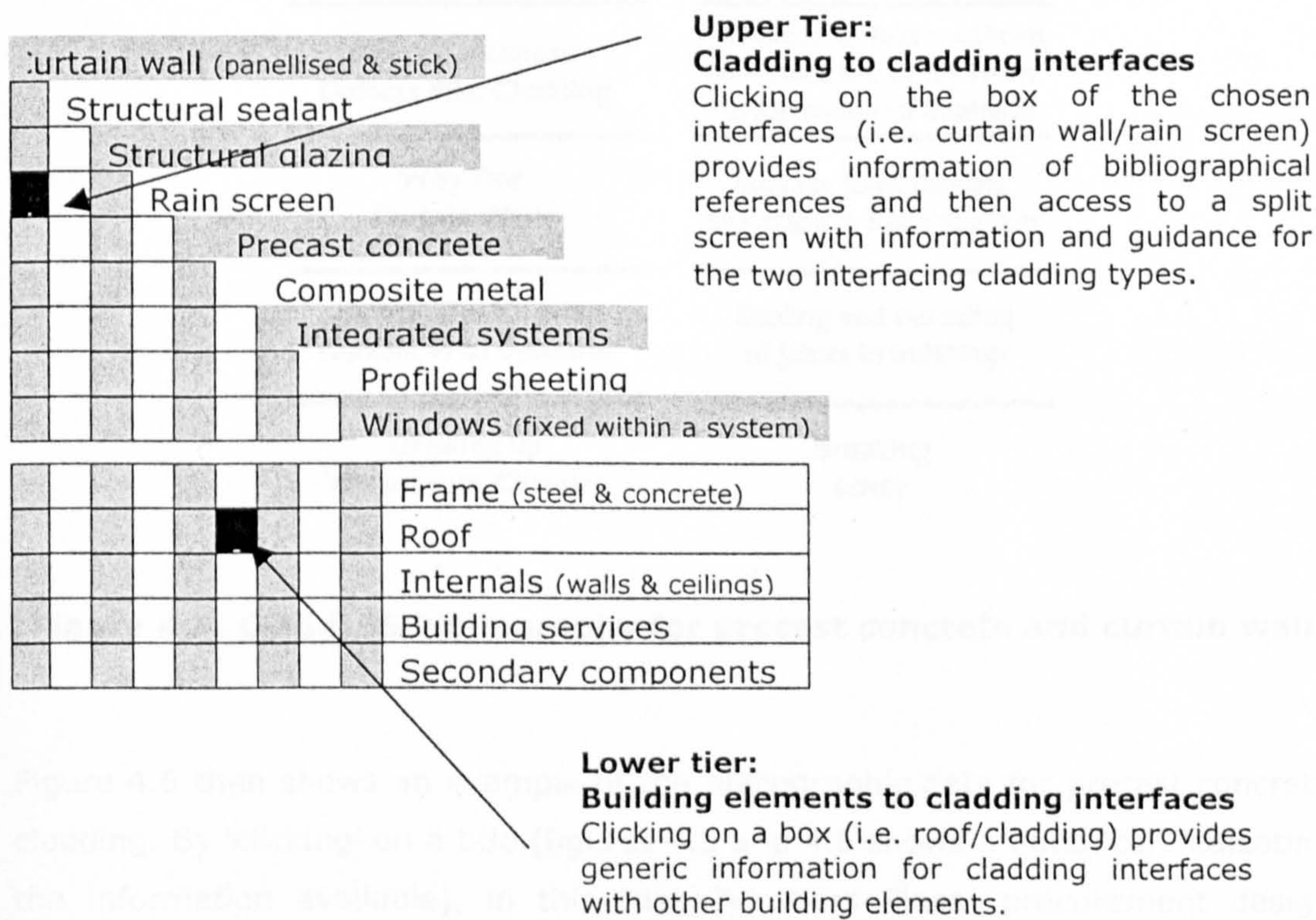


Figure 4.4: Interface Matrix

Once the interfacing systems have been identified, CladdISS shows the bibliographic references for the two interfacing cladding types, (in this example precast concrete and curtain wall, figure 4.5). Similar reference lists are provided for each interface.

CURTAIN WALL METAL + GLASS	PRECAST CONCRETE
Standard and Guide to Good Practice for Curtain Walling	Cast In Concrete: Reconstructed Stone and Precast Concrete
Cladding of Buildings	Precast Concrete Cladding
Cladding Fixings: Good Practice Guidance	Vintners Place: Procurement, Design Development...
Specification and Details on Curtain Wall Contract Packages	Architectural & Economic Considerations In the Design of Prefab...
Seeping Skiness: Defects File: Cladding	Advances In Test methods to Assess the Long Term Performance of Sealants
Why Test Curtain Walls	Sealant Joint Design, Selection & Specification
Lateral Buckling In Curtain Wall Systems	Sealing and resealing of Joints In buildings
Drawing up Waterproof Curtains	Breaking cover

Figure 4.5: CladdISS bibliography for precast concrete and curtain wall

Figure 4.6 then shows an example of the bibliographic data for precast concrete cladding. By 'clicking' on a title (figures 4.5 and 4.6 shows a hand icon indicating the information available), in this case "Vintners Place: procurement design development" reveals the title, author, publishing details and synopsis (taps).

precast concrete bibliography | Cladd:ISS

Cast In Concrete: Reconstructed Stone and Precast Concrete	T Vintners Place: Procurement, design development and construction of a complex building facade
Precast Concrete Cladding	A Gibb, Alistair G. + Brand. P. R.
Vintners Place: Procurement, Design Development...	P Proceedings of the Institute of Civil Engineers (Structure and Buildings), London, February 1996, vol. 116, Issue 1, page 96-108
Architectural & Economic Considerations In the Design of Prefab...	S Discussion of the management and construction techniques for an office building in London. The interface strategy is presented and discussed.
Advances In Test methods to Assess the Long Term Performance of Sealants	
Sealant Joint Design, Selection & Specification	
Sealing and resealing of joints In buildings	
Breaking cover	

Figure 4.6: Vintners Place: Procurement design development reference

4.6.4 Step 3: Classify interface profiles

Following the cladding type identification the next step is to classify the interface joint profiles. CladdISS developed six generic interface profiles based on Michael Rostron's joint classification diagrams (1964), shown in figure 4.7.

Throughout the process CladdISS will identify whether the profiles are compatible with the different cladding types. The project design team must then choose the joint profile for each interface.

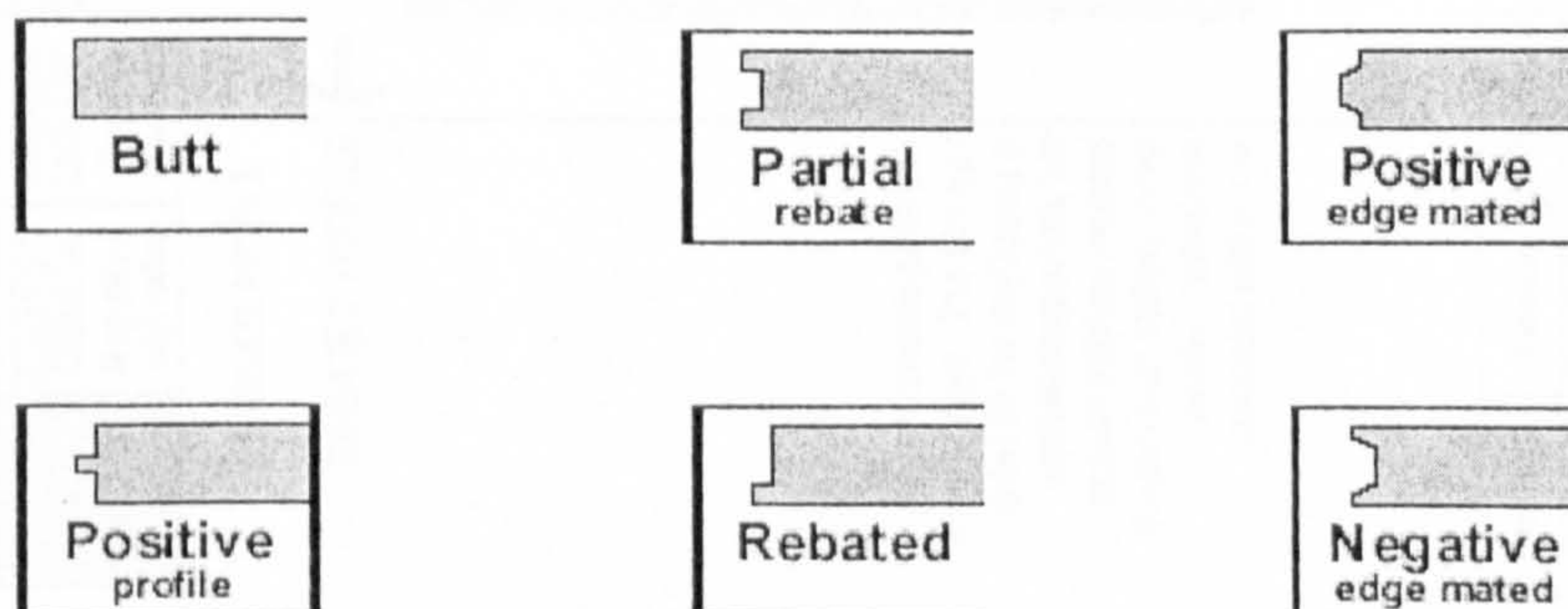


Figure 4.7: Joint Profiles

At this juncture the user has the opportunity to consider the profiles of both cladding types; this is accessed by the use of a split screen (figure 4.8) this facilitates efficient comparisons between the two interfacing elements. The example shows the precast concrete rebated profile adjacent to the curtain wall butt profile with the aluminium channel option. Figure 4.8 also shows that the positive profile is not compatible with precast concrete cladding whereas only the butt and positive profile are used with curtain walling.

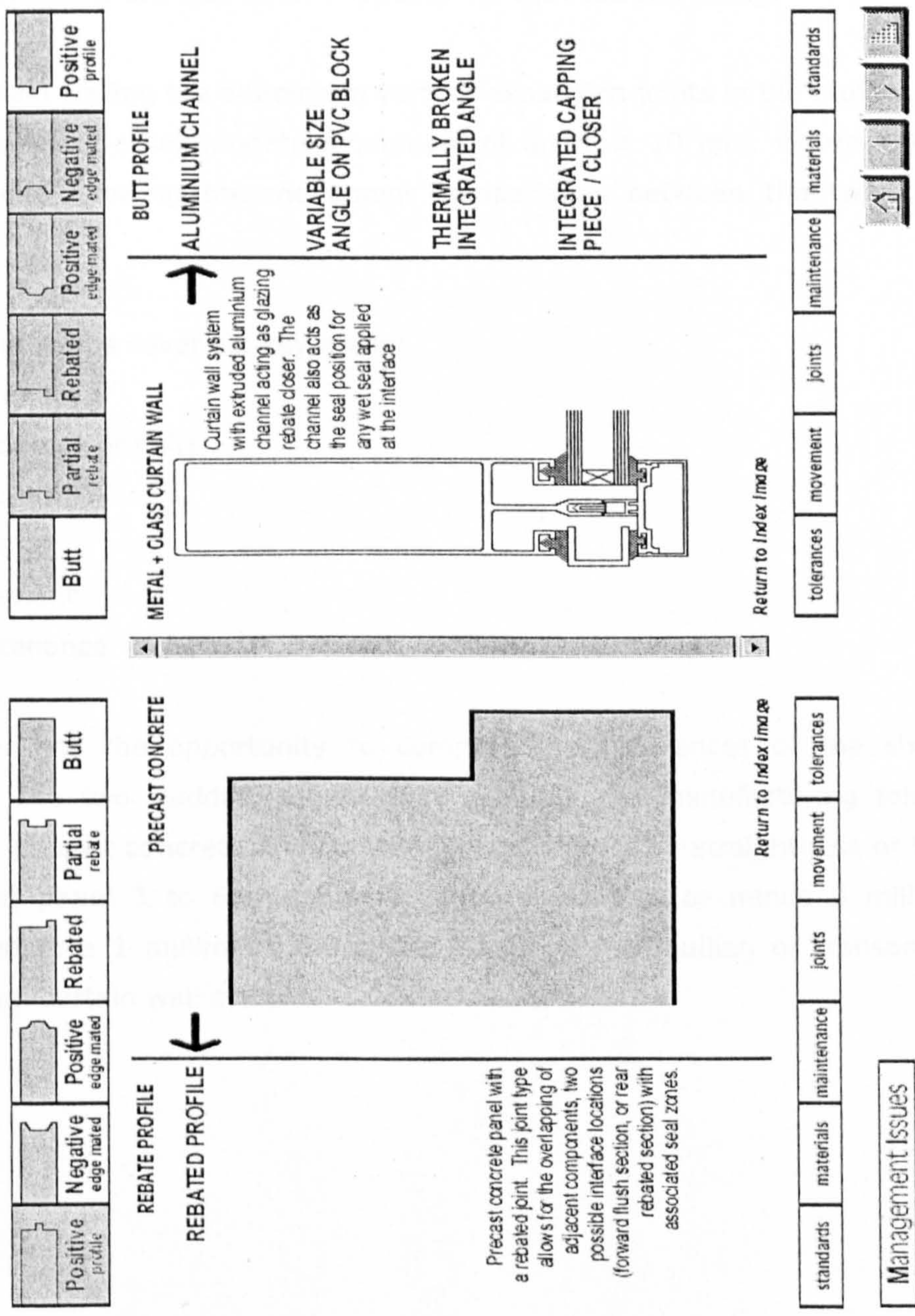


Figure 4.8: Split screen format for the interface between precast concrete and curtain wall

At this stage the designer may want to consider critical comparisons between the two cladding types for example the tolerances, standards, materials, maintenance, joints and movement. The differences between the two will be crucial in design.

For example with precast concrete thermal expansion and other inherent deviations of the concrete panels are relatively minor (approximately + 1mm in 3m) depending on temperature during curing, concrete type, water content etc. These deviations are also accommodated via the restraint fixing.

With curtain walling the aluminium vertical expansion joints in the mullion, will in most cases will accommodate movement of up to ± 10 mm. Figure 4.9 is the split screen showing the movement comparisons between the two cladding types.

The comparisons cover six key areas:

- Tolerances
- Standards (British)
- Materials
- Joints
- Movement
- Maintenance

The user has the opportunity to compare the differences of the six areas between the two cladding types. For example the manufacturing tolerances between precast concrete and curtain wall will vary. The straightness or bow for a precast panel 3 to 6 metre in length will be plus or minus 9 millimetres compared to a 1 millimetre along the length of the mullion or transom in an aluminium curtain wall system.

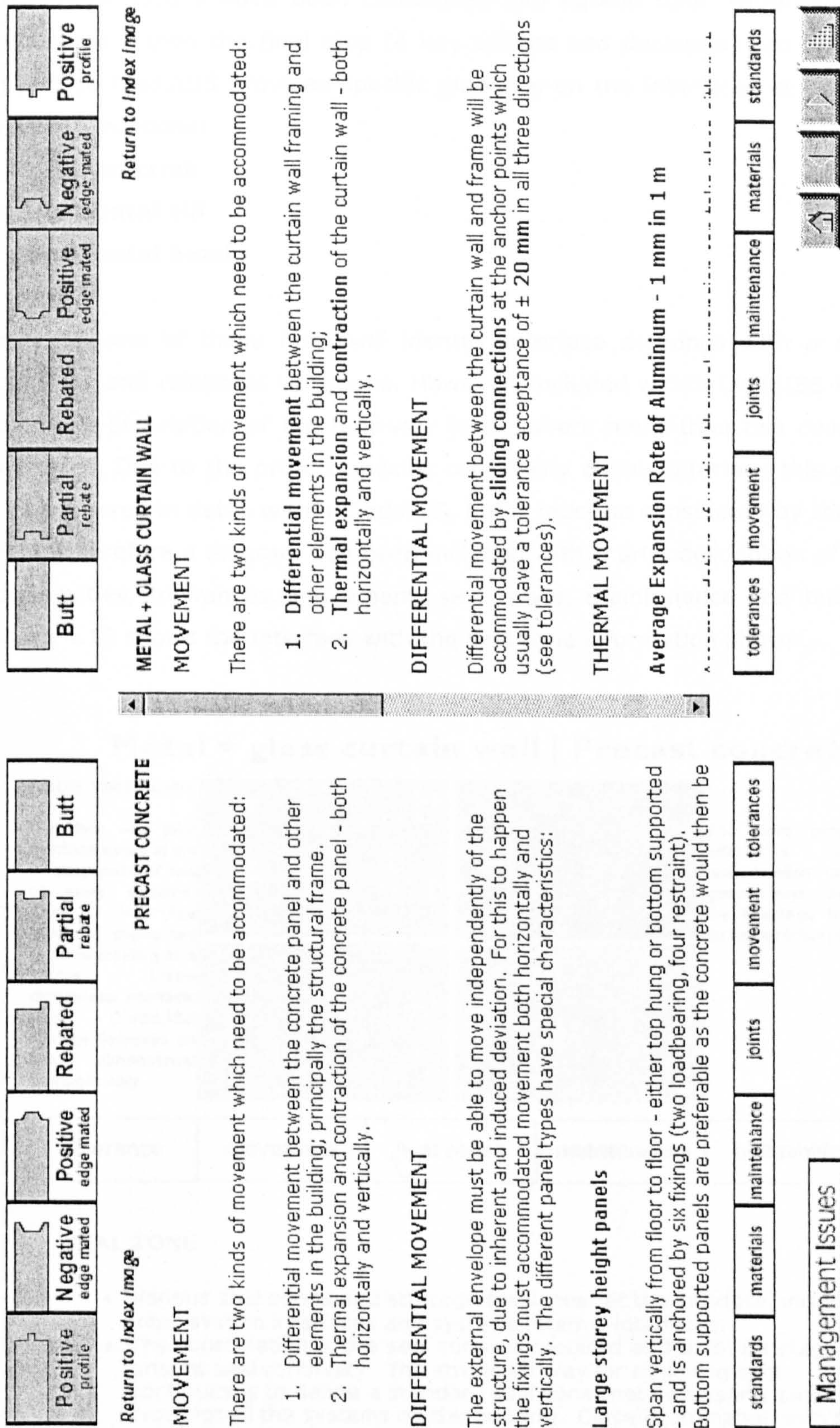
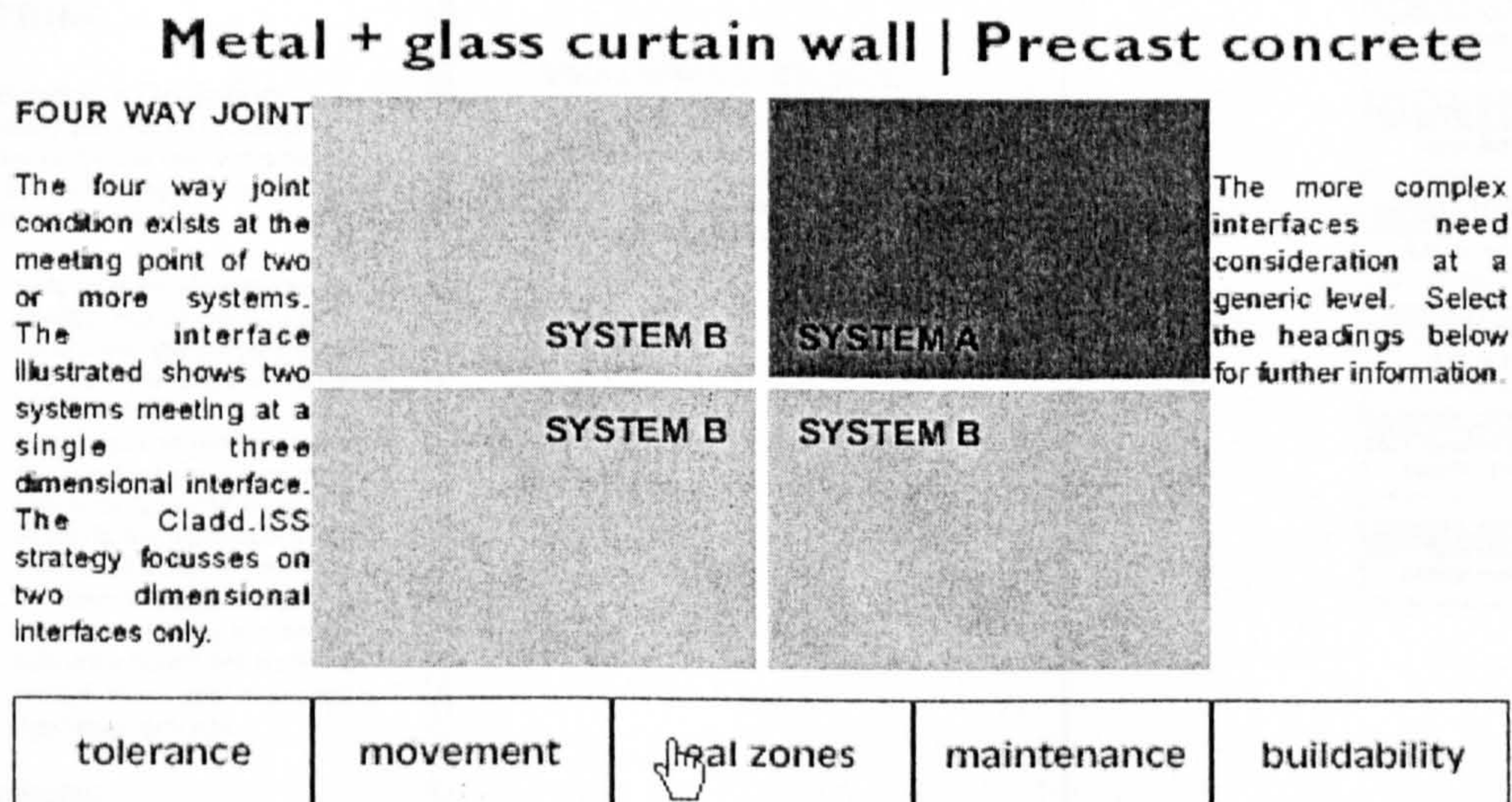


Figure 4.9: Split screen format showing the movement comparisons between the two cladding types. (The text screens scroll down to reveal more information.)

Once these issues have been considered and agreed upon within the design development then the final step (4 key actions and decisions) can proceed. At this stage CladdISS provides specific guidance on the interfaces at each of the following locations:

- **Vertical jamb**
- **Horizontal cill**
- **Horizontal head**

Selecting one of these links will identify interface drawings with a series of positional and relational variations. However, included within CladdISS is a brief positional description of the four-way joint (where more than two components interface). Due to the project-specific complexity of this interface this condition is not covered in detail within CladdISS, but it must be considered by the project team. Therefore a diagram has been included with a brief description of five key complexities, tolerances, movement, seal zones, maintenance and buildability. Figure 4.10 shows the interface with the seal zone information shown.



SEAL ZONE

- Various seal zones and strategies will meet at the interface, including inter-system interfaces and systems internal interfaces.
- The coordination of the seal zones is required at the design stage to ensure seal continuity. The strongest way for achieving seal continuity is to define a standard seal zone (not necessarily seal type) for all the systems on the building. Close coordination with the specialist subcontractors is necessary to achieve this.
- Seal material compatibility is also crucial. Consult the sealant manufacturer(s) to identify any problems.

Figure 4.10: Four-way joint with seal zone information shown

4.6.5 Step 4: Consider key issues and actions

After the initial interface detail has been considered by the project design team then the final CladdISS step (4) should be discussed before the design is agreed, namely to consider the key issues and actions. These include; tolerance and deviation, seals and their zones, profile characteristics, erection sequence, movement, maintenance and interface responsibility.

At this point (Figure 4.11) the user can view generic information on key actions and decisions for the two cladding types, on the left hand side of the CladdISS screen. On the right hand side of the screen there is a selection of buttons (the number will vary depending upon the interface chosen). When activated, these reveal detailed interface scenarios with specific actions and decisions. Table 4.3 shows the complete generic actions and decisions for precast concrete and curtain wall.

The screenshot displays the CladdISS software interface for a 'Metal + glass curtain wall | Precast concrete' interface. The interface is divided into three main sections:

- KEY ISSUES AND ACTIONS:**
 - Tolerance + Deviation:** The manufactured and erection tolerances for the two systems may vary by quite a degree. Strategies for the tolerance include:
 - Early determination of the panellisation of the facade - particularly the precast concrete will allow the tolerance range to be calculated;
 - Ensure that all parties involved at the interface are aware of all the tolerance issues involved, including the consequences of inability to achieve tolerance;
 - Coordinate the specialist subcontractors to ensure all tolerance issues are resolved;
 - Include worst case scenarios in the design process.
 - Movement:** Induced and inherent loads will place variable stresses on the interface, strategies for which include:
- SPECIFIC INTERFACE SCENARIOS:** The text on the left of the screen identifies the key generic issues for metal + glass curtain wall | precast concrete panels vertical interface. Select the buttons on the right to view the specific interface scenarios, with specific key issues.
- Cladd:ISS Buttons:** A vertical column of buttons on the right side of the screen, each with a small diagram and a number:
 - 1 BUTT BUTT
 - 2 BUTT BUTT
 - REBATE POSITIVE
 - 3 BUTT BUTT
 - 1 REBATE POSITIVE
 - 2 REBATE POSITIVE

Figure 4.11: Interface scenarios for precast concrete rebated and curtain wall butt interface

<p>Tolerance + Deviation</p> <p>The manufactured and erection tolerances for the two systems may vary by quite a degree. Strategies for the tolerance include:</p> <ul style="list-style-type: none"> • Early determination of the panellisation of the facade - particularly the precast concrete will allow the tolerance range to be calculated; • Ensure that all parties involved at the interface are aware of <u>all</u> the tolerance issues involved, including the consequences of inability to achieve tolerance; • Co-ordinate the specialist subcontractors to ensure all tolerance issues are resolved; • Include worst case scenarios in the design process.
<p>Movement</p> <p>Induced and inherent loads will place variable stresses on the interface, strategies for which include:</p> <ul style="list-style-type: none"> • Determine the expected movement rates for the various systems and components. The panellisation of the facade will affect the rates of movement, in much the same method as the tolerance; • Ensure the specified sealant will be able to accommodate the expected rate of movement. Co-ordination with the sealant supplier is essential.
<p>Erection Sequence</p> <p>Strategies and issue for an achievable erection sequence include:</p> <ul style="list-style-type: none"> • Where possible, surveys to ascertain level of variation should be carried out prior to cladding installation; • Ensure the anticipated erection sequence is achievable with regard to expected procurement routes and lead times; • The erection sequence may involve possible damage to components once installed. This possible problem should be considered at the design stage and tendering process.
<p>Seal Type + Zone</p> <p>Seal zone strategies include:</p> <ul style="list-style-type: none"> • Ensure continuity of seal zones through the interface, including drainage routes; • Co-ordinate sealant specification to maintain compatibility between the various seal zones; • Ensure seal system will accommodate expected movement.
<p>Interface Responsibility</p> <p>Strategies for the interface responsibility include:</p> <ul style="list-style-type: none"> • Assign the interface responsibility at the earliest stage possible. The responsibility for design, installation and supervision are the key assignments;
<p>Maintenance</p> <p>The key maintenance issues and strategies are:</p> <ul style="list-style-type: none"> • Access. Visual access is paramount for inspection and assessment. Physical access should be facilitated where possible to ensure regular cleaning, maintenance and repair; • Material degradation rates should be predicted, along with the identification of 'weak' elements in the envelope; • Determine the likely failure mode of the interface, and develop strategies; • System maintenance issues should be identified so that they may be incorporated into the interface strategy; • All the component life cycles should be identified and built into the O/M Manual. Where achievable, the interface design should facilitate component replacement.

Table 4.3: key actions and decisions for precast concrete rebated and curtain wall butt

This is the final stage of the CladdISS process with an interface scenario generically detailed. Figure 4.12 shows the completed interface.

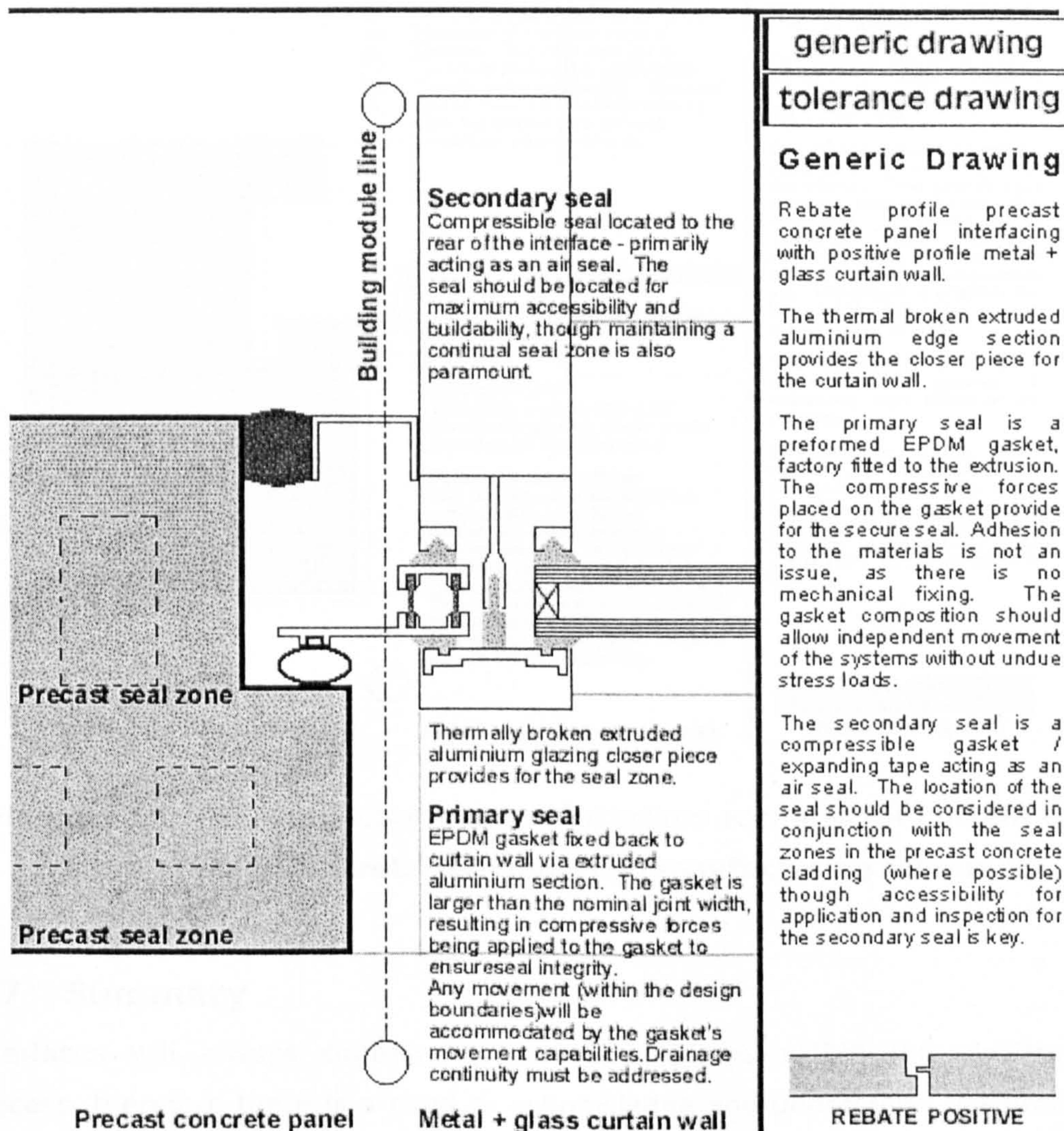


Figure 4.12: The completed generic interface for curtain wall and precast concrete

Throughout the interface management section the issue of tolerances within manufacture and construction has been identified. With this in mind CladdISS has included the same detailed design but with the added information of the tolerances of the two differing cladding types (figure 4.13).

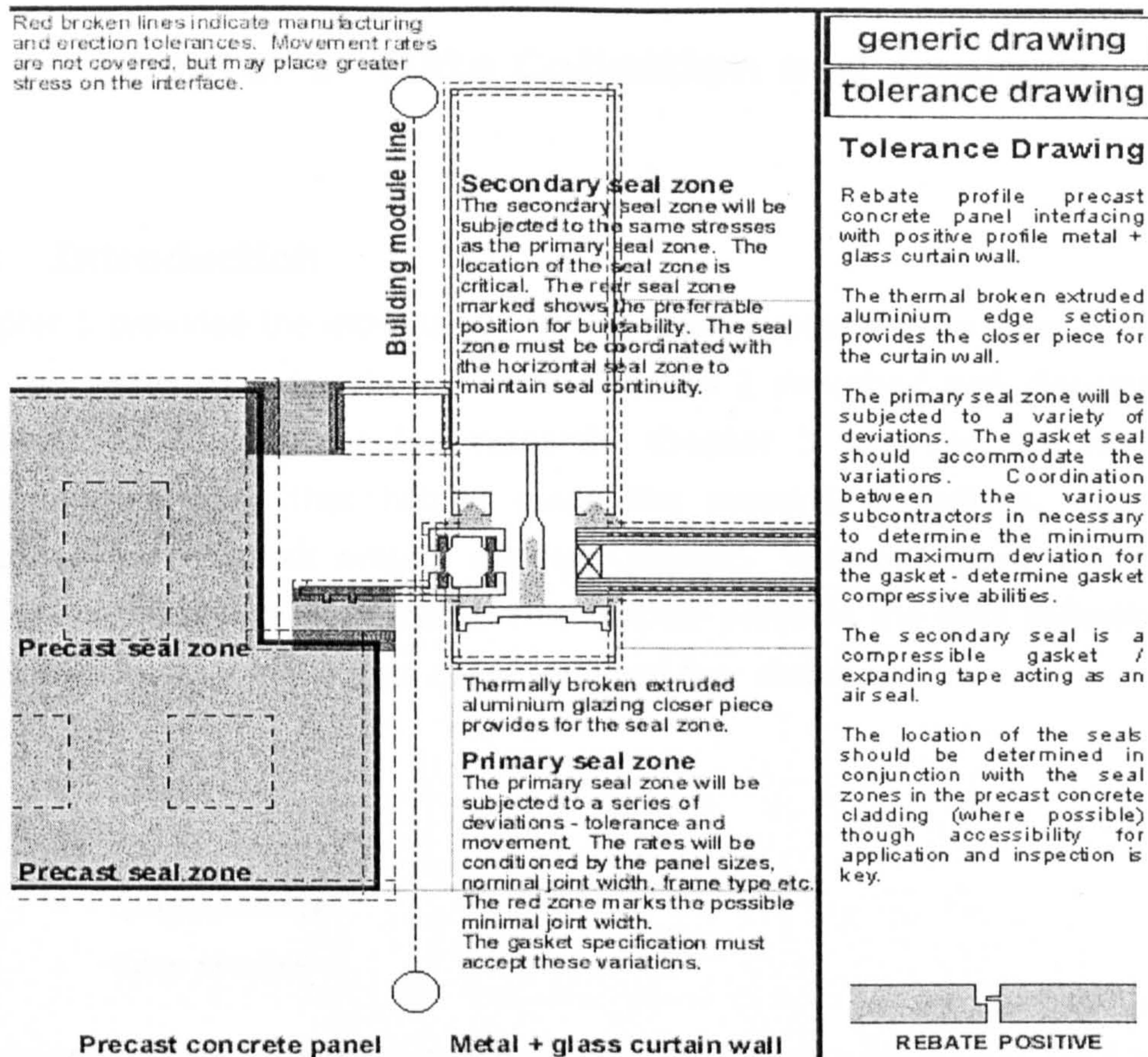


Figure 4.13: The completed generic interface scenario for curtain wall and precast concrete showing the manufacturing tolerances

4.7 Summary

Interfaces will always continue to cause problems within the construction process, therefore there is a need to acknowledge and understand the problems as early as possible. CladdISS is a tool that addresses these problems. It is intended to be useful to the whole construction process so that the issue of interface management becomes part of the construction process, from inception through to handover (Pavitt and Gibb, 2000).

Furthermore, all EPSRC funded research projects all have to be critically reviewed on completion. The CladdISS project attained a very high assessment rating; Appendix C shows the full judgement from the assessment panel. This further emphasises the importance and success of the research.

Chapter 5 Data Collection and Analysis

5.1 Introduction

Chapter 1 provided the introduction to the thesis explaining the aims, objectives and the justification for the research. Chapter 2 described and discussed the methodology adopted for the research. Chapter 3 provided the review of published literature that helped guide the research objectives. Chapter 4 described the research project entitled CladdISS "a standardised strategy for window and cladding interfaces". This chapter presents the data collection and analyses the results. The data collection used four methods:

- Interviews
- Focus groups
- Questionnaire
- Case studies

5.2 Key expert interviews

5.2.1 Introduction

The interviews were the first method of data collection following the literature review. At this stage the author was still relatively uncertain of the real-life details of how cladding projects were procured within the construction industry, on more specifically how the interfaces were managed as very little published information existed on these subjects.

5.2.2 Types of Interviewee

In total 40 key experts were interviewed they representing the following types of organisations:

- Architect/design (6)
- Structural Engineer (1)
- Consultant (4)
- Client (2)
- Frame contractor (2)
- Specialist cladding contractor (12)
- Major contractor (13)

It was essential that the interviewees had a high level of experience in their respective fields. The majority of the interviewees were contacts given by the project steering group. Therefore, most of the interviewees were known professionals who held senior positions within their respective companies.

5.2.3 The interview proforma

The interviews followed a semi-structured approach. This method allows the interviewee scope to answer the questions broadly but still allows the interviewer to remain within the boundaries of the topic area.

The interviews had two sections, firstly a matrix proforma sheet then a set of questions. The matrix questions were based upon three key areas;

- Design
- Manufacture
- Installation

The interviews took between one and two hours. The rationale behind the interview format and reasoning is fully explained in chapter 2; the methodology. In the second section of the interview the questions became more specific and covered the following key areas:

- Cladding types
- Common interfaces with the building envelope
- Interface warranties
- Interface tolerances
- Sealants at interfaces
- Health and safety
- Site based problems
- Procurement of cladding
- Common problems with interfaces
- Methods of improving management of the interfaces

Finally the interviewees were asked a series of questions relating to specific project phases. During this time the questions allowed the respondents to comment upon the interface issue away from the constraints of the specific matrix themes. A copy of the matrix proforma are included in Appendix D.

5.2.4 Purpose of the matrix

During the matrix questions the respondents were asked to use an involvement rating scale. Its purpose was to find out when the interfaces were actually considered in a project. Also to find out which if any of the interfaces appear to be prioritised over others. The project phases are separated into twelve stages and there are six levels of involvement (the involvement levels are shown in 5.2.5). The project phases are;

- 1 Inception
- 2 Client Brief
- 3 Concept Design/ Performance Specification
- 4 Project Specific Design
- 5 Full Specification
- 6 Product Production Drawings
- 7 Manufacture of Product Parts
- 8 Deliver to Site
- 9 Installation on Site
- 10 Handover
- 11 Facilities Management/ Maintenance
- 12 Demolition

5.2.5 The Matrix Questions

The matrix (shown in Appendix D) was based upon the following 23 key issues, which are grouped into four sections;

1 Choice of cladding type

- Cladding type

2 Cladding to building element interfaces

- Frame/Cladding
- Cladding/Cladding
- Services/Cladding
- Internals/Cladding
- Roof/Cladding
- Features/Cladding

3 Design detail interfaces

- Sealants at Interfaces
- Interface Tolerances
- Interface Warranties
- Interface Construction Sequence
- Maintenance of the Interfaces
- Workpackage Contents

4 Site interfaces

- Health & Safety
- Cranage/ Scaffold
- Testing Interfaces
- Protection to the Works
- Site Access
- Transportation
- Deliveries/ Storage
- Installation
- Inspect Interfaces
- Cleaning Down

The interviewees were asked to consider the 23 issues against the following levels of issue resolution (LOIR);

- **Nc** Not considered
- **A** Raised in general terms
- **B** Strategy considered
- **C** Strategy agreed
- **D** Details agreed
- **E** Situation resolved

Prior to the analysis of the 23 issues it is necessary to explain how the results have been established. The following information had to be established;

- Involvement time
- The LOIR mean for each issue
- The overall LOIR mean.

5.2.6 Involvement time

The purpose of the matrix was to find out when the issues are being considered. The first part of the LOIR is *not considered* therefore there is no involvement; the remaining LOIR *raised in general terms to situation resolved* is the total involvement period. Therefore, it is necessary to compare the *not considered* phases with the involvement phases for the 23 issues. Table 5.1 shows the results.

Two lines have been included in the table; a solid line shows the range of the start to finish of the involvement (*raised in general terms to situation resolved*) and a dashed line for the range of the durations of the *not considered*. In addition, there is an overlap between *not considered* and the involvement time, this was due to the varying responses from the interviewees. Some interviewees stated that the *not considered* period lasted longer (across more phases) than other respondents, thus causing the overlap.

5.2.7 Analysis of involvement time for the 23 issues

Table 5.1 shows the phases when the interfaces are *not considered* (dashed line). The table shows that the results are virtually the same within the respective subdivisions except for (3e), (4i) and (4j) which are explained in section 5.2.10.

- **1 Choice of cladding type**

The cladding type has the shortest *not considered* period of the 23 issues (phase 1-2) and the shortest involvement period (resolved at phase 8). Which was expected (explained further in 5.2.10, LOIR exceptions).

- **2 Cladding to building elements interfaces**

The six issues show virtually identical results with the *not considered* between phase 1-3 and the involvement period starting at phase 1 and resolved at phase 9. The one exception is cladding to services (2c) where the *not considered* is between phases 1-4.

- **3 Design details**

This subdivision shows that the *not considered* results range between phases 1-4 except for interface tolerances (3b), which was phases 1-3. Also, maintenance of the interface (3c) has the longest range between phases 1 – 5. However

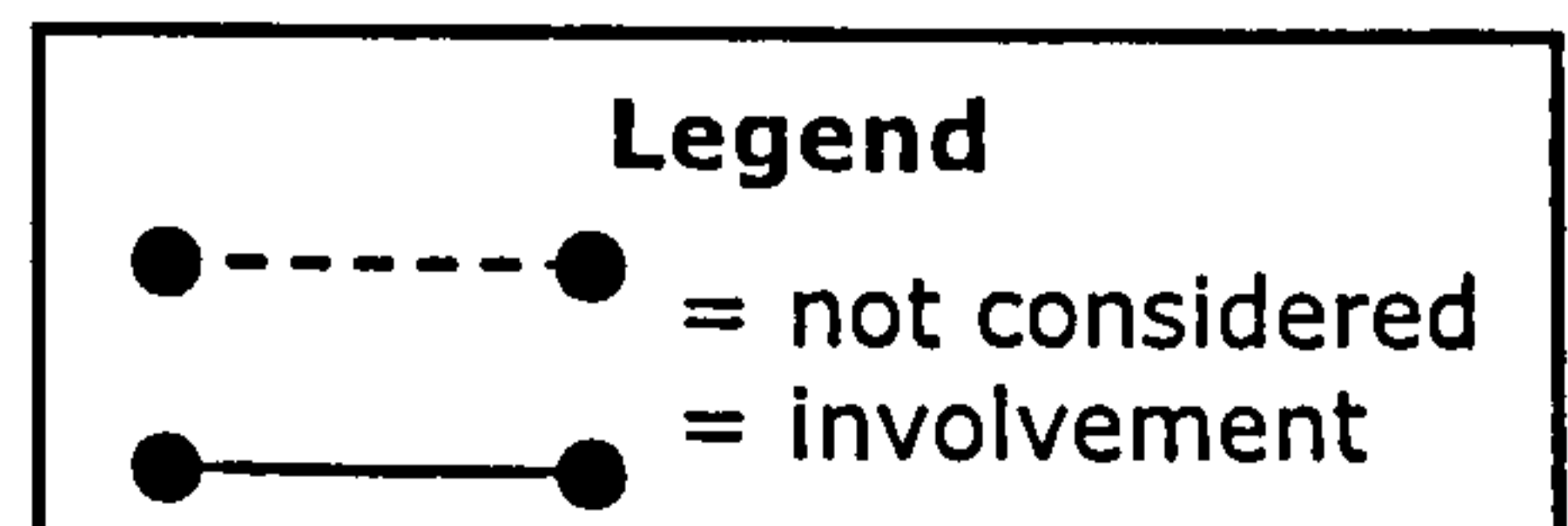
interface warranties (3c) and workpackage contents (3f) involvement does not start until phase 2.

- **4 Site interfaces**

This subdivision shows that the *not considered* results range between phases 1-4 except for inspect interfaces (4i) and cleaning down (4j), which range between phases 1-8 and 1-7 respectively. Also this subdivision shows that the involvement period starts later than the other three at phase 2. With the exception of health and safety and site access which start in phase 1.

		Phase 1 Inception	Phase 2 Client Brief	Phase 2 Concept Design Performance Spec	Phase 4 Project Specification Design	Phase 5 Full Specifications	Phase 6 Product Production Drawings	Phase 7 Manufacture of Product Parts	Phase 8 Deliver to Site	Phase 9 Installation on Site	Phase 10 Handover	Phase 11 Facilities Management/	Phase 12 Demolition
		1 Choice of cladding type											
1a	Cladding type	●	●	●						●			
		2 Cladding to building elements											
2a	Frame/Cladd	●	●	●	●						●		
2b	Cladding/Cladd	●	●	●	●						●		
2c	Services/Cladd	●	●	●	●						●		
2d	Internals/Cladd	●	●	●	●						●		
2e	Roof/Cladd	●	●	●	●						●		
2f	Features/Cladd	●	●	●	●						●		
		3 Design details											
3a	Sealants at Interfaces	●	●	●	●							●	
3b	Interface tolerances	●	●	●	●							●	
3c	Interface warranties	●	●	●	●							●	
3d	Interface construction sequence	●	●	●	●							●	
3e	Maintenance of interfaces	●	●	●	●							●	
3f	Workpackage contents	●	●	●	●							●	
		4 Site interfaces											
4a	Health & Safety	●	●	●	●								●
4b	Craneage/ Scaffold	●	●	●	●							●	
4c	Testing Interfaces	●	●	●	●							●	
4d	Protection to the Works	●	●	●	●							●	
4e	Site Access	●	●	●	●							●	
4f	Transportation	●	●	●	●							●	
4g	Deliveries/ Storage	●	●	●	●							●	
4h	Installation	●	●	●	●							●	
4i	Inspect Interfaces	●	●	●	●							●	
4j	Cleaning Down	●	●	●	●							●	

Table 5.1: The involvement time



5.2.8 The LOIR mean for each issue

An example is needed to illustrate how the LOIR means were established. Issue two of the matrix; 'frame to cladding' interface is used throughout the following sections as the example. The mean for the LOIR was calculated by firstly finding the five means for each issue; table 5.2 shows the example results.

	1	2	3	4	5	6	7	8	9	10	11	12			
Cladding/Frame Interface	Phase 1 Inception	Phase 2 Client Brief	Phase 3 Concept Design/ Performance Spec	Phase 4 Project Specific Design	Phase 5 Full Specification	Phase 6 Product Production Drawings	Phase 7 Manufacture of Product Parts	Phase 8 Deliver to Site	Phase 9 Installation on Site	Phase 10 Handover	Phase 11 Facilities Management/ Maintenance	Phase 12 Demolition	Total	Mean=total/2	Phase where mean falls
nc Not considered	20	16	2										38	19	1
A Raised in general terms	9	9	10										28	14	2
B Strategy considered	2	6	12	15	2								37	19	3
C Strategy agreed			5	11	16	2	1						35	18	5
D Details Agreed			2	5	9	20	4	2					42	21	6
E Situation Resolved					4	9	26	29	31				99	50	8

Table 5.2: Mean for the 5 LOIR for the cladding to frame interface.

Therefore the means for the cladding to frame interface can be summarised as:

- **N c** Not considered: Phase 1 Inception
- **A** Raised in general terms: Phase 2 Client Brief
- **B** Strategy considered: Phase 3 Concept Design/performance specification
- **C** Strategy agreed: Phase 5 Full Specification
- **D** Details agreed: Phase 6 Product production drawings
- **E** Situation resolved: Phase 8 Deliver to Site

This approach was used for all the issues.

5.2.9 The overall LOIR mean

Once the LOIR means were calculated for the 23 issues the overall mean for the LOIR was calculated. This was achieved by totalling each LOIR for the 23 issues and establishing the mean, for example the mean for (A) *raised in general terms* was calculated using the following method; there was one mean in inception (Phase 1), two in client brief (phase 2), sixteen in concept design (phase 3), three in project specific design (phase 4) and one in full specification (phase 5).

The responses per phase were then multiplied by the phase number, for example client brief (phase 2) has two responses therefore (2x2) equals 4. The totals were then added together and divided by 23 (the total issues). Therefore the mean for *raised in general terms* was calculated as;

$$1 + (1) + 2(4) + 16(48) + 3(12) + 1(5) = 70/23 = 3$$

Therefore the mean for raised in general terms is 3, concept design and performance specification. The same procedure was carried out for all the LOIR. The results for the overall LOIR means are shown in table 5.3.

	1	2	3	4	5	6	7	8	9		Mean phase
A Raised in general terms	1	2	48	3	1						3
B Strategy considered		2	6	56	25	6					4
C Strategy agreed				4	75	42					5
D Details agreed					5	66	56	24			6
E Situation resolved							7	112	45	30	8

Table 5.3: The means for the five involvement LOIRs

Therefore the overall LOIR means can be summarised as:

- A** Raised in general terms: Concept design/performance specification (phase 3)
- B** Strategy considered: Project specific design (phase 4)
- C** Strategy agreed: Full specification (phase 5)
- D** Details agreed: Product production drawings (phase 6)
- E** Situation resolved: Deliver to site (phase 8)

Table 5.4 shows the mean LOIR for each of the 23 issues. Where the issues LOIR varies from the overall mean this has been highlighted by a shaded box. For instance choice of cladding type LOIR all vary from the overall mean, whereas for the frame to cladding interface only A (*raised in general terms*) and B (*strategy considered*) vary from the mean and the other stages (CDE) occur in the same phases as the overall mean for the 23 issues. The exceptional LOIR is covered in the following sections.

		Phase 1 Inception	Phase 2 Client Brief	Phase 3 Concept Design/ Performance Specification	Phase 4 Project Specific Design	Phase 5 Full Specification	Phase 6 Product Production Drawings	Phase 7 Manufacture of Product Parts	Phase 8 Deliver to Site	Phase 9 Installation on Site	Phase 10 Handover	Phase 11 Facilities Management/ Maintenance	Phase 12 Demolition
1 Cladding type													
1a	Cladding type	A	B		C	D		E					
2 Cladding to building elements													
2a	Frame/Cladd		A	B		C	D		E				
2b	Cladding/Cladd			A	B	C	D		E				
2c	Services/Cladd			A	B	C		D	E				
2d	Internals/Cladd			A	B	C	D		E				
2e	Roof/Cladd			A	B	C	D		E				
2f	Features/Cladd			A	B	C	D		E				
3 Design detail interfaces													
3a	Sealants at Interfaces			A	B	C	D			E			
3b	Interface tolerances			A	B	C	D			E			
3c	Interface warranties				A	B	C		D		E		
3d	Interface construction sequence			A	B		CD		E				
3e	Maintenance of interfaces				A	B	C	D			E		
3f	Workpackage contents			A	B	C	D		E				
4 Site interfaces													
4a	Health & Safety		A	B		C		D		E			
4b	Cranage/ Scaffold			A	B	C		D	E				
4c	Testing Interfaces			A	B	C	D		E				
4d	Protection to the Works			A		B	C	D		E			
4e	Site Access			A	B	C		D	E				
4f	Transportation			A	B	C	D		E				
4g	Deliveries/ Storage				A		BC	D	E				
4h	Installation			A	B	C		D	E				
4i	Inspect Interfaces				A	B	C		D		E		
4j	Cleaning Down					AB	C		D	E			

Table 5.4: The overall LOIR results

Legend	
A	= Raised in general terms
B	= strategy considered
C	= strategy agreed
D	= Details agreed
E	= Situation resolved
Shade	= LOIR off the mean

5.2.10 Explanations of LOIR exceptions

1a Cladding type exceptions (all LOIR are earlier than the overall mean)

The results show that the cladding type is before the mean throughout the LOIR. This is expected, as the cladding type should be one of the first considerations when designing the façade for a building. This supports the view that the results are accurate.

2a Frame to cladding exceptions (LOIR A and B are earlier than the overall mean)

The frame interface has been acknowledged as being one of the most crucial interfaces and possibly the hardest to manage (see focus group and questionnaire results). Therefore it is understandable that they are considered earlier, however the involvement only appears in the early involvement stages and from the *strategy agreed* (C involvement) onwards it is with the mean. For the benefit of the early involvement to be fulfilled this should carry through to completion.

2c Services to cladding exceptions (LOIR D is later than the overall mean)

LOIR A-C has the same timing as the overall mean. Also LOIR E returns to the mean timing. However LOIR D is later than the mean. Also this was the only issue in the cladding to building elements subdivision to have a LOIR after the mean. The resolution of this particular issue tends to need a high degree of specialist information; most designers have little understanding of building services and specialists complete the majority of the design. Therefore, the details can only be agreed with the appointment of such specialists. The involvement of building services engineers in the early design has also been a source of dissatisfaction, which further emphasises the fact.

3a/3b Sealants at interfaces/interface tolerances exceptions (LOIR E is later than the mean)

Both of these are in the design details subdivision and, until LOIR E both have been with the mean. It was expected that the sealants at the interface might not be resolved fully until the installation phase because, despite being in the detail design division sealants still have important site implications. If the interface between two or more elements is designed late it is doubtful whether the sealants have been fully considered.

The perplexing result was the interface tolerances. Throughout the research the tolerance issue has been underlined as such an important issue with a need to consider this early. However the results show that the situations are not resolved until installation on site which suggests an ad-hoc, last minute approach to tolerances at the interface.

3c/3e Interface warranties/maintenance of interfaces exceptions (all LOIR are later than the overall mean)

In the design details subdivision the results show that the involvement for the interface warranties and the maintenance of the interfaces are raised and resolved late in a project. A concern is that the interface warranties situation is not resolved until the project is at the handover stage. Also, financial claims could occur against any of the contractors, especially if the interfacing parties disagree on the ownership of the interface or if a warranty has not been formally agreed at the contract agreement stage. Ultimately this will mean a cost to the project if not resolved.

However with the maintenance of the interfaces the respondents may have misunderstood the meaning of this issue. The author's intention was to identify when any decisions about maintenance have to be made. Maintenance of a project as its name indicates cannot be managed until the completion of a project. Therefore the respondents may have interpreted this as meaning that full resolution cannot occur until the handover stage.

Nevertheless the author emphasised during the interviews that the meaning of the maintenance of the interfaces was in its planning and not its implementation. With this in mind CDM regulations state the need for greater maintenance understanding in design, for this not to be resolved until handover means the health and safety plan that is handed to the client at completion could be technically incomplete.

3d Interface construction sequence exceptions (LOIR C is later than the overall mean)

It is possible that this result is a misrepresentation of the actual results and could be with the mean as the other categories are all with the mean. It is possible that mean for *strategy agreed* (phase 5), which is close to design completion, because at this stage in the process the project emphasis changes from design to manufacture. From this point onwards the main contractor has a

greater involvement in the process and the designers a lesser involvement. Ultimately the sequencing of the works will be the responsibility of the principal contractor who generally becomes the lead party at phase six (product production drawings) onwards. Therefore it may be considered by the respondents that responsibility of the interface lies with the principal contractor.

4a Health and safety exceptions (LOIR A and B appear before and D after the overall mean)

Out of all the issues this is the only one that has LOIR's both before and after the mean, therefore the results are confusing. As the LOIR (A) *raised in general terms* and LOIR B *strategies considered* are both before the mean, the involvement appears to be properly managed at the early stages. However as the project develops, the involvement seems to slip with *strategies agreed* being on the mean but *details agreed* and *situation resolved* after the mean.

With the introduction of the CDM regulations the author can only assume that this is due in part to legal requirements placed upon designers to consider health and safety in their designs. If this is the case it is worrying that once the interface design has been formulated it appears that health and safety then becomes less important the nearer the site operations become.

4b Cranage/scaffold and installation exceptions (LOIR D is later than the overall mean)

Cranage/scaffold and installation are very similar; both are predominantly site-based activities. In the design process the design team will have to consider the use of cranes and methods of installation for the design to be successful, however the *details agreed* is part of the remit of the principal contractor. The principal contractor will coordinate all cranage on site, especially if general user cranes are used: This also relates to installation, the contractor will produce a programme of works to suit the procurement of the building and installation will be included in the programme rationale.

4e Protection to the works exceptions (LOIR B, C, D and E are after the overall mean)

After the issue is first raised the other LOIR's are all one phase after the mean. It appears that after its early consideration at concept design stage it is then considered less important and probably becomes the responsibility of the specialist contractors to agree between themselves.

The protection of works between interfacing trades has to be suitably coordinated particularly if they are sequential, by definition cladding (2) cannot start before cladding (1) is finished. One element may be finished before the commencement of the next. This could affect the principal contractor because, if this has not been properly identified in the specialist contractors bid, additional costs will be incurred by either of the specialist contractors or the principle contractor in protecting the work.

4g Deliveries and storage exceptions (LOIR A, B, C and D are after the overall mean)

The results show that the *strategy considered* (B) is particularly late, two phases off the mean. However the *situation resolved* (E) has returned to the overall mean, this would indicate that deliveries and storage does not appear to be a priority at the early design of a project and it is the responsibility of the site management to consider its coordination. In a way this is expected, but if a site has peculiarities in its arrangement, for instance if there is little storage available on site or deliveries have to be at abnormal times, this could affect the design of the building.

4i Inspection of the interfaces/ cleaning down exceptions (all LOIR are after the overall mean)

The results show that all the LOIR are dealt with later than the overall mean. With inspection of the interfaces the resolution is at handover phase (10). If inspection of the interface is not resolved until this stage it may have been omitted from the cost plan. This can be insurmountable especially if cherry pickers or the like have to be used to inspect the interface.

With cleaning down, the *raised in general terms* does not appear until phase 5, full specification. By this time the specification has been finalised, therefore, if specialised cleaning agents are required on one cladding type this may have a detrimental effect on other interfacing cladding systems or building elements. Therefore this needs to be agreed before its use. The issue is resolved at installation on site probably by agreement between the interfacing specialist contractors.

5.2.11 Summary of the matrix questions

The matrix questions produced informative data; the information has shown how the interfaces are actually managed. It shows that certain aspects of the

interfaces are considered before others and some later than others. The choice of cladding type is considered and resolved first. Then the building element interfaces are considered, especially the frame to cladding interface which is addressed early in the initial stages. In general it appears that the design details and the site based interfaces are considered later than the building elements and possibly in some cases too late to ensure effective management.

5.2.12 Interview questions

The main source of data collection from the interviews was the matrix questions. Following this the interviewees were asked a set of questions related to interfaces. This section summarises the results from these questions. This is further explained in the methodology.

5.2.13 Managing the interfaces

The interviewees were asked if they had a strategy within their organisations for managing the interfaces and if so, how was it managed. Only half of the respondents claimed that they had a strategy - but few of these appeared to be fully worked out. One or two conducted workshops at early design stages but this was dependent on the procurement route adopted by the client. Some left it to the design team to review briefs and tender documents or relied upon standards such as ISO 9001. An interesting response from a cladding contractor was "no we do not have an interface strategy; the main contractor should consult the specialist contractor to do this".

5.2.14 Problems at the interface

The interviewees were asked what causes the problems at the interfaces. Pavitt and Gibb (1999) identified that the cladding process is divided into three sections, design, manufacture and installation. Therefore, wherever possible problems and solutions will be presented in these three groups.

Design

- Interface responsibility is not determined early enough (in early design wherever possible) and sometimes not until site installation. Also in worst-case scenarios some do not want to take the responsibility.
- Contractors are not appointed early enough to aid the design.
- There can be too much "over specification" of the cladding, causing complicated and sometimes impossible designs.
- Lack of understanding of the different materials.
- Lack of communication throughout the design stage.

- Lack of importance given to the interfaces.
- Incomplete design, especially of the interface.
- Insufficient design expertise from the specialist contractors.
- With standard systems you can never speak with the actual designer- this system was probably designed five years ago.
- Lack of design coordination.
- Often there is insufficient money allowed for the design of the interface because of this complexity.

Manufacture

- Lack of understanding of tolerances in manufacture and design. However, "The tolerance issue is not really a problem; it only becomes a problem when the interfacing specialists do not know the tolerances of the other products".
- Managing the lead times for materials. "Glass invariably will be on the critical path, as it can take up to 14 weeks for delivery. Problems occur when there is a change in design late in the process, there is no consideration for the delays that may happen".
- A cladding system will be complete in manufacture but has to be altered due to insufficient design of the interface. This is either carried out at site or has to be returned to the manufacturer's factory for the modification.

Installation

- Lack of training for site installation staff.
- Problems in getting the interfacing workpackage contractors to talk to each other.
- Contractors are not there when they should be- invariably this is due to the procurement route chosen by the client.
- Sequence in which the trades are programmed.
- "If a building is going to leak, 90% of the time it will be at the junction between two differing trades. More often than not it will be the roof to cladding interface, especially at complicated parapet details, up-stands and terraces".
- The term 'by others'. "Most contractors, to win work, especially with traditional procurement detail their own standard work and ignore anything over and above quoting 'by others'".

- There are 'unwritten' rules or assumptions made all the time with interfaces. For example, if there are windows installed inside precast openings, then the window installer should take the warranty of the interface, but this is rarely written down or agreed. Therefore the warranty 'falls' by default (not by agreement) in the package of the latest contractor.
- Frame to cladding interface. Invariably the two contractors are not formally contracted at the same time so assumptions have to be made. Exact fixing zones on the frame cannot be identified. So, often, revisits or reworks are required. With steel frame a method of rectifying this problem is to drill holes on site. However the cladding contractor does not like this because of the health and safety implications. Furthermore, to facilitate a hole in a steel frame at the factory is comparably cheap, but on site is expensive. Precast concrete cladding can be the worst, due to the weight of the panels bearing on the frame. In all cases loads need to be agreed not assumed.
- Sealants at the interface tend to be overlooked because there is no clear identification as to whose package they are in.

Some of the problems could appear in one or more of the categories but it does indicate that most of the problems occur in the design stage. Therefore if the design is properly managed the interface problems, particularly at the installation phase, could be reduced.

5.2.15 Project phase questions

Following the questions the interviewees were asked questions relating to the 12 project phases. An overriding issue that came from these questions was the issue of the procurement route; this will have a considerable bearing on the design, manufacture and installation of the interfaces.

5.2.15.1 Inception

At this stage is the cladding design discussed and in how much detail?

The majority of the responses were no. The main issue is the aesthetic appearance of the cladding, whether it will be stone or glass etc and the nature of the cladding type, or if the client has a preference. However, site location may dictate this as there might be a necessity to keep the appearance in line with the surrounding buildings.

5.2.15.2 Client brief

Is there a need to consider interface management at this stage?

The majority of the answers were no. However at this stage the procurement route may be discussed, which will have implications on interfaces. One interviewee responded "We have started to write briefs for clients, particularly the ones with little knowledge of construction. The issue of interfaces does come up often and we are now starting to think of them at this early stage. If there are two or more cladding types interfacing, you may be building in a problem, like whether different elements are compatible or hard to detail, so there is a need. However, invariably this never happens traditionally (project manger, anon)."

5.2.15.3 Concept design and performance specification

Have specialist contractors been considered at this stage?

Generally at this stage no contracts have been agreed, so specialists are not often contracted. However, the design team are in need of information. Wherever possible they will be talking in broad terms with specialist contractors to find out:

- Their workloads and timescales of projects.
- The type of company they are and whether they would be interested in the project. Can they procure the project financially and technically?
- Basic costs for the systems so budget costs can be ascertained.
- Some designers have preferences of a cladding system; they may consult the systems designers for lists of their preferred fabricators who could procure the system.
- If the overall project coordinator has been appointed at this stage they may be considering separating the workpackages between specialist contractors.

5.2.15.4 Project specific design

Do you specifically identify all the key interfaces for workpackages? (Shown example of register Appendix E)

The respondent's consensus was this was a good idea. All the designers said they tried to identify the interfaces but nothing as specific as the given example. The respondents concurred that if the project was procured by design and build or a management method it is the responsibility of the principal contractor to segregate the interfaces into separate workpackages. It appears that normally the interface details are provided by;

- A4 sketches
- Written in the specification
- Indicative drawings

5.2.15.5 Full cladding specification

How much input does the specialist cladding contractor have to the specification? And what type do you use?

The procurement route is crucial here, if the traditional route is used, there is very little input from the cladding contractor. Normally the specialist contractor designs their system to the specification. If a design and build or construction management route is undertaken then a considerable amount of input occurs. "They can input their own design criteria which can be the basis of the specification".

Whoever is responsible for writing the specification uses one of the following:

- NBS specification.
- CWCT standards (specifically for curtain wall and windows).
- Both of the above.
- In house, specification writers with NBS and CWCT "add ins."
- Consultants with NBS and CWCT "add ins."

One specialist contractor added, "the designer/architect is supposed to write it, however in my experience they are often massive generic documents that are slightly changed from project to project without much consideration of performance criteria".

5.2.15.6 Product production drawings

When producing the drawings, whose responsibility is it to detail the interface design, and who is responsible for their approval?

There were varying responses to this, depending upon the respondent's profession. All the designers/architects said it is the specialist contractor's responsibility to expand upon the initial or general arrangement drawings. Once these have been completed it is the responsibility of the design team to approve them. Furthermore, the interfacing parties normally design the interface and then the final design is agreed between them.

A significant factor was that there was only one respondent who indicated that the specialist contractor who has been given the responsibility of the interface must draw the interface. "Especially when there are complex interfaces such as

the frame to cladding or roof to cladding, then the responsibility has to be assigned. We (project managers) are responsible for the approval of the designs”.

Some specialist contactors replied that, “Often the interface is not designed at this stage. The interfacing systems are designed by the architect/ designer but not the actual interface, invariably this gets settled at site installation. However, the final approval will either be with the lead architect or the construction manager dependent on procurement route”.

5.2.15.7 Manufacture of product parts

How much communication with specialist suppliers is there at this stage?

The majority responded significant, but the matter of interfacing with other suppliers appears never to happen. The main communication at this stage appears to be:

- QA purposes either with the principal contractor or the design team taking the lead.
- Information for material manufacturing tolerances; especially glass manufacture and its supply time.
- Supply chain management issues especially for complex or long material supply routes. One respondent answered that “We like to be involved as early as possible with the suppliers, particularly with glass supply we are always endeavouring to find methods of reducing its lead and supply time.

5.2.15.8 Deliver product to site

How much communication is there with the principal contractor prior to delivery?

This question returned an unexpected response. This is principal contractor driven, to how much communication and planning is carried out depends upon the contractor. Comments include:

- “We work to a just in time principal we try to install our panels (precast) straight from delivery, therefore at this stage we are in constant communication with the principal contractor to plan this, however you would be surprised how many contractors manage this interface poorly and delays occur”.
- “Performance monitoring is required, especially if you have two specialists installing at the same time. Problems occur when there is one general user crane, a very common practice for inner city sites. The specialist and ourselves (principal contractor) need to have numerous interface meetings prior to site work and during the installation period. A problem

happens when the specialist contractor does not perform to the programme as promised”

5.2.15.9 Installation

Who is responsible for monitoring the frame tolerances prior to the cladding installation and does it ever happen that the frame, cladding and principal contractor check them together?

The majority responded with it's the frame contractor's responsibility to produce a frame to given tolerances. The principal contractor then accepts the frame after it has been surveyed. Comments included:

- “It should be written into the performance specification, if there is one, to stipulate acceptable construction tolerances for the frame.
- “Tolerances of the frame must be agreed as early as possible, however this sometimes never happens”.
- “It very rarely happens that three parties ‘sign off’ the frame, it is a good idea but often they are working to different time scales and often will not all be ‘on board’ so it cannot be achieved”.
- “We have had plenty of problems with this interface, wherever possible we will pay the cladding contractor extra to have a ‘token’ site presence available on site when the surveying of the frame happens, it adds extra cost but it saves holistically”.
- “This is one of our biggest problems, especially traditionally. We start to install our panels and the frame is all over the place, but it is too late as it is already built. So the contractor either ‘scabbles’ the concrete off or we have to get over it, generally altering our brackets. Ultimately extra cost is incurred, then the discussion starts about who will pay for this variation”.

5.2.15.10 Further points raised in the interviews

The following are general statements made during the interviews.

- “Estimating at the interface is a problem to us (specialist contractor). Who is fixing a particular flashing? We don't know so we have to tender on very sketchy information. Improved information will improve the tender process. Also we attend pre-order meetings and the architect has drawn detailed interface drawings and sometimes the sequencing of operations is wrong so it can't be constructed. Therefore the design that the tender is based upon is different to the actual design. This is a major problem especially if we have already won a contract as claims are incurred.”

- “Partnering is the big issue at the moment but it is difficult to partner with a principal contractor because invariably contractors will still be looking for lowest price. Clients don’t mind paying slightly more if the project is open early/on time (shops stores etc). With these types of projects the interfaces can be managed so much easier because the client and their partners are prepared to work together.”

5.2.15.11 Summary of the interviews

The interview findings can be summarised as;

Design

- Cost is the driving factor for all projects; the clients must be made aware of the holistic costs.
- Performance specifications are too long and put too much emphasis on the specialist contractor.
- There are too many design changes throughout the process.
- Some consultants carry the design too far and are “out of their depths” with the design.

Manufacture

- Longer lead times are required to enable easier management of the construction process.
- Clients should be made aware of the length of time for the supply chain (glass can take anything up to 15 weeks for delivery).

Installation

- Accurate programming is essential.
- Using the term ‘by others’ causes interface problems.
- Competitive tendering only achieves the lowest cost at the expense of quality
- The procurement route is a major factor. Routes that permit specialist contractor input allow the interfaces to be managed in an improved way.
- The workpackages are too separated and generally driven by cost (mainly by the contractors)
- Wherever possible the whole envelope should be undertaken by one sole contractor

5.3 Focus Groups

5.3.1 Introduction

Following the interviews the next form of data collection was the focus groups. In total there were two industrial focus groups, not including the mini focus groups convened during the project steering group meetings (see chapter 4, CladdISS). The intention of the focus groups was to expand upon the data gathered from the literature review and interviews and concentrate on specific issues as and when they became relevant.

5.3.2 Focus group one

The intention of the first focus group was to have representatives from all the major disciplines within the cladding process, these being design, cladding consultants, specialist cladding contactors and management of construction projects.

5.3.3 Attendants at the Workshop

The choice of attendees for the focus group was essential, it was necessary that they were experts in their given field. Also it was necessary that they would interact well with the other attendees during the meeting. Therefore the author chose attendees that he had previously interviewed and individuals that had shown an interest in the research.

It was necessary to keep the number of representatives to a relatively low number so that the group could remain 'controlled' and allow them to interact with each other. As there were two representatives from each discipline it was decided to separate the focus group into two sub-groups. Table 5.5 shows the representatives and their associated discipline and company.

Name	Company	Discipline
Andrew Brown	Sheppard Robson	Designer
Gareth Byatt	Bovis	Construction
Terry Charnell	Schuco	Cladding systems company
John Libby	Schuco	Cladding systems company
John Millington	Taylor Woodrow	Construction
Mike Stacey	Brookes Stacey Randall	Designer
Geoff Street	BAA	Client/Consultant
Steve Tanno	Buro Happold	Consultant

Table 5.5: Focus Group 1 Attendee

5.3.4 Aims of the focus group

The aims of the focus group were to;

1. Rank and rate the cladding interface categories
2. Ascertain information required at the different stages, and its originator
3. Establish problems occurring at the interfaces
4. Establish best practice ideas for managing the interfaces

5.3.5 Ranking and Rating of the Interfaces

Each person was asked to rank the most problematic management interface involving cladding to a building element. The focus groups ranked the issues as follows:

- 1 Cladding- frame
- 2 Cladding- cladding
- 2 Cladding- (features, cleaning, add-ons)
- 4 Cladding- roof
- 5 Cladding- services
- 6 Cladding- internals

However, due to the small sample size the author felt that the results were not conclusive enough to represent a true answer to the question. Moreover this assumption was further underlined by the nature of the respondent's discipline (e.g. designer, construction manager). For example a precast specialist contractor (Trent concrete) maybe affected more than an aluminium cladding system installer (CAP aluminium) when managing the frame/cladding interface, purely through the differing weights of the two systems.

Therefore at this juncture it was decided that this particular result was only preliminary and not conclusive and would be researched further via the questionnaire.

5.3.6 Information required at the different stages

The focus group delegates were all given a simplified version of the process protocol map (chapter 3, section 3.13). The group was then asked to suggest information required to manage the six interfaces and the phases in the process where the information is required to achieve optimum best practice.

The results are shown in tables 5.6-5.11. Due to the time constraints only the cladding to cladding interface was completed. The remaining five areas were later discussed at subsequent project steering group meetings, within the 'mini' focus groups.

• **Cladding to Cladding Interface**


Information required by whom & from whom		Type of info required	When (process protocol phases)	How is this info obtained
From Architect	By Client/ building owner	<ul style="list-style-type: none"> Liabilities if abutting to existing cladding Dates of installation plus presents conditions and warranties of existing If using existing systems which type is preferred 	Phase 2 Phase 3 Phase 3	Discussions Meetings through out Sketches early as possible
Architect	Specialist contractor	<ul style="list-style-type: none"> Manufacturers type and models if applicable Dimensions Movement and manufacturing tolerances Buildability and construction sequence 	Phase 2-4 Phase 2-4 Phase 2-4 Phase 3	GA drawings at detailed design
Specialist contractor	Specialist contractor	<ul style="list-style-type: none"> Outline information Actual details of the interface Waterproofing details Construction and manufacturing Tolerances Differential movement details 	Phase 4 Phase 7 Phase 7 Phase 7 Phase 7	
Structural engineer	Specialist contractor	<ul style="list-style-type: none"> Support conditions 	Phase 6	
Construction manager	Design team and Specialist contractor	<ul style="list-style-type: none"> Programme implications 	Phase 3- (outline) Phase 7- (detailed)	
Cladding consultant	Architect (design team)	<ul style="list-style-type: none"> Appearance internal/externally of the interface Structural movements at the interface 	Phase 5 Phase 6	

Table 5.6: Cladding to cladding interface results

- **Cladding to Frame Interface**

The focus group discussed whether frame considerations should be separated into elements, such as steel and concrete (in-situ or precast). It was decided that the principles of managing concrete and steel frame are virtually the same, therefore the interface is classified as "frame" throughout the findings, however if there are areas specific to a particular frame these have been identified and included.

Information required		Type of info required
By Cladding contractor	From Design team	<ul style="list-style-type: none"> • Cladding zone allowances • Rules, cast in sockets or not • Frame movements during construction and in service • Tolerances of frame material
Design team	Frame contractor/ cladding designer /Structural engineer	<ul style="list-style-type: none"> • Frame type • Form of attachment that is most efficient for cladding and frame • Spans between structure beams etc
Design team	Frame contractor/ cladding designer /structural engineer	<ul style="list-style-type: none"> • Frame movements predicted • Frame tolerances • Fixing methods • Cladding type with loads to be supported
Frame contractor	Cladding supplier	<ul style="list-style-type: none"> • Cladding movement predicted • Cladding tolerances • Weight of panels and spandrel areas
Structural engineer		<ul style="list-style-type: none"> • Standard edge detail to frame plus beam deflection • Optimum fixing/frame details

Table 5.7: Cladding to frame interface results

- **Cladding to Roof Interface**

Information required		Type of info required
By Cladding contractor/ roof contractor	From Design team	<ul style="list-style-type: none"> • Form of roof • Material compatibility • Nature and magnitude of movements in the structure at the interface
Roof contractor/ cladding contractor	Principal contractor	<ul style="list-style-type: none"> • Sequences of assembly
Architect	Specialist contractors	<ul style="list-style-type: none"> • Weathering principles who is responsible for it • Who warrants the interface • How and when the interface is tested
M&E engineer	Design team	<ul style="list-style-type: none"> • If ventilation is critical

Table 5.8: Cladding to roof interface results

- **Cladding to Internals Interface**

Information required		Type of info required
By Cladding contractor	From Design team	<ul style="list-style-type: none"> • Movement, dimensions and tolerance details of floors etc abutting to cladding
Dry liner/ cladding contractor	Design team	<ul style="list-style-type: none"> • Dry lining details of the perimeter and columns include space to build details
Ceiling contractor	Design team	<ul style="list-style-type: none"> • GRG ceiling detail to window edges • When and where blind boxes are positioned • Type of sections being used
Floor contractor	Cladding contractor	<ul style="list-style-type: none"> • Type and locations of cladding bracketry for support with floors especially if raised
Architect	Cladding contractor	<ul style="list-style-type: none"> • Buildability of all interfacing areas connected with the cladding

Table 5.9: Cladding to Internal interface results

- **Cladding to Services Interface**

Information required		Type of info required
By Cladding contractor	From Design team	<ul style="list-style-type: none"> • What are they • Dimensions and positions of the services particularly dust through, engineer will have to allow this in design
Cladding contractor	M&E contractor	<ul style="list-style-type: none"> • Access requirements during construction • Cast in services in the cladding • Limits of responsibility/ supply/ connections of different services
M&E contractor / Cladding contractor	Design team	<ul style="list-style-type: none"> • Tolerances , movement, and adjustments of the services • Fixing positions
Construction manager	M&E and Cladding contractor	<ul style="list-style-type: none"> • When in the programme are they installed • By whom

Table 5.10: Cladding to services interface results

- **Cladding to Secondary Components**

Information required		Type of info required
By Structural engineer	From Architect	<ul style="list-style-type: none"> • Brise soleil / entrance canopies, weight and movement are they independent of the structure or attached? • Weight of cradle and loads imposed on the façade • Wind loads and loads imposed upon joints
Specialist contractor	Architect	<ul style="list-style-type: none"> • Functional specification and performance requirements • Aesthetics and quality • How it is to be fixed • Material compatibility colours and textures • Testing requirements
Architect	Specialist contractor	<ul style="list-style-type: none"> • Any dimensions (standards) e.g. cradle sizes • Codes and regulations

Table 5.11: Cladding to secondary interface results

5.3.7 Problems and solutions at the interfaces

Finally the focus group delegates were asked to identify common problems that occur at the interfaces, followed by solutions. Due to time constraints only the cladding to cladding, roof, services and secondary components were discussed.

Cladding to cladding problems design

- Late design finalisation of the interface.
- Lack of understanding by designers of ALL the different types of cladding systems.
- Solid cladding systems interfacing with void cladding systems cause problems in design.
- Lack of fit between the two cladding systems
- Lack of understanding of how to design the interface between the two cladding systems
- The interface between a new and existing building, often due to inappropriate definitions due to early design assumptions.
 - Lack of information, design team should have a duty to inform the owners of the abutting/adjoining structure
 - No clear responsibility of interface tolerances and warranty.
- Inappropriate definition and assumption of the interface.

- Due to lack of buildability knowledge.
- Lack of performance knowledge.

Manufacture

- Following decision on the different cladding types
 - Different manufacturing and installation tolerances of the cladding systems
- Different movement issues of the cladding systems

Installation

- Confusion of responsibility in the event of problems occurring during installation.
- Programming /sequencing issues
 - Non optimised construction related to - sequencing/ programming/ logistics
 - Buildability issues due to design assumptions by the team without full understanding of the cladding systems
- Incorrectly installed interfaces
 - Due to lack of understanding by the installers
 - Too many differing sizes of panels etc at the interface
 - Inaccurate or poorly designed drawings of the interface, making the installer "bodge" the interface connection.

Cladding to cladding solutions

Design

- Appoint key parties at the same time. All of the cladding parties should be appointed early enough for substantial design involvement and for them to agree principles.
- Ownership in the design team for the design of the interface must be clearly defined as early as possible.
- Early involvement of the parties may occur by considering the different procurement options - construction management or design and build.
- Risk assess the design teams knowledge of that particular type of cladding, if possible, this may include assessing their expertise from previous similar projects and feedback from known clients or establish whether tools are available to provide this information.
- Make responsibility/ ownership of the interface a key point at all the stages in the design process, as early as possible and clear as possible.

- Obtain surveying reports as soon as possible regarding abutting to an existing building or cladding system.
- Wherever possible standardise building dimensions thus interface details will follow suit.
- Specific communications must be undertaken
 - At the briefing stage - the concept behind the design
 - From interface designer to the installer - so they understand the principles of the design and how the design works in practice
- Detailed design finalisation should be agreed before a project starts on site including all the interfaces.
- Increased use of EDI (electronic data interchange) to progress the design development.

Manufacture

- If design team are not knowledgeable in particular aspects of tolerances and movement, they must seek advice from specialists, and not make assumptions.

Installation

- Risk assess the consequences of lack of information in the process regarding
 - Disruptions in the programme
 - Cost
 - Any contingencies by the specialist contractors
 - How the specialists plan to manage the work

Cladding to secondary components problems

Design

- Material incompatibility problems.
- Tolerances and buildability at the penetrations.
- Different types of cladding will cause more problems than others especially penetration and sealing. Rainscreen cladding proves highly problematical
- Restraint details.
- Planning and environmental issues (where the building is situated will affect the design of the features).
- Cold bridging.
- Cleaning of the features.
- Cleaning cradles
 - Access plan

- Access systems are designed in accordance with CDM
- Restraints
- Profile
- Often the features are "after thoughts."
- Trapped water at the interfaces.
- Birds soiling and eating the sealants (thus maintaining the interface).
- Durability e.g. stone features (life cycle costs).

Installation

- Too much site drilling (thus added expense).
- Difficult access for installation.
- Corrosion at penetrations.
- Sealing the penetrations.
- Loads imposed on the cladding from the features especially that of heavy sunshading.
- Fixing the features to the cladding.
- Warranties at the interfaces.

Cladding to secondary components solutions

Design

- Try to avoid, wherever possible, hanging features off the structure- design for the load to be supported by the cladding. If the cladding is supported by the structure there is a risk of cold bridging and the interface detail will be harder to seal where it penetrates the cladding. Whereas supporting directly off the cladding will eliminate these problems.
- Restraint systems must be finalised at phase 6, coordinated design, and not post tender.
- To avoid cold bridging either omit completely from the design or, if not possible, consult expert analysis for solving the problem.
- Design to minimise birds resting on the cladding.
- Design to minimise streaking consider using hidden drains.
- Design the building plan as early as possible to avoid inaccessible areas for the cleaning cradles and access.
- Consider maintenance contract - specifically bought with the façade, who maintains the sealants, is it the responsibility of the supplier or is it the responsibility of the principal contractor?

Cladding to services problems

Design

- Often not enough space is allowed to accommodate the services.
- Lack of fit /buildability issues.
- Durability of the differing elements.
- Motorised blinds cause problems due to the complexities of their function.

Manufacture

- Glass failure due to shading system
- Type of coating on the glass will cause design implications due to heat gains and losses.

Installation

- Poor co-ordination of the erection sequences

Cladding to services solutions

Design

- Windows as a rule are made to open manually, keep the design as simple as possible
- Careful consideration of heat gains and losses must be included in the specification
- Services will almost certainly require the input of specialist M&E contractor early in the design development
- There must be flexibility in the design to aid the above problems.

Cladding to roof (the issues are similar to the cladding to cladding)

Design

- The design team should set the interface detail and the responsibility of the interface
- Wind can cause 'uplift' at the interface - make a check list to ensure this has been identified
- Cladding generally has higher performance requirements than a roof, but there is greater movement in the roof, this must be considered at the design stage

Installation

- "The interface might leak so who is responsible for this eventuality?"- Make sure the interface responsibility is clearly identified along with a warranty

5.3.8 Focus group one conclusion

Design

- The client, project manager and design team should risk assess the knowledge of parties before commencement of the project i.e. employ a designer with expertise in curtain walling to design a building with curtain walling not a building with profiled metal panels.
- The interface should be defined as early as possible along with the responsibility for its resolution.
- There must be a greater emphasis placed on buildability and its complexities.

Manufacture

- There must be a better understanding of manufacturing and construction tolerances. Also the tolerances must be managed from the onset.

Installation

- All installation details must be passed down to site level as clearly as possible and as soon as possible.

5.3.9 Focus group two

Focus group one collected excellent data on the design (phases 3-6) at the interfaces but very little relating to the post design period (phases 6-8). This was due in part to the dominance by some of the delegates at the focus group; however this is common with this type of data collection. This is further explained in the methodology (chapter 2). Therefore it was decided that the second focus group would concentrate on the "post tender" aspects in the process.

As for focus group one, the choice of attendees was essential and the author used contacts within the project steering group. Taylor Woodrow was asked to invite their construction managers, particularly ones involved with the day-to-day management of cladding. Also Kawneer were asked to invite some specialist cladding contractors involved with fabrication and installation of their cladding systems. In total there were twelve attendees table 5.12 shows the representatives and their associated company.

Focus group representative	Company
Kenneth Buckle	Taylor Woodrow
Peter Bryson	
Alan Cohen	
Ray Elliott	
Roger Evans	
Russell Fry	
Stuart Heaysman	
John Millington	
John Williams	
Martin Wilson	
Steve McAreyvey	
Martin Shepperd	
Dave Fletcher	Kawneer

Table 5.12: Focus Group 2 Attendees

5.3.10 Aims of the focus group

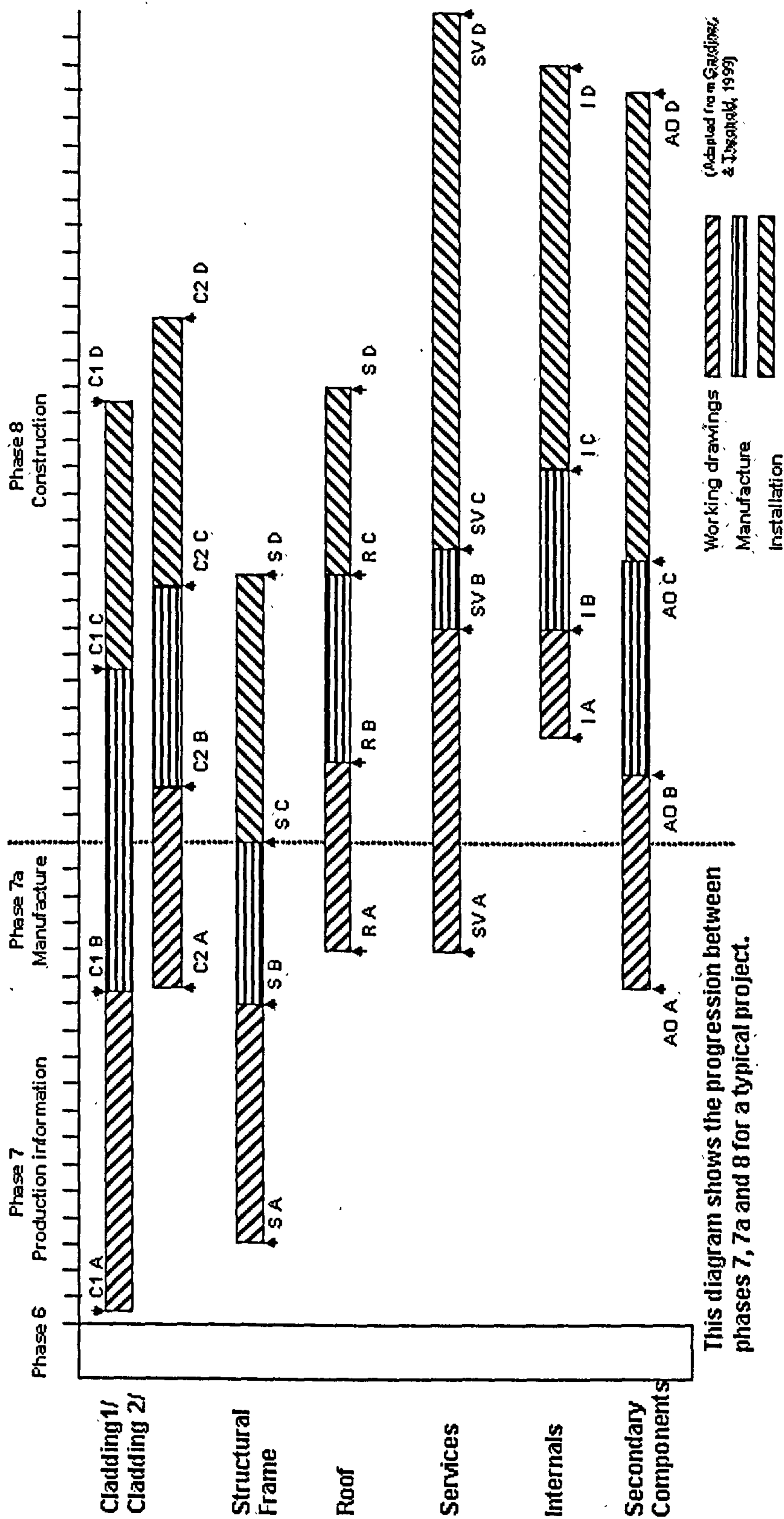
The aims of the focus group were established beforehand as follows;

- 1 To evaluate the authenticity of the bar chart displaying phases 6-8 of the process map (shown in figure 5.1).
- 2 To establish cladding interface problems that occur at the post tender stage, particularly at site level.
- 3 To establish methods of preventing these problems.

It was suggested at the start of the focus group that the ultimate aim for the discussions should be "best practice".

The focus group acted as a brainstorming session initially and then discussed the interface problems.

Cladding interfaces at production / construction phase



This diagram shows the progression between phases 7, 7a and 8 for a typical project.

Figure 5.1: Phase 6-8 bar chart

5.3.11 Bar chart evaluation

From previous data the author formulated a bar chart that represented the post tender (phases 6-8) production. The production has been separated into three elements.

- Design
- Manufacture
- Construction

The bar chart was displayed on a screen for all the delegates to view. The purpose was to ascertain its authenticity and whether there was a need for changes and additions.

The comments were;

- The chart is slightly too simplistic.
- The working drawing section would generate many stages therefore there is a need to express this process.
- The chart would be the ideal solution but in real projects the design of the structural frame would happen before the cladding design.

5.3.12 Post tender problems

The following statements have been compiled from comments made at the focus group. They are all issues that occur commonly in construction although the author acknowledges that they are not inevitable for every contract. Therefore, a high proportion of this data was used in the validation questionnaire (section 5.4).

Design problems

- The design team has problems with differential movement of materials.
- Design tolerances are unrealistic and cannot be achieved on site especially when interfacing with other materials.
- Material compatibility can be a problem if not considered thoroughly.
- The designs are too complicated, unrealistic and not thought through enough.
- There is a lack of buildability knowledge especially in early design this then causes problems when it comes to site assembly.
- The details of the structure are always unclear making the cladding loads impossible to be accurately calculated.

- Drainage between two cladding systems is overlooked or poorly designed and detailed.
- Lack of understanding of the system production and design. For example how the water is drained from the system and how the seal is achieved.
- There is no design input at site level, thus if design problems occur it will be the responsibility of the installer to "get over" the problem.
- Non-standard designs fail particularly those at the interface. Therefore these are the details that need to be tested.
- There is a lack of standardised components.
- Added eyebolts etc are always the place where the leaks occur. The seal is 'bodged' using sealants to overcome the problem.
- There is unclear definition of what is intended by the term contractor design.
- Designers tend to concentrate mainly around the concept of the design and pass the responsibility for detailed design to others, usually the specialist contractor.
- Bid packages are not clearly defined.

Manufacture problems

- The design team and clients are unaware of the lead times for certain materials. On some projects there has been over ordering of the material to accommodate breakage or damage.
- Lead times are too short causing insufficient design times for crucial designs, such as the non-standard interfaces.
- There is a lack of manufacturing and installation awareness by designers especially when different materials or cladding types interface.

Installation problems

- The building envelope is always the part of the construction process that causes the most problems, in construction and through latent defects.
- It is not usually possible to place contracts for all cladding package orders at the same time.
- 5% of the problems take 90% of the effort to resolve and these are normally the interfaces.
- A need to 'weather' the building (make the building watertight) as soon as possible creates problems particularly at the roof to cladding interface. Often this interface will leak if the sequence of erection is changed.
- Changes in the construction process leads to more complicated details.

- Fast track construction is a 'nightmare' to manage when on site, especially if the programme has to be adjusted.
- There is a lack of supervision for setting out. Potentially the structure can be set out without the thorough knowledge of manufacturing tolerances and adequate setting out expertise. Also the building may end up too large or too small, thus the end panel of the cladding has to be altered, generally on site, thus compromising the design.
- If not clearly defined, the warranty for the interface can be overlooked or passed down the line and the principal contractor will often be first in line if the client has problems.
- Quite often UK cladding contractors are under resourced and the construction programme is impaired (see case studies 5.5).
- 'By others' items are often never priced by specialist contractors
- 'By others' is often put in tender documents by the specialist contractors and the knock on effect can cause severe effects if overlooked
- Cast in fixings can be out of place leading to post fixing and adjustment problems.
- There is a lack of trained installers and adequate supervision.
- Untrained labour 'bodge' good designs because they do not understand the principles behind the design.
- Damage and protection to the cladding. This is not identified or costed for, thus the cladding gets damaged and adds cost to the project.
- Temporary works and access to the cladding produce co-ordination problems for the principal contractor

5.3.13 Methods of preventing the problems 'best practice' design

- Post-drilled fixings could be used more if the reinforcement design accommodated the possibility of the drilling.
- Scheme drawings must be supplied earlier.
- There should be a co-ordinated design from concept thorough to installation this should involve all the parties of the design with clear identification of responsibilities.
- Buildability should be considered at the concept and detailed design stage.
- Design brackets to accommodate all of the manufacturing and construction tolerances and inaccuracies.
- All critical interfaces should be identified as early as possible.
- Reduce the number of interfaces wherever possible (Is there a need for six interfaces at one junction?).

- Building insurance should be taken out to cover the warranties. The insurers should inspect the work throughout the installation to ascertain its standard.
- Repeat clients/ partnership facilities should be encouraged to aid the process.
- The use of standard details should be used more, as bespoke designs cause more problems.
- Information should be passed from project to project. Especially successful designs particularly bespoke designs at the time of the project.
- Re-use successful details in similar/ same situations but beware of changes in circumstances.

Manufacture

- Increase off-site manufacture.

Installation

- The cladding contractor must be given the responsibility to protect their work. There must be specific money allocated for this protection to the works. A holistic approach must be undertaken on cost, as damage will always happen so the consequences must be mitigated as much as possible.
- There must be a realistic construction programme; the principal contractor and the specialists should agree this. All parties must understand the repercussions of the programme faltering. This can either be the specialist not performing to the programme due to under resourcing or the principal contractor programming the specialist to start too early in order to keep the project ahead of schedule or other contractors non-performing.
- A 'programme to build' should be developed not a 'build to' programme (avoid contractors part installing to accommodate other contractors). In this the sequence of installation should be clearly identified.
- Consider using a common contractor for the whole package; however this may add to cost.
- Knowledge of tolerances and their knock on affect must be considered when setting out.
- Increase training for supervisors of site works.
- Use of trained installers must be encouraged or enforced.

5.4 Questionnaire

5.4.1 Introduction

Following the interviews the next method of data collection was the validation questionnaire. The intention of the questionnaire was to validate the data gathered from the interviews and focus groups. Also the respondents had the opportunity to add further comments to their answers. This information was then validated with the project steering group. As the questionnaire was based on the overall CladdISS research not all the questions are applicable to this thesis. Therefore the author has only shown and commented on the questions relevant to the thesis. The full results of the questionnaire are included in Appendix A.

5.4.2 Questionnaire respondents

In total 165 questionnaires were sent out to industry with 64 being returned which is nearly a 38% success rate. Due to the fragmented nature of the cladding and construction industry it was necessary to group the respondents under main headings. This was carried out at the author's discretion following consultation with members of the project steering group.

Table 5.13 shows the respondents to the questionnaire. Furthermore it shows the percentages of sent out and returned questionnaires per discipline.

Discipline	Number sent out	Number returned	% returned	% of responses
A	B	C	D (C/Bx100)	E (C/64x100)
Cladding Contractors	45	14	31	22
Cladding consultants	29	14	48	22
Designers/ Architects	39	14	36	22
Principal contractors	32	15	46	23
Systems designers	19	7	37	11
Totals	165	64	n/a	100

Table 5.13: Questionnaire responses shown as percentages

5.4.3 Questionnaire Answers

5.4.4 Introduction

The questionnaire comprised 26 questions; the full results are included in Appendix A. The figures shown in the tables represent percentages unless they are ranking figures, which are then explained within the question. However, the author considers that some of the questions which attained a low score across the varying disciplines may have been because the respondent considered that the issue was 'somebody's else's responsibility' therefore it was given a low score. This is emphasised in 5.4.10 *the drainage design of the cladding system is always poorly detailed at the interfaces*, where there was a wide spread of results.

The detail of descriptive statistics is also represented in the results. The variables were normally distributed as the skewness (the degree of asymmetry of a distribution. If the distribution has a longer tail before the mean the function has negative skewness, otherwise, it has positive skewness) and kurtosis (how peaked or flat the results distribution is) were satisfactory (-2 - +2) except for sections 5.4.8, 5.4.9 and 5.4.14, where the kurtosis was high, but this was expected due to the nature of the questions. Following the results are the comments included with the questionnaire. These represent a response from one of the five categories. Enclosed in brackets at the end of each statement is the respondents answer to that question,

During the first focus group the delegates were asked to rank the most problematic management interface involving cladding to a building element. However due to the small numbers it was felt that this needed to be validated further; this is the first question shown and discussed (5.4.5).

5.4.5 Score the 6 interfaces regarding difficulty to manage

(subdivision 2 of the matrix questions). (1-easiest, 6-most difficult)

Table 5.14 shows the overall results for the six interfaces. Table 5.15 shows the results for the cladding to frame interface; showing the differing results between the five disciplines. The comparisons for the other five interfaces are included in Appendix B.

		subject types	clad/ frame	clad/ roof	clad/ internals	clad/ services	clad/ secondary	clad/ cladding
N	Valid	64	60	60	60	60	60	60
	Missing	0	4	4	4	4	4	4
Mean			4.233	3.583	3.467	3.667	2.967	3.517
Mode			6.00	3.00	4.00	2.00	1.00	1.00
Std. Deviation			1.817	1.619	1.621	1.654	1.832	1.855
Skewness			-.641	.044	-.012	-.025	.530	-.044
Std. Error of Skewness			.309	.309	.309	.309	.309	.309
Kurtosis			-1.005	-1.104	-1.090	-1.254	-1.149	-1.455
Std. Error of Kurtosis			.608	.608	.608	.608	.608	.608

Table 5.14: Subdivision results

subject types	consultants	designer	system designer	principal contractor	cladding contractor	Total
easiest	2		1	2	3	8
2.00	2		2	1	1	6
3.00		1	1	1	1	4
4.00	5	2		2	1	10
5.00		4		3	3	10
most difficult	5	7	1	6	3	22
Total	14	14	5	15	12	60

Table 5.15: Results – cladding to frame

The results concur with the focus group that the cladding-frame interface is the most problematic to manage, with the mean at 4.23 and the mode at 6 (most difficult). However 25 percent of the cladding contractors ranked it the easiest (table 5.15), but 50 percent ranked it between 5 and 6, the most difficult.

The cladding to roof, services, other cladding type and internals had very similar means. The mode shows that the internals ranked 4, roof 3, services 2 and internals 1. Furthermore the cladding to secondary components had the lowest mean and scored 1 with the mode, however this should not imply this is an interface that is easily managed.

Cladding consultant: *"The timing of the interfaces is important; the most difficult ones to manage are those elements of construction that are concurrent, which is often cladding to cladding".*

5.4.6 The lack of buildability understanding by project designers/ architects causes more than 10% extra cost to the project.

Throughout the data collection the issue of buildability has provoked a concern. The author therefore wanted to discover to what extent and to find out whether it had cost and programming ramifications for a project. Table 5.16 shows the overall result and table 5.17 shows how the results differ between the five disciplines.

Sections (5.4.6 – 5.4.14) use a five response system for the answers. To enable analysis of the questions it was necessary to assign a number to the response. Therefore when the mean and mode are being discussed using a numerical reference it is referring to the following system;

- 0 missing value
- 1- strongly disagree
- 2- disagree
- 3- uncertain
- 4- agree
- 5- strongly agree

	Q3	subject types
Valid	64	64
Missing	0	0
Mean	3.797	
Mode	4.00	
Std. Deviation	1.057	
Skewness	-.994	
Std. Error of Skewness	.299	
Kurtosis	.341	
Std. Error of Kurtosis	.590	

Table 5.16: Buildability – 10% added costs results

		subject types					Total
		consultants	designer	systems designer	principle contractor	cladding contractor	
Q3	strongly disagree	1	1				2
	disagree	1	5		3		9
	uncertain	1	2	1			4
	agree	6	5	5	9	9	34
	strongly agree	5	1	1	3	5	15
Total		14	14	7	15	14	64

Table 5.17: Buildability cost results between the 5 disciplines

Table 5.16 shows that mean is nearly 4 (agree) and the mode is 4. This indicates that the respondents consider a lack of buildability knowledge adds at least 10 percent cost to the project. However, table 5.17 shows that nearly 50 percent of the designers are in disagreement. Generally it is the designer's responsibility to understand buildability and allow for it in design. Therefore the respondents could be defending their responsibilities. Nevertheless nearly 50 percent agreed. Coupled with the results from the other disciplines this indicates that buildability is a problem in design.

- **Principal contractor:** *"Lack of system and buildability understanding by any significant member of the team may lead to notable additional costs and disruption of the project". (agree)*
- **Cladding consultant:** *"Lack of buildability knowledge either causes delays or leads to poorer quality - either can be used as a reason to withhold money from subcontractors: the end result can be lower costs." (strongly agree).*

5.4.7 The lack of buildability understanding in design causes more than 10% extra time to be added to the construction programme

Table 5.18 shows the overall result and table 5.19 shows how the results differ between the five disciplines.

	subject types	Q20
Valid	64	64
Missing	0	0
Mean		3.688
Mode		4.00
Std. Deviation		1.022
Skewness		-.713
Std. Error of Skewness		.299
Kurtosis		-.281
Std. Error of Kurtosis		.590

Table 5.18: Buildability – 10% extra time cost

		subject types					Total
		consultants	designer	systems designer	principal contractor	cladding contractor	
Q20	strongly disagree		1				1
	disagree	2	5	1	2	1	11
	uncertain	1	2	2	1	1	7
	agree	8	5	4	8	8	33
	strongly agree	3	1		4	4	12
Total		14	14	7	15	14	64

Table 5.19: Buildability time between the 5 disciplines

The results are virtually the same as buildability costs and concurs that a lack of buildability understanding adds time to the construction programme. The mean is 3.7 which verges on agreement but the mode is 4. The designers responded the same as for buildability costs. Furthermore, the principal contractors and the cladding contractors both gave identical results and are in agreement. Predominantly they are the disciplines that manage buildability at site; therefore the results demonstrate delays will occur at the construction phase if buildability is not correctly understood.

- **Principal contractor:** *"I agree with the basic premise. However where did the 10% come from."* (agree)
- **Principal contractor:** *"Not just the designers the whole team have a lack of understanding of buildability."* (agree)

5.4.8 If the specialist cladding contractor made design input at concept design phase the interfaces would be easier to manage and co-ordinate?

The issue of integrated teams and getting the specialist contractors involved at an earlier stage has been identified throughout. The author wanted to ascertain the importance of this factor and also wanted to see if there was any reluctance to accept this. Table 5.20 shows the overall results and table 5.21 shows how the results differ between the five disciplines.

	subject types	Q4
Valid	64	64
Missing	0	0
Mean		4.328
Mode		4.00
Std. Deviation		.7358
Skewness		-1.844
Std. Error of Skewness		.299
Kurtosis		6.445
Std. Error of Kurtosis		.590

Table 5.20: Specialist cladding contractor input at design results

	subject types					Total
	consultants	designer	systems designer	principal contractor	cladding contractor	
Q4 strongly disagree	1					1
disagree	1					1
uncertain				1		1
agree	6	11	3	9	5	34
strongly agree	6	3	4	5	9	27
Total	14	14	7	15	14	64

Table 5.21: Specialist cladding contractor input at design results between the 5 disciplines

The results shows that the mean is 4.3, between agree and strongly agree, with the mode 4. The only respondents to disagree with the idea are two consultants. Consultants are paid by clients to give advice on a project. Perhaps they were concerned that if the specialist contractor has too much input to the project then their role might be lessened thus their reluctance to the suggestion. However the results show that all the disciplines think there is a need for specialist contractor input earlier in a project.

- **Principal contractor:** *"I agree that the specialist needs to be part of the team very early in the project process. However few would be able to participate at concept design stage. Their involvement might best begin immediately after concept and before details begin to emerge."*(agree)
- **Principal contractor:** *"It would help but could compromise the Main contractor commercially."* (agree)
- **Cladding contractor:** *"There must be recognition of specialist knowledge by the specialist contractors and applied to the design as early as possible."* (strongly agree)
- **System designer:** *"Experience has shown that when the cladding designers, fabricators, installers are brought onboard as early as possible, the advantages far outweigh the disadvantages in terms of interface detailing and project progression."* (strongly agree)
- **Cladding consultant:** *"Getting the subcontractor in earlier can be used to avoid nasty surprises later in the process."* (agree)

5.4.9 The responsibility for completing the interface on site should be agreed by the project team at scheme design stage?

Table 5.22 shows the overall result and table 5.23 shows how the results differ between the five disciplines.

	subject types	Q5
Valid	64	64
Missing	0	0
Mean		4.516
Mode		5.00
Std. Deviation		.6665
Skewness		-1.719
Std. Error of Skewness		.299
Kurtosis		4.276
Std. Error of Kurtosis		.590

Table 5.22: Responsibility for completing the interface results

		subject types					Total
		consultants	designer	systems designer	principal contractor	cladding contractor	
Q5	disagree		1			1	2
	agree	5	6	3	6	5	25
	strongly agree	9	7	4	9	8	37
Total		14	14	7	15	14	64

Table 5.23: Responsibility for completing the interface results between the 5 disciplines

The focus groups and the interviews identified assigning the interface responsibility as early as possible as a solution to some of the problems. The author expected this to be confirmed in the questionnaire but not to such a high degree. In fact the mode was 5, strongly agree. It maybe somewhat idealistic for it to happen so early (scheme design) thus the high agreement rate, however, it does indicate that the respondents would like the responsibility considered as early as possible.

5.4.10 The drainage design of the cladding system is always poorly detailed at the interfaces? (As defined in question 1)

Table 5.24 shows the overall result and table 5.25 shows how the results differ between the five disciplines.

	subject types	Q12
Valid	64	64
Missing	0	0
Mean		3.281
Mode		4.00
Std. Deviation		1.031
Skewness		-.148
Std. Error of Skewness		.299
Kurtosis		-1.061
Std. Error of Kurtosis		.590

Table 5.24: Drainage at the interface results

		subject types					Total
		consultants	designer	systems designer	principal contractor	cladding contractor	
Q12	strongly disagree					1	1
	disagree	4	2	4	4	4	18
	uncertain	3	3	1	4	2	13
	agree	5	8	2	6	5	26
	strongly agree	2	1		1	2	6
Total		14	14	7	15	14	64

Table 5.25: Drainage at the interface results between the 5 disciplines

The results show that the answers are divided between four disciplines. The mean is 3.3 which are just above uncertain. However the mode is 4, agree. This implies that there is uncertainty with this question. However 32 of the respondents (50%) are in agreement compared with 19 (30%) who disagree. The respondents who disagreed returned virtually identical results across the disciplines which would indicate that there is no bias to the views from the disciplines. However the designers principally agree with the question. As designers have the responsibility for coordinating the design this indicates this maybe a problem.

5.4.11 There should be a strategy to standardise interface design details

Table 5.26 shows the overall result and table 5.27 shows how the results differ between the five disciplines.

	subject types	Q16
Valid	64	64
Missing	0	0
Mean		3.813
Mode		4.00
Std. Deviation		.8333
Skewness		-.820
Std. Error of Skewness		.299
Kurtosis		.435
Std. Error of Kurtosis		.590

Table 5.26: Standardise interface design results

		subject types					Total
		consultants	designer	systems designer	principal contractor	cladding contractor	
Q16	disagree	1	2	2		2	7
	uncertain	2	3	2		1	8
	agree	10	9	2	8	10	39
	strongly agree	1		1	7	1	10
Total		14	14	7	15	14	64

Table 5.27: Standardise Interface design results between disciplines

To enable improved management of the interfaces the author has considered methods of simplifying the process, this has included standardising the interfaces. This suggestion was also raised in the focus groups. The results show that the mean is almost in agreement and the mode is 4. All the principal contractors are in agreement which was expected as a standard design will make site installation a lot easier. However, the systems designers disagree. Too often the word standardise is thought to limit flair and innovation, this is why they may disagree with the idea.

- **Principal contractor:** *"Standard interface designs between elements incorporating a zonal concept of the interface at tender stage would assist the process."* (strongly agree)
- **Designer:** *"This idea is impractical."* (disagree)

5.4.12 Cladding contractors often overestimate resources during tender negotiation

Table 5.28 shows the overall result and table 5.29 shows how the results differ between the five disciplines.

	Q18	subject types
Valid	63	64
Missing	1	0
Mean	2.730	
Mode	2.00	
Std. Deviation	.9194	
Skewness	.572	
Std. Error of Skewness	.302	
Kurtosis	-.402	
Std. Error of Kurtosis	.595	

Table 5.28: Cladding contractors often over estimate resource results

		subject types					Total
		consultants	designer	systems designer	principal contractor	cladding contractor	
Q18	strongly disagree				1	1	2
	disagree	4	5	2	7	11	29
	uncertain	5	6	4	2	1	18
	agree	3	3	1	4	1	12
	strongly agree	2					2
Total		14	14	7	14	14	63

Table 5.29: Cladding contractors often over estimate resources results between the 5 disciplines

The mean shows a result of 2.73 with the mode 2 indicating disagreement. However, it was expected the cladding contractors would be in disagreement. The comment below implies that repetitive contracts (partnering) reduces this problem. Unexpectedly the principal contractors responded with the cladding contractors with 8 disagreeing. This was surprising as it was the principal contractors that raised the issue in focus group two. However, they may have justification as *case study C* experienced this problem during the construction phase.

- **Cladding contractor:** *"If we are to produce more accurate tenders then more information must be made available at tender stage. The idea of partnering I feel, is that the trust learning curve is taken out of the equation leaving the way clear to issue more detailed information. In my opinion partnering is design and build with the adversarial factor removed."*
(disagree)

5.4.13 The cladding design, from concept to detail, should be carried out by one design team.

Table 5.30 shows the overall result and table 5.31 shows how the results differ between the five disciplines.

	subject types	Q23
Valid	64	64
Missing	0	0
Mean		3.703
Mode		4.00
Std. Deviation		1.243
Skewness		-.892
Std. Error of Skewness		.299
Kurtosis		-.262
Std. Error of Kurtosis		.590

Table 5.30: Cladding design by one-design team results

		subject types				Total	
		consultants	designer	systems designer	principal contractor		cladding contractor
Q23	strongly disagree	1			3	1	5
	disagree	1	3		2	3	9
	uncertain	1		1	1	1	4
	agree	7	7	4	5	5	28
	strongly agree	4	4	2	4	4	18
Total		14	14	7	15	14	64

Table 5.31: Cladding design by one-design team results between the 5 disciplines

This question followed the topic of standardisation, this time attempting to standardise the design team. The author wanted to find out if there was a benefit in retaining one design team throughout. The mean and the mode are virtually in agreement indicating this is a good idea. However there are 3 principal contractors strongly disagreeing, traditionally the principal contractor will have little design input; therefore the respondents may consider this idea limits their input to the design. This assumption is further validated in the comments below and in section 5.4.14, a question relating to procurement options.

- **Principal contractor:** *"No. The designer who initiates the concept should be the basis of the design team, which should be supplemented by specialist skills and advisors as the process develops. The initial concept designer seldom has the detail design skills and the corollary is usually true of specialist contractors."* (strongly disagree)

- **Principal contractor:** *"The architect should only design the concept. The "competent" cladding supplier would then be best placed to design and install the system co-ordinated at detailed design stage."*(strongly disagree)
- **Principal contractor** *"Single action tendering and design development involving the architect, principal contractor, specialist contractor, and if possible building control. Also honesty in design requirements and what is being offered by the subcontractor in his tender return."* (disagree)

5.4.14 Rank the 4 different project procurement options on their effective influence on management of construction interfaces

This question used a different ranking system. The respondents were asked to rank the four different procurement options in order of effectiveness. A four point ranking system was used. 1 the best and 4 the worst.

Table 5.32 shows the overall results with partnering being the best option with a mean of 1.3 and a mode of 1. The worst option was seen to be traditional with a mean of 3.5 and a mode of 4. Table 5.33 and 5.34 shows how the results differ between the five disciplines for partnering and traditional respectively. The results show that all the disciplines are in agreement. (The results for the two remaining procurement options are shown in Appendix B.)

	D&B	Trad	Man	Part	subject types
Valid	57	57	57	57	64
Missing	7	7	7	7	0
Mean	2.561	3.491	2.404	1.368	
Mode	3.00	4.00	2.00	1.00	
Std. Deviation	.9823	.7102	.8836	.7229	
Skewness	-.060	-1.053	.224	1.950	
Std. Error of Skewness	.316	.316	.316	.316	
Kurtosis	-.967	-.212	-.580	3.053	
Std. Error of Kurtosis	.623	.623	.623	.623	

Table 5.32: Procurement effectiveness results

		subject types					Total
		consultants	designers	systems designers	principal contractors	cladding contractor	
partnering	best	8	10	4	11	10	43
	2.00	2	2	1	2	1	8
	3.00	1	1		1	2	5
	4.00					1	1
Total		11	13	5	14	14	57

Table 5.33: Partnering (most effective) results

		subject types					Total
		consultants	designers	systems designers	principal contractors	cladding contractor	
traditional	2.00	1	1	1	1	3	7
	3.00	3	2	2	3	5	15
	4.00	7	10	2	10	6	35
Total		11	13	5	14	14	57

Table 5.34: Traditional (least effective) results

5.4.15 Rank the twelve statements in order to improve interface management for the cladding interfaces

To enable all twelve statements to be viewed the statements have to be represented by a letter, listed below in order they were presented to the respondents;

- A- Eliminate the term 'by others'
- B- Identify the Interface responsibility as early as possible
- C- Ensure there is a greater understanding of buildability
- D- Improve the programming and sequencing at site level
- E- Ensure there is a greater understanding of all tolerances
- F- Ensure all installers have attended an approved training course
- G- Appoint cladding and frame contractors at the same time
- H- Appoint the specialist contractors earlier
- I- Develop tools that identify and aid interface management
- J- Standardise interface designs
- K- Reduce adversarial effects within the process
- L- Risk assess the designers knowledge of cladding systems from previous projects

Table 5.35 shows the twelve statements ranked in order of importance, based on the mean responses; also it shows the mode results. Table 5.36 shows the full statistical results.

Rank	Statement	Mean	Mode
1	Identify the interface responsibility as early as possible	3.138	1
2	Appoint the specialist contractors earlier	4.586	1
3	Ensure there is a greater understanding of all tolerances	5.276	4
4	Ensure there is a greater understanding of buildability	5.552	3
5	Appoint cladding and frame contractors at the same time	6.259	6
6	Develop tools that identify and aid interface management	6.328	8
7	Standardise interface designs	6.448	10
8	Reduce adversarial effects within the process	6.655	10
9	Risk assess the designers knowledge of cladding systems from previous projects	6.948	2
10	Improve the programming and sequencing at site level	7.379	5
11	Eliminate the term 'by others'	7.931	12
12	Ensure all installers have attended an approved training course	8.190	11

Table 5.35: Ranking order of the twelve statements

	A	B	C	D	E	F	G	H	I	J	K	L	subject types
Valid	58	58	58	58	58	58	58	58	58	58	58	58	64
Missing	6	6	6	6	6	6	6	6	6	6	6	6	0
Mean	7.931	3.138	5.552	7.379	5.276	8.190	6.259	4.586	6.328	6.448	6.655	6.948	
Mode	12.00	1.00	3.00	5.00 ^a	4.00 ^a	11.00	6.00	1.00	8.00	10.00	10.00	2.00	
Std. Deviation	3.539	2.717	2.829	2.858	2.674	3.165	3.492	3.393	3.069	3.336	3.507	3.909	
Skewness	-.524	1.773	.158	.088	.680	-.558	.201	.833	-.170	.013	-.195	-.228	
Std. Error of Skewness	.314	.314	.314	.314	.314	.314	.314	.314	.314	.314	.314	.314	
Kurtosis	-.841	2.700	-.791	-1.175	.056	-.915	-1.198	-.406	-1.071	-1.251	-1.326	-1.494	
Std. Error of Kurtosis	.618	.618	.618	.618	.618	.618	.618	.618	.618	.618	.618	.618	

a. Multiple modes exist. The smallest value is shown

Table 5.36: Improvement Statements results

The table show that B- "Identify the interface responsibility as early as possible" ranked the most effective with a mean of 3.13 and a mode of 1. F- "Ensure all installers have attended an approved training course" ranked least effective with a mean of 8.19 and a mode of 11. However, A- "Eliminate the term by others" had a mean slightly less (7.93) but with a mode of 12.

However, these two must not be construed as unimportant because of the poor ranking. All twelve are important and should be considered for improved interface management. Furthermore, the ranking of (B) has identified the need for the interface responsibility to be identified as early as possible. Table 5.37 shows how the five disciplines ranked (B) and table 5.38 shows how they ranked (F).

	subject types					Total
	consultants	designers	systems designers	principal contractors	cladding contractor	
Identify the interface best	5	2	2	4	5	18
responsibility as 2.00	2	6	2	5	2	17
early as possible 3.00	2				2	4
4.00	1	3	1	1	2	8
5.00	1			1	1	3
6.00	1			1		2
7.00				1		1
9.00		1				1
10.00			1		1	2
11.00					1	1
worst		1				1
Total	12	13	6	13	14	58

Table 5.37: Identify the interface responsibility as early as possible result

		subject types				Total
		consultants	designers	systems designers	principal contractors	
Ensure all installers have best						1
attended an approved	2.00				1	1
training course	3.00	2		1		5
	4.00		2	1		3
	5.00	1			1	4
	6.00	1		1		3
	7.00	3	1	1		6
	8.00				2	3
	9.00	2	2		1	7
	10.00	1	1		2	4
	11.00	1	3	2	6	14
	worst	1	2		1	7
Total		12	13	6	13	58

Table 5.38: Ensure all installers have attended an approved training course results

Table 5.38 shows that there is a range of results between "best and worse". The cladding contractors ranked it across almost all the categories, therefore showing no significant trend across that discipline. As it is the cladding contractor's responsibility to have their installers trained it is possible there are two thought processes, perhaps they assume the cost of the training outweighs any benefit, thus the small response to the idea. However, it is possible that a trained installer will work more efficiently thus being more cost effective. The principal contractors primarily ranked it low which is unexpected as this discipline highlighted the problem in the focus groups.

5.5 Case Studies

5.5.1 Introduction

The case studies were carried out following the completion of the CladdISS project (chapter 4). The purpose of the case studies was to allow the author to observe 'live' projects and to see how the interfaces are actually managed within a project. This also acted as validation of how the industry works. The author only observed the case studies and had no input to any decision-making; this method of case study data collection is explained in greater depth in the methodology (chapter 2). The purpose of the case studies was twofold;

- To demonstrate the benefits of the CladdISS framework within a project.
- To highlight industry "normal" working practices and demonstrate how using these methods can create problems.

5.5.2 Choice of case studies

In total five projects were chosen, drawn from various projects involving the project steering group companies. The projects and there relevant disciplines are listed below. Due to some of the information being confidential the projects are presented anonymously. Therefore from this point the project has been given a letter as identification.

- **Project A Specialist cladding contractor**
- **Project B Principal contractor**
- **Project C Specialist cladding contractor**
- **Project D Specialist cladding contractor**
- **Project E Specialist cladding contractor**

5.5.3 Case study time periods

The author was limited to six months to review the projects. As most construction projects can take many years to complete, from inception through to completion the case studies are only a 'snapshot' of the overall project.

Due to this fact the author tried to cover as many of the phases (process protocol) as possible within the five studies. Therefore some of the case studies produced a limited amount of information particularly the ones in the early design phases (3-5). In addition, the author was allowed access to some historical data for the projects. This included minutes from meetings, letters and tender documents.

However, during the write up stage of the thesis the author was contacted by associates involved with one of the case studies, the purpose was to update and relay information to the author on the progress of the projects. Therefore there was the opportunity to include additional information to the study over and above the original case study period.

5.5.4 Project A

Introduction

Project A involved constructing a new building on a university campus. The architectural organisation for the project is a nationwide practice with considerable high profile expertise.

The author studied the project early in the design process, between phase 3 and 4, "substantive feasibility and outline conceptual design." The purpose was to ascertain what or if any consideration was given to the interfaces. The interface factors that are relevant were:

- Cladding to cladding
- Structure to cladding
- Design team/principal contractor/specialist contractor communication

The project circumstances

The project designer contacted the specialist-cladding contractor to gain information on their products. An informal meeting was held between the two parties, its purpose was to explain the nature of the project, approximate time scales and aesthetic appearances. The design team requested the specialist contractor provide budget prices and details of their products.

Design Input and problems

Following the meeting the specialist contractor supplied the designer with the following information:

- Panel sizes and unit rates
- Panel weights
- Basic fixing details
- Thermal details for the panels

All the above information was based upon certain criteria and assumptions; for example general user cranes and general site scaffolding.

To the knowledge of the author, the specialist contractor had no further contact with the design practice during the case study period. The specialist contractor informed the author "this is common, we will send out budget costs to numerous design practices. The project is either never heard of again, we were too expensive or the project may have been shelved. Alternatively we may be

contacted again from the design team or commonly we have tender documents sent to us from contractors bidding for the project”.

Within five months of the budget costs being sent out the specialist contractor received tender documents including bills of quantities for the project from several principal contractors pricing the project. The specialist contractor sent the principal contractors priced unit rates for the cladding package. The unit rates were approximately 10 percent lower than the budget costs supplied to the design team at the initial enquiry. This was because they had more specific drawings and information to price the cladding works compared to the initial enquiry information.

Also included in the returned tender submissions was the following observation regarding the tender. *“Whilst we have submitted costs for the cladding panels as specified on your drawing number xx (omitted for confidentiality purposes), it appears that above and below floor slabs there are some glazed openings. Our units would be designed to approximately 150mm thickness and therefore would encroach the same area as the glazed openings”.*

Therefore the tender documents had been developed with a cladding-to-cladding problem already evident. Also assumptions had been made for numerous issues such as cladding to frame connections and site plant availability.

Solutions

It is not possible for the author to state whether problems occurred on the project as it was still in design whilst this thesis was being written. However if the specialist contractor was allowed greater design input following the initial enquiry it is possible that there might have been a cost saving on the project and obvious concept design problems may have been reduced.

5.5.5 Project B

Introduction

Project B was a hospital development project. The development involved constructing a new hospital on the site of an existing hospital. The architectural organisation for the project is a nationwide practice involved in designing numerous high profile projects.

Initially the author studied the project at concept design, phase 5, "Full conceptual design." However, this case study was reviewed further at the construction phase (the updated project). The interface factors that are relevant were:

- Workpackage contents
- Appointment of the specialist contractor
- Role of the specialist contractor
- Design team/principal contractor/specialist contractor communication.

The project circumstances

The principal contractor was employed by the client to construct the hospital under a PFI procurement route. The contractor would undertake the maintenance and facilities management of the project for 28 years following completion. With PFI (see chapter 3, literature review) the principal contractor has significant input to the project design.

Design input and problems

The concept architect produced a specification for the project. A part of the specification stated: The design intent stated the contractor must provide a high quality building in accordance with end user requirements. All critical horizontal and vertical features are aligned and level. The design of all the components must be fully coordinated with other related and / or adjacent works (a reference to interfaces but with no specific detail of responsibility)

The specification included separate façade sections for the cladding types and associated secondary components, these included;

- Rainscreen
- Curtain walling
- Profiled metal cladding
- Patent glazing
- Windows and brise soleil
- Glass block walling

For all the sections the following clauses were included: production drawings must include a minimum of;

1:50 plans, sections and elevations of the relevant areas of work.

1:10 details of key junctions e.g. windows, cills head etc (as applicable).

1:10 details of areas of interface with other components parts.

As the façade was complex in design with numerous interfaces, the principal contractor decided to tender the façade on a two stage tender basis with the successful cladding contractor taking the responsibility for the whole façade. This was due in part to the long facilities management period imposed on the project by the client.

Due to the size and complexity of the cladding package (approx £5-6 million) the principal contractor had a problem finding a suitable specialist contractor to undertake the project. From initial enquiries the tender list was reduced to three suitable companies with the eventual specialist contractor being the only realistic bidder. Therefore the principal contractor only carried out a basic evaluation of the cladding contractor's expertise and resources for the project. The expertise was evaluated to be more than sufficient based on previous projects. However there was a reservation on the resources available and potentially the cladding contractor was stretching its resources to undertake the project, however it was deemed sufficient.

The project design went through the second stage tender process. The tender increased the cladding package by approximately 25 percent. This ended the initial case study period.

Follow up period

During the construction phase (phase 8) the specialist-cladding contractor went into liquidation. The façade was approximately a third complete. The principal contractor informed the author that they had to employ the cladding contractor's designers and installer's directly enabling the façade to be completed to programme. Obviously the principal contractor was now taking the responsibility for the façade warranties and ultimately they had to manage all the complex interfaces. An issue they tried to avoid by employing one contractor for the whole façade.

Furthermore, it became apparent that the cladding contractor had separated most of the cladding packages into smaller sub-sub workpackages to reduce cost on the project. Therefore the principal contractor had to manage all the material supply and procurement of all the workpackages.

Solutions

The principal contractor should have had a better process of evaluating the resources available to the specialist contractor. In addition, during the detailed design and manufacture period (phases 6-7) the principal contractor should have monitored the procurement process of the workpackages and their supply chain in a more efficient manner.

5.5.6 Project C

Introduction

Project C was situated on a 180-acre business park. The site had permission for 2.25million sq feet of predominantly business space divided amongst 14 plots. Project C was one of the plots. Several of the other plots had been developed prior to the case study. A nationwide construction company under a JCT 98 contract was commissioned for the project.

The author studied the project from completion of the substructure through to the frame completion and partial cladding installation involving the cladding testing period. At commencement of the case study all the cladding contractors were in initial detail design (phase 6). The façade consisted of three cladding types; precast concrete backing panels, rainscreen and curtain walling with windows (the specialist-cladding contractor allied to the PSG). Also within their workpackage was the sunshading (brise soleil).

Project circumstances

The specification stated that test results should be supplied for the cladding; if not available then an off-site test should be carried out on the façade. As no such data was available a test was included within the curtain wall package along with the responsibility for its coordination. The relevant interface factors were;

- Cladding to cladding
- Interface testing
- Interface responsibility
- Interface management between specialist contractors.

Design input and problems

Shown below is an extract covering the overall design intent taken from the cladding specification, this shows the complexities of the interfaces without specifically addressing them.

It is intended that the building envelope be more similar to a traditional solid monolithic wall than a thin skin curtain wall. The windows are set back in traditionally deep reveals, creating strong shadow lines. The outer skin of rainscreen cladding is not dissimilar in function to a brick outer skin of a cavity wall construction. Any water passing through to outer skin into the cavity drains out at the base of the wall. A combination of D.P.Cs and cavity trays connected between the window unit and the precast concrete backing wall, ensuring a secondary line of defence exists within the wall. The window units are to be installed in factory made prefabricated sections modulated to suit the typical 7.5M, 9M bays and corner conditions.

The brise soleil are also bolted back to the concrete panels. The pre-cast concrete backing panels are to be modulated to suit the sub-contractors design. These units are secured to the floor slabs, then the window units are fixed into their exact location, D.P.Cs etc, are located ensuring a 'dry' building within which to work. The rainscreen can then be positioned taking its installation off the critical path of the building works. The capping sections of curtain walling creating window linings and cill sections can be installed either before or after the rainscreen cladding to suit the sub-contractors proposals. Any deflections occurring within the main concrete frame of the building at floor level are to be dealt with via the connection of the precast panels to the slab.

Throughout the six-month case study period the design team held frequent design team meetings, shown below are relevant points generated by the meetings;

Meeting 1

- Fixing zones around the precast panels, the rainscreen specialist contractor (RSC) was investigating cast in channels as the main method of fixing to the precast panels
- The precast specialist contractor (PSC) agreed to check panel thickness for the drylining abutments.
- PSC issued generic details/elevations based on their panels
- PC issued preferred sequence of erection for the cladding (elevation by elevation)

Meeting 2

- PSC indicated that in their preliminary drawing off site fixing inserts were to be used for the rainscreen fixings.

- Curtain wall specialist contactor (CWSC) advised that the windows would be pre-assembled units with cill and head liners. Lips to receive the DPM were included. The precaster required information for head and cill insert positions.
- CWSC needed to obtain information from the systems designers on mullion beads.
- The interface test was discussed- dates, deliveries, requirements and availability at the test centre.
- (All cladding contractors continued to design their products)

Meeting 3

- The CWSC confirmed that the test date had been set at the test centre. They also issued a general arrangement drawings issue date.
- PSC advised on programming for the precast panels for the test.
- RSC raised the issue of a clash with the parapet corner detail fixing points.
- RSC informed the precaster the required lengths for their fixing inserts
- A clash between cladding panels was identified; more information was required by all the cladding contractors to see if this was an issue.
- RSC questioned whether the fixing inserts should not be in the PSC package rather than theirs. They asked what the cost would be to change the work between packages.
- (All cladding contractors continued to design their products)

Meeting 4

- The issue was raised whether the precaster should price all the fixing inserts. The CWSC informed that their inserts were 'off the shelf' and may be cheaper, but was happy to put it in the PSC package.
- RSC informed that their package allows for a lump sum for site fixing, but there is a benefit using the inserts.
- CWSC informed the PSC that they need extra inserts for the brise soleil.
- CWSC stated the test date would be in approx 2 months time they would get more details to the PSC by the next day. The PSC said they need at least 2 months for the test panel to be ready.
- (All cladding contractors continued to design their products)

Meeting 5

- CWSC stated they needed an instruction to clarify to who would supply the fixing inserts.
- The PSC agreed to allow the CWSC an allowance for the inserts being exchanged between the two workpackages.

- RSC was concerned about the DPM under the window cill interfacing with their panels (this was discussed in great depth) the concern was how the flashing was going to remain fixed to the precast panel and remain watertight.

Meeting 6

- A discussion was held concerning the cavity tray over the window head liner. Apparently this was not in any of the cladding packages. The principal contractor was going to check to see if it was in the rainscreen package. PC asked the RSC and CWSC to give a rate for installing the cavity tray.
- CWSC gave a status report on their drawings. They advised that they had sent the support information to the testing centre for comments, and that a date was available for the test. RSC stated their panels would be available in that time period.
- PC asked CWSC to produce a test programme
- RSC stated that originally they had allowed a smaller panel for the test, they would advise the PC of any cost issues.
- The PSC would reassess their factory sequence of work against their factory production time after programming changes.
- (All cladding contractors continued to design their products)

Meeting 7

- The PSC stated that they would start production of their panels the next week.
- CWSC to issue the test programme the following week, also to check who is responsible for sealing around the rainscreen during the test.
- CWSC issued a price for the additional DPM around the head detail.
- PC asked all cladding contractors to issue a process map for their respective supply chains. This was to enable problem solving if and when problems arose with their material supply. All contractors obliged.

Meeting 8

- CWSC confirmed test date and information required by the test centre from the PSC. They issued a programme for the test.
- It was agreed that the RSC would supply and fix the cavity tray for the test rig.
- All cladding contractors confirmed status of their detail drawings (approx all 75% complete)

(The author had no further contact with the project until the cladding test)

Cladding test

The introduction to the test report explaining the generic parameters of the test is as follows:

The test sample comprised a window sample, concrete panels, rainscreen cladding and brise soleil, manufactured for the xxx project.

Taywood Engineering (TEL) is accredited by the United Kingdom Accreditation Service as UKAS Testing Laboratory No.0057 and is also approved with Lloyds Register of Quality Assurance for ad-hoc in-service inspections and tests to ISO 9001.

The tests were carried out during May and June 2001 and were to determine the weathertightness of the test sample. The test methods, as amended by the project specification, were generally in accordance with BS5368 Test Methods for windows and CWCT Standard test methods for curtain walling for:

Air permeability (BS).

Watertightness using static pressure (BS).

Watertightness using dynamic pressure (CWCT).

Wind resistance - serviceability & safety (BS).

The testing was carried out in accordance with Taywood Engineering Method Statement: C5 09/MsrevO and the HOK International Limited project specification VR 3 1 0 Curtain Wall, Section 8.

This test report relates only to the actual sample as tested and described herein.

The tests were witnessed wholly or in part by:

S. Tycer	-	CAP Aluminium Systems
M. D. Jones	-	CAP Aluminium Systems
R. Holmes	-	CAP Aluminium Systems
J. Davey	-	CAP Aluminium Systems/D. Construction
D. Cullen	-	SIAC
R. D. Williams	-	SIAC
E. Randall	-	HOK

M. O'Brien	-	HOK
M. Carlisle	-	HOK
S. Ryan	-	Kawneer
L. Marley	-	Kawneer
P. England	-	BBCL
A. Hewitt	-	BBCL
B. Moritz	-	Arup Facade Engineering
G. Carlos	-	Arup Facade Engineering
W. Moisidis	-	Arup Facade Engineering
D. Anderson	-	Arup Facade Engineering
T. Pavitt	-	Loughborough University

In total the cladding was tested five times before finally passed, mainly failing at the interfaces. Details are provided in Appendix F of the cladding failures throughout the test and its remedial actions.

Solutions

The main issues to be learnt from this project are;

- Interface responsibility- the responsibility for the DPM should have been identified earlier in the project
- Workpackage contents- the fixing inserts should have been assigned to one contractor ideally the PSC.
- Interface design- the interface design was relatively complex. The architect should have consulted the specialists earlier to gain expert advice.
- Cladding to cladding interface- the specialist contractors appeared to work to their own time schedules and not together. The design process would have run a lot smoother if the cladding contractors worked together.

5.5.7 Project D

Introduction

Project D was an office building constructed on a business park on the periphery of a large city centre. The development was already partially complete. Therefore the completed buildings acted as a benchmark for the aesthetic appearance for the new structure. A nationwide construction company under a design and manage procurement contract were commissioned for the project.

The principal contractor is on the preferred contractors list for their building works.

The author studied the project from the start of the site enabling works /site set up through to approximately 1 month prior to the specialist contractor's commencement on site. Two different specialist contractors were appointed to manufacture and install the precast concrete panels and the curtain walling. The relevant interface factors were:

- Interface tolerances
- Interface sequencing between specialists contractors
- Interface warranties
- DPM interface
- Cladding to cladding

Design input and problems

The author attended the first façade detailed design team meeting. This involved the specialist contractor (precast), architect, frame contractor and structural engineers. The problem at this stage was that the client had not yet issued a formal letter of intent for the project. The specialist contractors were content to continue with their design within reason but stated that delays may occur soon if no such letter was forthcoming. Throughout the six-month case study period the design team held frequent design team meetings. Relevant points generated by the meetings are shown below;

Meeting 1

- PSC requested steelwork connection details from them the steel frame contractor as they had made assumptions in their initial design.
- The PSC issued a copy of their tolerance details they will be working to and asked for comments.

Meeting 2

- Principal contractor confirmed the start date of enabling works and stated letters of intent would be issued in due course.
- PSC confirmed that the mould manufacture had started and issued a start time for panel manufacture.
- Architect agreed to issue glazed area information.
- Frame contractor requested drawings from the PSC.

Meeting 3

- All orders with design intent had been issued.
- Structural engineer identified a few clashes (interfaces) between service holes, steelwork and the cladding.
- Frame contractor tabled drawings indicating steelwork details that needed to be omitted so that the PSC could install their panels. Frame contractor to issue their drawings.
- Architect confirmed that there is no anchorage points for window cleaning required in the curtain walling.

Meeting 4 (precast panels in manufacture)

- Structural engineer had revised location of some holes in the floor slabs to rectify clashes with the structure
- PSC required approval of current drawings
- Roofing contractor to be brought "on line" for the Kalzip roofing soffits and fascias. They would be present at next design meeting).

Meeting 5

- All steel work is in manufacture
- All precast panels in manufacture
- Curtain walling contractor revising punched openings
- Curtain wall contractor issued their drawings for comment.

Figure 5.2 is taken from one of the drawings issued at the meeting. The drawing shows a ground floor detail with the frame, precast concrete cladding, curtain walling, insulation and DPM. On the drawing it identifies that the insulation and the DPM is 'by others'. The precaster undertook the insulation; however the DPM was omitted from any of the workpackages.

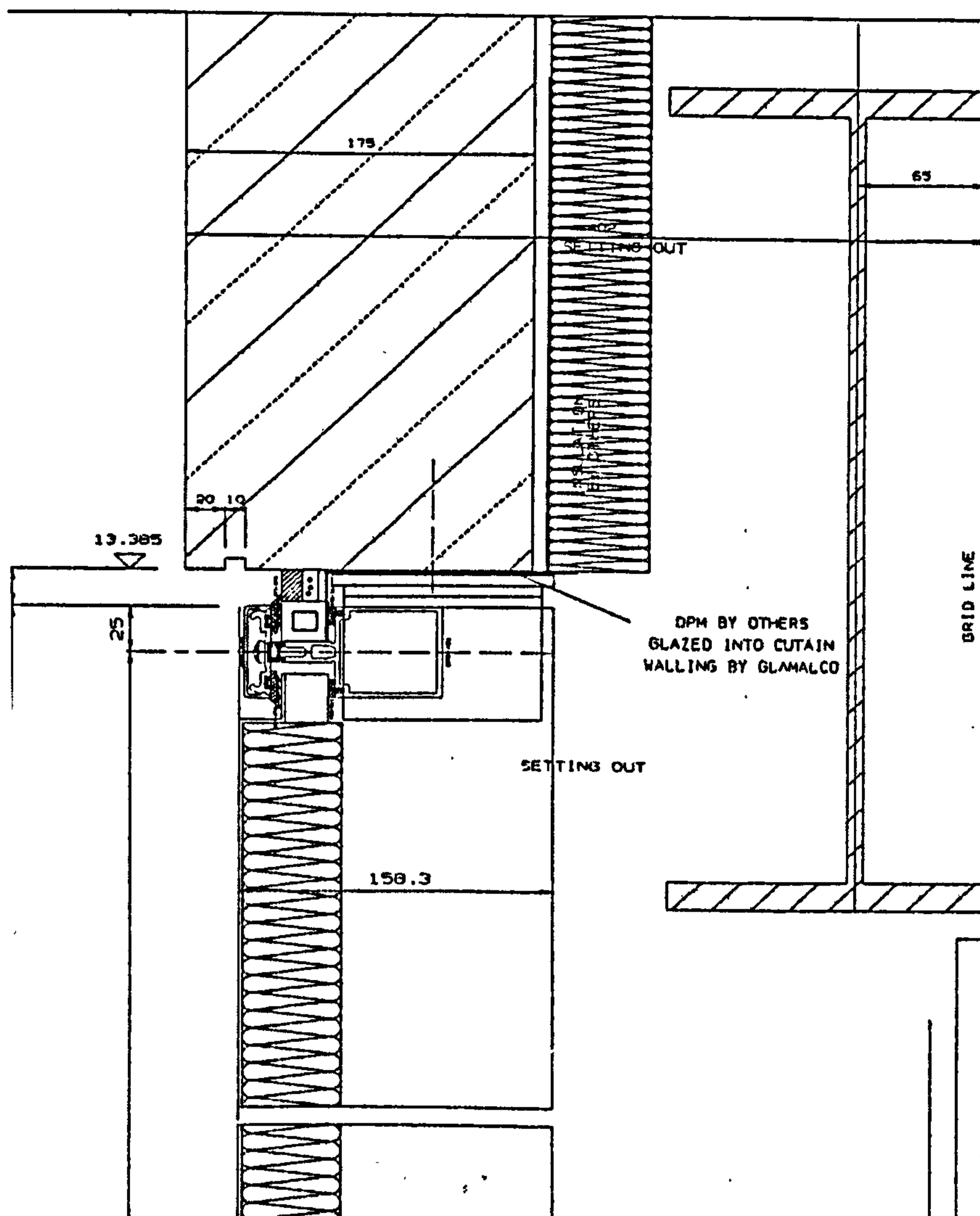


Figure 5.2: Cladding drawing emphasizing 'by others'

Neither of the cladding contractors wanted the responsibility of fixing the DPM. Therefore the principal contractor had to take responsibility for the supply and fix of the DPM. Consequently this action relieved the two cladding contractors of the responsibility of the interface warranty which could lead to difficulties in determining responsibility should the interface fail during the building's life.

Solutions

Throughout the detailed design process the information was late and all the subcontractors were designing their systems based on assumptions. The process could have been simplified if the information was made available earlier. Also the issue of 'by others' could have been eliminated if the design team or the contractor had specified the responsibility prior to detail design.

5.5.8 Project E

Introduction

Project E was an inner city development with very limited space. The site was virtually the footprint of the structure. The author studied the project at site installation phase for the cladding panels. The following interface factors were relevant:

- Frame to cladding interface
- Specialist cladding contractor design input

The project circumstances

Due to site limitations it was agreed early in the project that no mobile cranes could be used around the perimeter of the site, thus a general user tower crane would be provided. It was impossible to position the crane at the centre of the site therefore the reach of the crane would be an influencing factor in the installation of the cladding panels.

The precast cladding contractor was not appointed early enough in the process to provide information on cladding panel weight compared with panel size when installing from a crane. Appendix G shows the site plan with the crane radius/capacity provided in the tender documents. At two locations on the structure the limitation of the crane lifting capacity was 3 tonnes. This caused design problems for the precast concrete cladding designer due to limiting the weight per cladding panel. Figure 5.3 shows the confined site with the tower crane overhead.

Design input and problems

The intention of the architect was to keep the façade as aesthetically pleasing as possible. Thus the jointing between the panels was essential in design; the intention was to keep them all symmetrical wherever possible. This was not possible because the panels had to be designed with weight in mind. The panels had to be reduced in size so that they could be installed in accordance with the crane allowance. After a design meeting between the cladding contractor and the architect a 'compromise' was developed involving the introduction of a secondary steel system between the primary steel and cladding panel. The purpose of this was to enable the panels to be manufactured larger thus reducing the number of panels and joints in line with the rest of the façade.

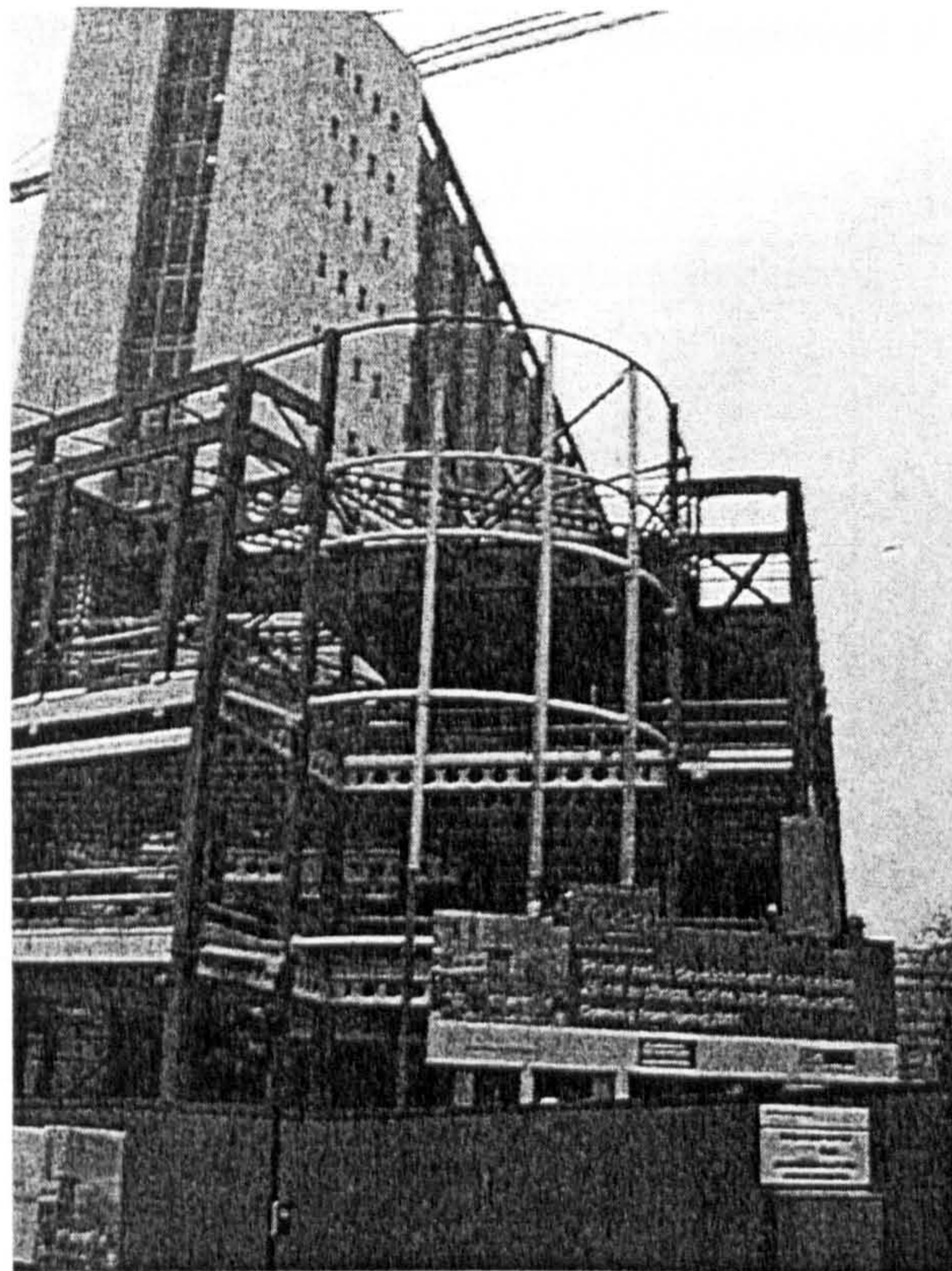


Figure 5.3: The confined site with the site crane in the background

The solution

If the specialist-cladding contractor had been appointed earlier in the process they could have provided the design team information on precise panel weights and sizes required for the project in relation to crane capacities. The specialist-cladding contractor has advised the author that if a holistic approach had been adopted the project could have saved money for the principal contractor and ultimately the client. The specialist-cladding contractor could have allowed extra money in their tender package to upgrade the crane so that extra weight could have been lifted thus allowing for the larger panels to be used. Furthermore if they had design input at the same time as the steel frame contractor, the position of the primary steel frame could have been altered to accommodate the cladding panels, therefore the secondary steel could have been eliminated culminating in a substantial cost saving to the client.

5.5.9 Case study summary

The case studies provided the author with an excellent insight to how the industry works and manages the interfaces. Table 5.39 shows the interface problems that occurred on the projects during the case studies and table 5.40

highlights how the projects could have been improved if the issues identified in *table 5.35* had been implemented.

Project	Interface problems												
	Cladding to Cladding	Building element to cladding	Design communication	Workpackage content	Appointment of specialist contractor	Role of the specialist contractor	Interface testing	Interface responsibility	IM between contractors	Interface tolerances	Interface sequencing	Interface warranties	Specialist contractor design input
A	✓	✓	✓										
B			✓	✓	✓	✓							
C	✓						✓	✓	✓				
D	✓							✓		✓	✓	✓	
E		✓											✓

Table 5.39: Interface problems identified in the case studies

Project	Improved interface management issues												
	Eliminate the term "by others"	Identify the interface responsibility as early as possible	Ensure there is a greater understanding of buildability	Improve the programming and sequencing at site level	Ensure there is a greater understanding of all tolerances	Ensure all installers have attended an approved training course	Appoint cladding and frame contractors at the same time	Appoint the specialist contractors earlier	Develop tools that identify and aid interface management	Standardise interface designs	Reduce adversarial effects within the process	Risk assess the designers knowledge of cladding systems from previous projects	
A		✓						✓	✓				
B				✓					✓				
C	✓	✓		✓				✓	✓	✓			
D	✓	✓		✓	✓		✓		✓				
E							✓	✓	✓				

Table 5.40: How the case studies could have been improved

Project A

If the specialist contractor was appointed earlier and allowed greater design input there would have been a cost saving on the project. Furthermore the cladding to cladding interface responsibility would have been identified earlier.

Project B

If the principal contractor had a better process of programming and sequencing the site operations the procurement process of the workpackages and their supply chain would have been improved.

Project C

If the interface responsibilities had been identified earlier then the issues of the DPM and the fixing inserts would have been simplified. The interface design was relatively complex, if standard interface designs were used the cladding test would have been a lot easier.

Project D

If the cladding contractors and the frame contractor were appointed at the same time the cladding contractors wouldn't have had to make assumptions regarding fixings and loads. Also the issue of 'by others' could have been eliminated if the design team or the contractor had specified the responsibility prior to detail design.

Project E

If the specialist-cladding contractor had been appointed earlier they could have provided the design team information on precise panel weights and sizes required in relation to crane capacities.

5.6 Summary

In total there were four methods of qualitative and quantitative data collection used for the research.

- Interviews
- Focus groups
- Questionnaires
- Case studies

The matrix questions produced informative data; the information has shown how the interfaces are actually managed. It shows that certain interfaces are considered before others and some later than others. The choice of cladding type is considered and resolved first. Then the building element interfaces are considered, especially the frame to cladding interface which is addressed early in the initial stages.

The focus groups produced specific details of interface problems and solutions at differing stages in a construction project from design to installation. The questionnaire validated the findings from the interviews and the focus groups. Finally the case studies produced data on how the industry actually manages the interfaces.

All four methods produced useful data and formed the basis for the management framework for improved management for cladding interfaces as described in chapter 6, research results and validation.

Chapter 6 Research Results and Validation

6.1 Introduction

The first four chapters of the thesis presented the theoretical and methodological framework for the research with chapter four providing a generic overview of the results. This enabled qualitative and quantitative data analysis in Chapter five. This chapter presents the research results by producing a framework for improved management of cladding interfaces. Finally validation results are shown and discussed.

6.2 Research results

6.2.1 Introduction

The results are based on the management sections of CladdISS. Actions required at different project phases have been developed. They are presented as a process map that identifies significant cladding interface management actions and decisions in a project, from its inception through to facilities management.

The process map was adapted from the process protocol (Salford, 1998). In total there are twelve phases, from phase 0 "demonstrating the need" to phase 10 "demolition/decommission". The information has been divided into 3 sections for each phase;

- **Cladding Interface Management (IM).** Advises on crucial cladding interface management issues at particular stages within the project.
- **Cladding Process (CP).** The cladding process has been included to show how the interface management issues relate to stages in the cladding process. (The cladding process shown is generic and would need to be developed to represent the particular project circumstances).
- **CladdISS Review Points.** These are situated at the end of crucial project phases. They advise that, before progression to the next stage, the review point outcomes must have been established. There are six in total; figure 6.1 shows the phases that precede each review point.

The results are mapped onto the twelve phases. Figure 6.1 shows the twelve phases of the process map and the positions of the review points. However, for phase 0 (demonstrating the need), where the principal outcome is to establish

the need for the project and its business case, it was decided that there are no cladding and interface issues.

Phase 0: Demonstrating the need	
Phase 1: Conception of need	Cladd:/SS Review 1
Phase 2: Outline feasibility	
Phase 3: Substantive feasibility study and outline financial authority	Cladd:/SS review 2
Phase 4: Outline conceptual design	
Phase 5: Full conceptual design	Cladd:/SS review 3
Phase 6: Co-ordinated design, procurement & full financial authority	Cladd:/SS review 4
Phase 7: Production information	
Phase 7a: Manufacture	
Phase 8: Construction/ Assembly	Cladd:/SS review 5
Phase 9: Maintenance/ facilities management	
Phase 10: Demolition decommission	Cladd:/SS review 6

Figure 6.1: The twelve phases of the process map

The validation of the framework was confirmed by a questionnaire. The CladdISS CD was shown to a cross section of professionals from the construction industry including cladding contractors, architects and construction managers. During this time they completed the questionnaire.

The first section of the questionnaire asked general questions on the impact of the framework and is discussed in 6.6. The final section asked specific questions relating to the six review points. These results are included with the project phase discussion (sections 6.3.4, 5,10,12,16 and 18).

6.2.2 Mapping the Process

Mapping the data information onto the process map was a procedure that involved the focus groups and the project steering group meetings. Timing of the information is essential; the information must be available at the right time to enable maximum impact to a project.

Focus group one (5.3.6) asked the representatives to identify what type of information and when is it required to achieve optimum best practice. Table 6.1 shows an example of the cladding-to-cladding information obtained from the focus group.

Information required by whom & from whom		Type of info required	When (protocol phases)	How is this info obtained
By Architect	From Client/ building owner	Liabilities if abutting to existing cladding	Phase 2	Discussions
		Dates of installation plus conditions and warranties of existing	Phase 3	Meetings through out
Architect	Specialist contractor	If using existing systems which type is preferred	Phase 3	Sketches early as possible
		Manufacturers type and models if applicable	Phase 2-4	GA drawings at detailed design
		Dimensions	Phase 2-4 Phase 2-4	↓ Throughout the process
		Movement and manufacturing tolerances	Phase 3	
		Buildability and construction sequence		

Table 6.1: Cladding to cladding information requirements

After the focus group the author added the information onto the process map. At subsequent project steering group (PSG) meetings the PSG discussed the validity of the actions and decisions at each phase and refined them until they considered that they represented best practice. During this time it was suggested that a system should be introduced to allow the information flow to start from a broad generic state to a level of specific agreement. This is the project progression method.

The project progression method (PPM) requires differing levels of information at different phases in the project. As previously described the "actions required at different project phases" has three sections; cladding process (CP), interface management (IM) and review points. The subdivisions for these categories are:

- Consider
 - Develop
 - Agree
 - Coordinate
 - Establish
- } **Interface management/cladding process**
- } **Review points**

The purpose of the subdivisions is to enable the design team to extend the interface issues as the project develops. The information must be introduced at critical times in the process; too much information too early can be as

detrimental as not enough too late. However it may not be necessary or applicable to use all four subdivisions.

The IM and CP occur only in the project phases. The information in the project phases forms the basis of the review points where the actions and decisions need to be established. This shows the importance of the review points.

IM actions and decisions at the different project phases and the review points are now discussed.

6.2.3 Phase 1 Conception of the need

Figure 6.2 shows the actions and decisions for the cladding process (CP) and interface management (IM) for phase one.

Main Project Process Protocol Actions & Decisions	PHASE 1 Conception of need Prepare project brief Prepare design brief Assess site and environmental issues Revise project/process execution plan Revise business case	Cladd:ISS Review 1
Cladding Process CP Actions & Decisions	Consider current guidance on CP (e.g. CWCT documents) Consider business case implications on cladding type (e.g. budget, image) Consider planning constraints re cladding types	
Interface Management IM Actions & Decisions	Consider project brief for interface management arrangements Consider requirements for design teams experience and expertise. Consider the need for specialist cladding input	

Figure 6.2: CP and IM issues for phase 1 (taken from CladdISS)

The phase shows that there are three interface actions and decisions;

- Consider project brief for interface management arrangements.
- Consider requirements for design teams experience and expertise.
- Consider the need for specialist cladding input.

1 Consider project brief for interface management arrangements.

It was identified in the interviews that some of the organisations do have a strategy for managing the interfaces (5.2.14). However this appears to be very ad hoc. Therefore the interface arrangements should be considered at this early stage but in a planned manner. A strategy should be considered for how the interfaces will be managed. This probably will be dependant on the project and the procurement route undertaken.

The interface management arrangements could involve employing a person to manage the interfaces throughout the project or delegating a member of the design team, for example the architect. If the procurement route does not allow one person to undertake this role then it will be necessary to consider a chain of responsibility for the task. For example architect to quantity surveyor to principal contractor.

2 Consider requirements for design teams experience and expertise.

During focus group one (5.3.7), one of the problems identified was the lack of understanding by designers of all the different types of cladding systems. Therefore there is a need to assess the design team's knowledge of the particular types of cladding to be used on the project; this may include assessing their expertise from previous similar projects and feedback from known clients.

Part of the validation questionnaire (*question 26 5.4*) asked the respondents to rank twelve methods for improved interface management. "Risk assess designer's knowledge of cladding systems from previous projects" ranked relatively low. However the cladding contractors scored this quite high.

Generally the cladding contractor will complete detail design for their cladding from the design team's initial concept. Therefore they may experience the lack of expertise in the concept design more than the other professionals and appreciate the magnitude of the problem.

3 Consider the need for specialist cladding input

Throughout the research the emphasis has been on the need for specialist knowledge. At phase 1 consideration should be made for this involvement. However this will depend upon the complexity of the project and the expertise within the design team.

If the project is completely bespoke with complex interfaces then specialist knowledge will be required early. However, if the project is simplistic or repetitive then this knowledge may not be required until later in the project. The design team should consider these decisions.

6.2.4 CladdISS review point 1

CladdISS review point 1 precedes phase 2. Figure 6.3 shows the general review point outcomes and specific CladdISS outcomes. The general outcomes are the same for all the review points; therefore from this point forward the remaining review points will only show the CladdISS review outcomes.

Cladd:/SS Review 1
<p><u>General Review Point Outcomes</u> The following will be the main outcomes 1 Pass/fail or postpone the phase review for a later date 2 Critical decisions on financial authority to proceed 3 Consider strategy for addressing issues and actions in the next phase (listed in the next column) 4 Set date for next phase review meeting 5 Ensure phase review minutes are distributed to all attendees and relevant parties.</p>
<p><u>CladdISS Review Point One Outcomes</u></p> <p>Establish members of the design team.</p> <p>Establish the need for specialist cladding contractor advice</p> <p>Establish requirements for interface management</p>

Figure 6.3: Review point 1 outcomes (taken from CladdISS)

Part of the framework validation questionnaire asked the respondents to rank the review points. The respondents were asked two questions per review point.

- Indicate by means of 5 headings the relevance of each outcome using the following headings;
 - Would do at this stage
 - Do not use at this stage but consider a good idea
 - Don't use at this stage- too early
 - Don't use at this stage- too late
 - Don't use at all as not good idea

- Rank the outcomes in order of importance, for example review point 1 (see table 6.1) has three outcomes. (Therefore the importance ranking ranged from 1-3. All the outcomes were added together and column 8 gives the cumulative totals, the lowest figure being the most important).

The review shows that there are three outcomes;

- Establish members of the design team
- Establish the need for specialist cladding contractors advice
- Establish requirements for interface management.

Table 6.2 shows the results from the validation survey for review point 1. Columns 2-6 show the 5 relevance options. Column 7 and 8 show the order of importance ranking and totals.

	Actions required at project phases	Answers in percentages (%)					Importance	
		2	3	4	5	6	7	8
	1	Would do at this phase	Don't use at this phase but consider good idea	Don't use at this phase too early	Don't use at this phase too late	Don't use at all as not a good idea	Order of importance	Total = 176
A	Establish members of the design team	70	27		3		1	40
B	Establish the need for specialist cladding contractors advice	20	37	43	3		2	62
C	Establish requirements for interface management.	23	53	23	3		3	74

Table 6.2: Review point 1 validation results

The results show that the design team members should be established at this phase. It shows that 70 percent do anyway- 30 percent don't, however most think they should and a small number (3%) think it's too early (3% in terms of the sample is 1 respondent). Therefore it was expected it would rank highest in importance.

(B) *Establish the need for specialist cladding contractor's advice* and (C) *Establish requirements for interface management*, show less than a quarter (20 and 23%) do this anyway. Almost half consider it is too early in the process for (B) and a quarter said they do it the same for (C). However, a considerable

number of respondents (37 and 53) don't do it but consider it worthwhile and, by implication, may do so on future projects.

The need for (B) *specialist cladding advice* ranked second, which was surprising as the requirements for (C) *interface management* scored 53 percent for "do not use but consider a good idea". Perhaps the respondents were thinking of cost (the information may relate to a cost) but holistically when choosing they can see the benefit of early input from the specialists.

6.2.5 Phase 2 outline feasibility

Figure 6.4 shows the actions and decisions for the cladding process and interface management for phase two.

Main Project Process Protocol Actions & Decisions	Phase 2 Outline Feasibility Feasibility study for each option Re-assess site and environmental issues Revise business case
Cladding Process CP Actions & Decisions	Consider off site pre assembly. Obtain specialist contractors input. With reference to any environment issues (e.g. noise, dust) Develop outline planning constraints for aesthetic appearance Consider on site storage capacity Consider implications of cladding panel size(e.g. craneage) Consider the need for specialist cladding contractor input for cladding supply chain Consider if on/ off site testing is applicable, especially to the cost build up
Interface Management IM Actions & Decisions	Consider cladding interfaces with other elements and systems <i>* Note* "Increase in cladding types and building elements will increase interface complexity"</i> Consider compatibility between different systems/elements (e.g. precast on light steel frames).

Figure 6.4: CP and IM issues for phase 2 (taken from CladdISS)

At this phase there are two interface actions and decisions.

- Consider cladding interfaces with other elements and systems
- Consider compatibility between different systems/elements (e.g. precast on a light steel frame).

1 Consider cladding interfaces with other elements and systems

During the interviews (5.2.15) this issue was raised. If there are two or more cladding types or elements interfacing, a problem could develop within the design. It is possible that differing materials produce difficulties such as incompatibility.

Solid cladding systems interfacing with void cladding systems was also identified as causing problems in designs (5.3.7). Furthermore the drainage of interfacing cladding systems may be insufficiently detailed (*question 12 and 5.3.12*) due to the complexity of the interface.

2 Consider compatibility between different systems/elements (e.g. precast on a light steel frame).

This was also identified as a problem (5.2.15), and was further emphasised by one of the interviewed architects who singled out this interface as problematic and avoids it wherever possible.

A note was included with the phase stating "Increase in cladding types and building elements will increase interface complexity". This point was added to interlink the two actions and decisions as an awareness point.

6.2.6 Phase 3 Substantive feasibility study

Figure 6.5 shows the issues for the cladding process and interface management for phase three. At this phase there are five interface actions and decisions.

<p>Main Project Process Protocol Actions & Decisions</p>	<p>Phase 3 Substantive feasibility study and outline financial authority Prepare procurement plan, concept design plan and CDM assessment Define key systems and criteria & Inform on statutory & regulatory issues Revise project brief, business case, project/process plan, site and environmental issues</p>	<p style="writing-mode: vertical-rl; transform: rotate(180deg);">Outline Planning Approval</p> <p style="writing-mode: vertical-rl; transform: rotate(180deg);">Cladd:ISS review 2</p>
<p>Cladding Process CP Actions & Decisions</p>	<p>Consider defining cladding systems types Consider cost implications of off site pre assembly to onsite installation Consider the cladding supply chain Agree outline planning constraints for aesthetic appearance Consider system budget costs inline with business case Consider life cycle costs Consider risk assessing the process Consider specification type Check CDM planning supervisor/co-ordinator knowledge of cladding</p>	
<p>Interface Management IM Actions & Decisions</p>	<p>Consider strategy for simplifying/resolving interface (include samples and mock-ups). This should include testing costs Consider standardisation strategy (e.g. panel sizes and fixings) Develop register of cladding interfaces to include all interfaces and consider responsibilities for each interface. Develop compatibility between different systems/elements (e.g. precast on light steel frames) Consider cladding buildability (in particular interfaces)</p>	

Figure 6.5: CP and IM issues for phase 3 (taken from CladdISS)

1 Consider strategy for simplifying / resolving interface (include samples and mock-ups). This should include testing costs.

Considering the interface early enough can give the designer the opportunity to simplify the detail. This may include the need to standardise building dimensions (5.3.7). Simplifying the interface may also make the design easier to detail.

2 Consider standardisation strategies (e.g. panel sizes).

Standardisation was identified as very important. Furthermore, it was stressed that standardisation should be employed strategically. Section 5.3.7 (cladding to cladding solutions) identified a standardised interface will be easier to detail and design.

3 Develop a register of cladding interfaces to include all interfaces and consider responsibilities for each interface.

The interviews and the focus groups emphasised the need to delegate the interface responsibility as early as possible. Therefore it is necessary to develop a list or a register of the interfaces for important building elements. Once this has been compiled it is possible to consider who will take the responsibility of the interface. At this stage it is not necessary to be too specific just generic interfaces need to be considered such as frame, roof and services etc.

4 Develop compatibility between different systems/elements (e.g. precast on light steel frames).

Phase 2 considered the action; phase 3 now develops the action. The relative expertise of the design team may dictate how this is developed. For bespoke projects it might need specialist input from contractors or consultants. However, irrespective of the source, the information will benefit the final design.

5 Consider cladding buildability (in particular interfaces).

The focus groups identified poor understanding of buildability as a problem. This was expected from the construction site team (focus group 2) as predominantly they have to manage this during installation. However, for designers (focus group 1) to identify this as a problem was considered significant. If buildability cannot be achieved in design then invariably the problem will be passed to the installation phase as well. Focus group two suggested buildability should be considered at the concept and detailed design stage.

6.2.7 CladdISS review point 2

CladdISS review point 2 precedes phase 2. Figure 6.6 shows the outcomes from the review.

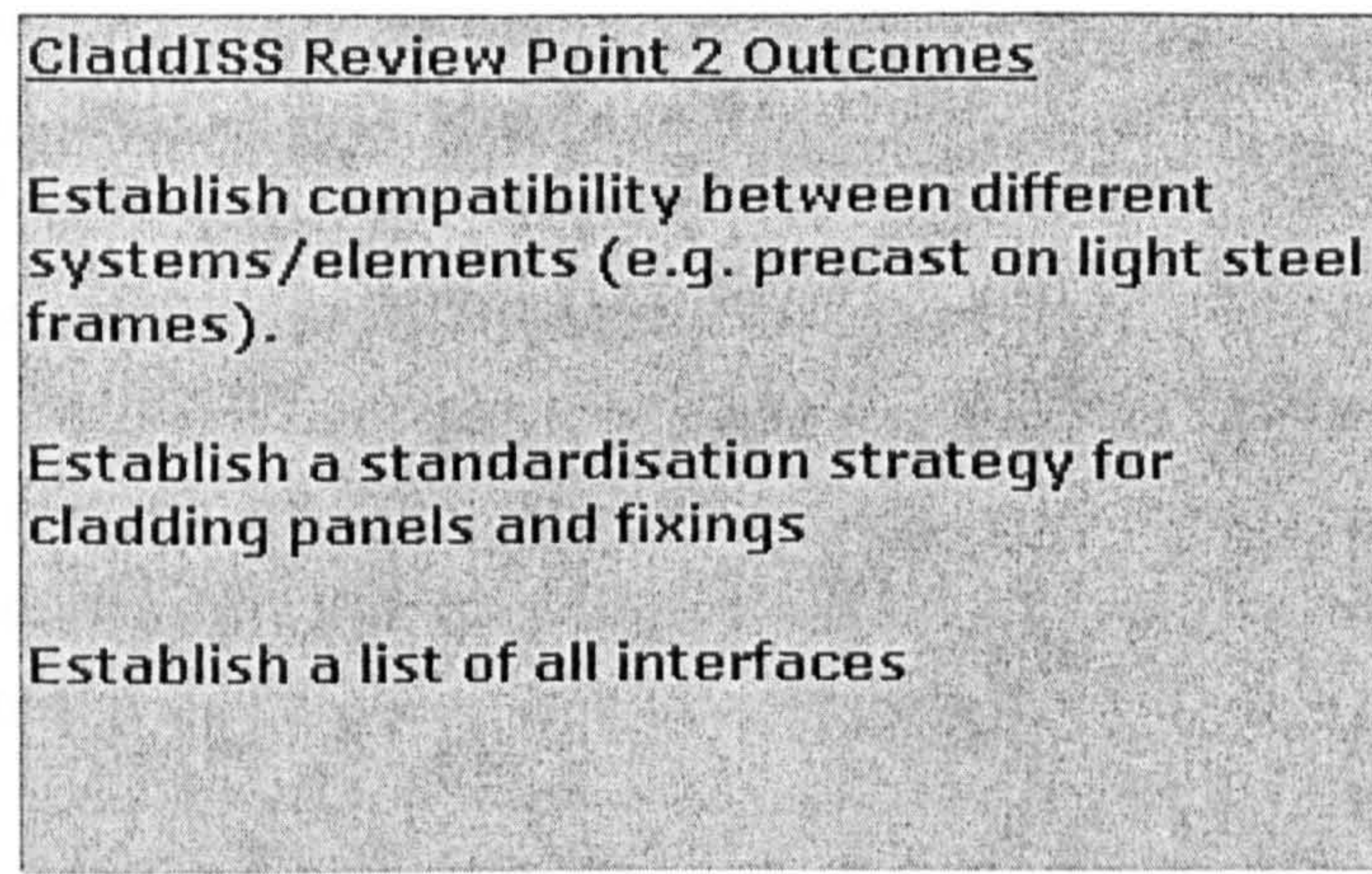


Figure 6.6: Review point 2 outcomes (taken from CladdISS)

The review shows that there are three outcomes;

- Establish compatibility between different systems/elements (e.g. precast on light steel frames).
- Establish a standardisation strategy for cladding panels and fixings.
- Establish a list of all interfaces.

Table 6.3 shows the results from the validation survey for the review point 2. Columns 2-6 show the 5 relevance options. Column 7 and 8 show the order of importance ranking and totals.

	Actions required at project phases	Answers in percentages (%)					Importance		
		1	2	3	4	5	6	7	8
			Would do at this phase	Don't use at this phase but consider good idea	Don't use at this phase too early	Don't use at this phase too late	Don't use at all as not a good idea	Order of importance	Total = 180
A	Establish compatibility between different systems/elements (e.g. precast on light steel frames).		80	10	10			1	48
B	Establish a standardisation strategy for cladding panels and fixings		60	23	17			2	58
C	Establish a list of all interfaces		30	40	30			3	74

Table 6.3: Review point 2 validation results

The results show that the compatibility between different systems/elements (e.g. precast on light steel frames) should already have been established. Apparently 80 percent already do this as a matter of course. The author has reservations as to whether this actually happens as there was little sign of this during the case studies, however it does show the perceived importance of the issue. Therefore it was expected it would rank highest in importance.

The need for a standardisation strategy had encouraging results. 60 percent do as a matter of course, 23 percent consider it a good idea. This indicates that the majority can see the benefits. The 17 percent who ranked it too early may consider standardisation limits design flair at this stage and can only be established later.

Establish a list of interfaces had divided results with 30 percent claiming regular implementation. 40 percent consider it a good idea, which strengthens the results; however the 30 percent that think it is too early may think this is the definitive list. At this stage the design team is only considering a generic list of interfaces, the development and the agreement of the interface register is completed later in the process. Therefore it is not surprising this ranked third in importance.

6.2.8 Phase 4 Outline conceptual design

Figure 6.7 shows the issues for the cladding process and interface management for phase four.

Main Project Process Protocol Actions & Decisions	PHASE 4 Outline conceptual design Prepare cost plan, outline concept designs and inform design process Revise project brief, business case, project/process execution plan, procurement plan, site and environmental issues and CDM assessment
Cladding Process CP Actions & Decisions	Consider cladding project specific design Develop budget costs in client brief Develop maintenance and access plan for cladding in compliance with CDM Consider outline method statements including protection of works and cleaning down Agree specification type and develop QA criteria Consider testing regime
Interface Management IM Actions & Decisions	Develop standardisation strategy Consider interface warranties Develop cladding buildability in particular with interfaces Consider tolerances and movement (live load deflections) Structure to cladding interface is crucial - consider cladding fixing types and zones Develop interface responsibilities within interface register Consider strategy for plant implications with interfacing workpackages Consider interface testing

Figure 6.7: CP and IM issues for phase 4 (taken from CladdISS)

At this phase there are eight interface actions and decisions.

- Develop standardisation strategy
- Consider interface warranties
- Develop cladding buildability in particular with interfaces
- Consider tolerances and movement (live load deflections)
- Structure to cladding interface is crucial - consider cladding fixing types and zones
- Develop interface responsibilities within interface register
- Consider strategies for plant implications with interfacing workpackages
- Consider testing interfaces

1 Develop standardisation strategy

Phase 3 considered the standardisation strategy and phase 4 develops this further. Taking precast concrete as an example, the design team should develop standard panel sizes.

2 Consider interface warranties

The interview findings (*table 5.4*) show that the interface warranty is not fully resolved until handover. Furthermore the involvement for the interface warranty is late throughout. Therefore to prevent legal repercussions it is necessary to

consider the warranties during the design formation phases. If the design team are preparing an interface register it would be beneficial to consider the warranty at the same time. This could be as simple as all succeeding subcontractors taking on the warranty. Often this is the scenario but is not always formally agreed, but just assumed. However, sequential ownership cannot happen in all cases and the design team needs to start considering the responsibility.

3 Develop cladding buildability in particular with interfaces

At this juncture the interface register is being prepared. The buildability of the interfaces can be developed further by reviewing the register and allowances made for complex designs.

4 Consider tolerances and movement (live load deflections)

Tolerances and movement also need to be considered at this stage. The data collection identified this as a major problem with little understanding. Focus group 1 (*table 5.9*) suggested that the design team should obtain tolerance and movement details from the specialist contractors. This should happen at phase 3-4; also interfacing workpackages need to gain the same information as well.

5 Structure to cladding interface is crucial - consider cladding fixing types and zones.

The interviews and the focus groups identified the cladding to frame interface as the most problematic interface (*5.4.5 confirmed this*). Often the specialist contractors would be designing their cladding systems or elements assuming cladding fixing zones from experience. If the fixing zones and types are considered at this phase the downstream problems can be reduced.

6 Develop interface responsibilities within interface register

The interface register needs to be developed further; this may involve developing the generic interface into more specific details. Information from cladding systems companies may be required.

7 Consider strategies for plant implications with interfacing workpackages

In the design development it will be necessary to consider plant implications especially cranes. Inner city developments will have logistical problems with cranes, off loading and storage. *Case study F* identified the crane problems with

an inner city development, particularly the weight of the cladding panels and the limitations of the crane regarding the reach/weight combination.

8 Consider testing interfaces

The complexity of the project may dictate that the interfaces need to be tested. *Question 5.2.15* identified that if a building is going to leak, invariably it will be at an interface, especially a complex one. Therefore the design team needs to consider the complexities of the interfaces to evaluate whether they need to be tested. A cladding test can be expensive and the details will be needed for the cost evaluation.

6.2.9 Phase 5 Full conceptual design

Figure 6.8 shows the issues for the cladding process and interface management for phase five.

Main Project Process Protocol Actions & Decisions	PHASE 5 Full conceptual design Prepare full concept design and maintenance plan Continue cost plan Revise project brief, business case, project/process execution plan, procurement plan, site and environmental issues and CDM assessment	Cladd:SS review 3
Cladding Process CP Actions & Decisions	Develop cladding project specific design Maintenance and access developed (details supplied by specialist contractors if appointed) Budget costs required for project specific designs Design team check to see if project is statutory compliant Develop cladding supply chain strategy Develop testing regime	
Interface Management IM Actions & Decisions	Develop strategy for plant implications with interfacing workpackages Develop cladding fixings Agree standardisation strategy Agree all cladding interfaces and complete interface register Agree all cladding interface responsibilities Develop strategy for plant implications with interfacing workpackages and consider the warranties Agree fixing zones Develop interface warranties Develop Interface testing regime	

Figure 6.8: CP and IM issues for phase 5 (taken from CladdISS)

At this phase there are nine interface actions and decisions.

- Develop strategy for plant implications with interfacing workpackages
- Develop cladding fixings
- Agree standardisation strategies
- Agree all cladding interfaces and complete interface register

- Agree all cladding interface responsibilities
- Develop strategy for plant implications with interfacing workpackages.
- Agree fixing zones
- Develop interface warranties

1 Develop strategy for plant implications with interfacing workpackages

During the project development the design team should develop a strategy for interfacing workpackages. This may involve the workpackages installing concurrently or sequentially. The ideal scenario would be sequentially, however this is not always possible therefore the development process should involve evaluating the plant usage and timings.

2 Develop cladding fixings

The primary interface between the cladding and the frame is the cladding fixings. If the cladding fixings design is developed early enough the problems at the interface will be reduced. The requirements of the cladding to structure interface are (information taken from CladdISS- cladding to frame bracketry information);

- Transfer of loads from the cladding to the frame.
- Provide restraint to prevent unwanted cladding movement.
- Accommodate frame deviations and cladding deviations.
- Be adjustable with sufficiently fine adjustment to allow alignment of the cladding.
- Allow for movement of the cladding to contain inherent deviations of;
 - Frame movement
 - Cladding thermal movement
 - Cladding moisture movement
 - Cladding movement due to cladding loads
(Wind, self weight, other imposed loads)
- Be durable and resistant to corrosion.
- Be simple to install.
- Be easy to inspect.
- Be economical and easy to manufacture.

- Be used with as many repetitions as economically possible.

Furthermore the cladding fixing method should be developed. There are two basic methods; cast in/ fabricated or site applied. Whichever method is selected will have a bearing on the frame; therefore the design team needs to consider this further.

3 Agree standardisation strategies

Before detailed design commences (phase 6) the standardisation strategy has to be agreed. Invariably this agreement will be by the project designer, but this may vary depending upon the procurement route. If the specialist contractor has been appointed or has design input they will agree this with the approval of the design team.

4 Agree all cladding interfaces and complete interface register

At this stage the design should be developed enough to establish all the interfaces and complete the register. The register can then be included with tender documents (if applicable). This will allow the bidding contractors sufficient time to appraise the complexity of the interfaces.

5 Agree all cladding interface responsibilities

After the completion of the interface register the design team can then make the decision on who will take the responsibility for the interface. If there are numerous interfaces within the façade it might be necessary to appoint one contractor to undertake the whole package this was identified in *case study D* and a solution from focus groups (5.3.9.4). It was identified this may appear to add cost to the project, but holistic costs must be considered.

6 Develop strategy for plant implications with interfacing workpackages

The development process should include programming information. For instance exactly how much time a specialist requires to install their works. If a workpackage is installing large panels such as unitised curtain wall or precast concrete panels then they will be predominately reliant on cranes. However, if the task emphasis is on site assembly then the priority will be delivery of materials to site locations and less on installation as the parts will be in controllable sizes. The development process may need information from the principal contractor.

7 Agree fixing zones

To enable the fixing types to be developed (point 1) the zones need to be agreed. The zone for the cladding fixings will invariably be in the area at the junction between column and slab. Too often the specialist contractor is designing the fixings in assumed zones thus added costs will be incurred (see *chapter 4 CladdISS programming*). Furthermore in this zone there may be added bracing for the frame. If the zones are agreed the fixing design can be produced without too much alteration at a later stage.

8 Develop interface warranties

The interface responsibility has been agreed (point 3) therefore the interface warranties should be developed. This may involve one contractor taking the warranty for the whole façade as stated with interface responsibility.

9 Develop interface testing regime

If the design team has stated the interfaces are going to be tested (point 8, phase 4) then the development will include the nature of the test. There are two types of test: on-site or off-site. The complexity of the interface may dictate this, the off-site test will be far more onerous than a site test. The off site test may involve the CWCT (1993) test (for curtain wall and windows), whereas the site test maybe as straight forward as a hose pipe test on a sample section of the cladding.

However the hosepipe test is covered in the CWCT document and should be consulted by the cladding contractor and agreed in the contract. *Case study C* highlighted the difficulties of interfaces achieving the performance requirements of an off-site test. Therefore the design team must decide how thorough the test needs to be.

6.2.10 CladdISS review point 3

Review point 3 precedes phase 6. Figure 6.9 shows the outcomes from the review.

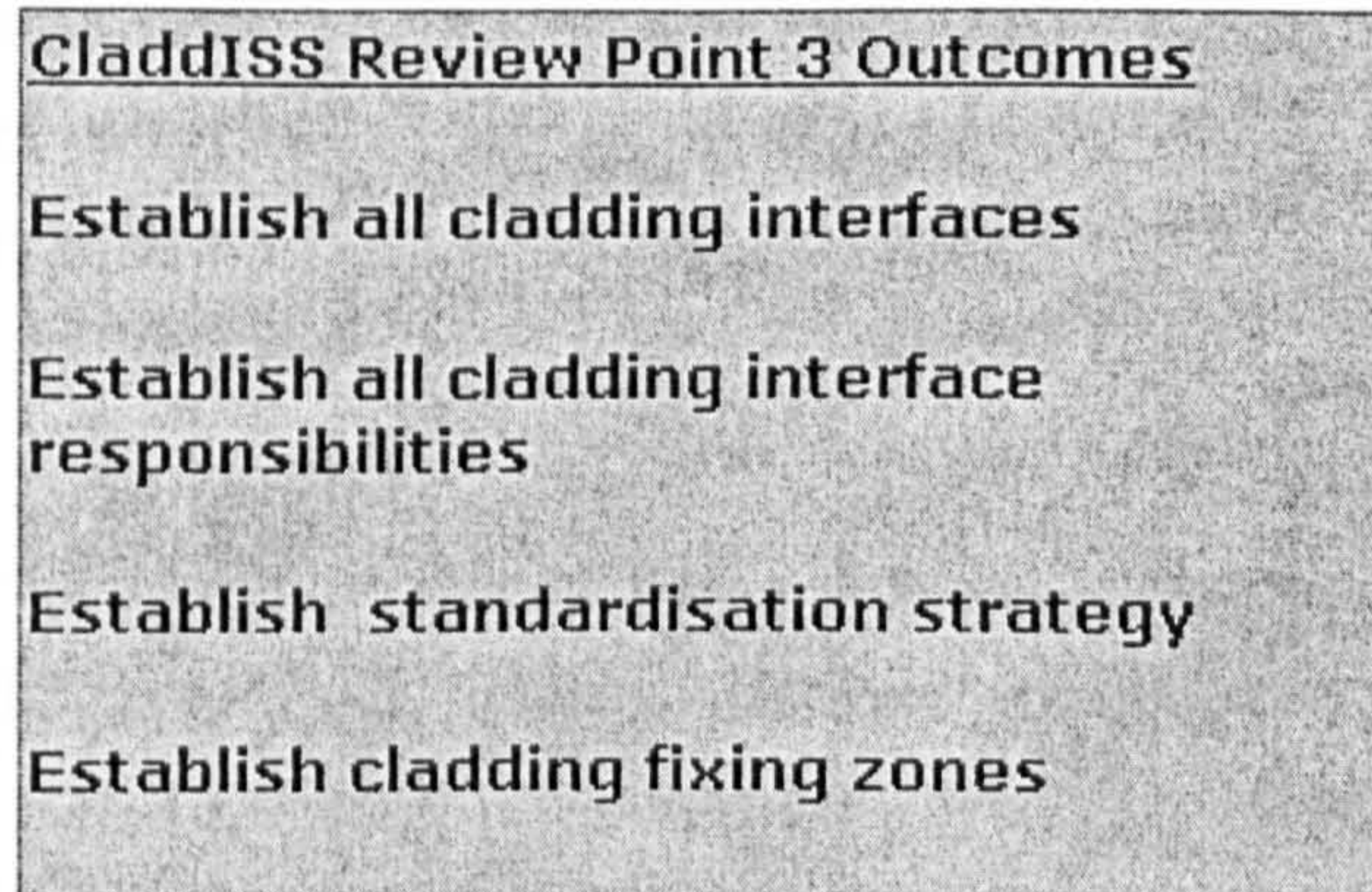


Figure 6.9: Review point 3 outcomes (taken from CladdISS)

The review shows that there are four outcomes;

- Establish all cladding interfaces.
- Establish all cladding interface responsibilities
- Establish standardisation strategy
- Establish cladding fixing zones

Table 6.4 shows the results from the validation survey for the review point 3. Columns 2-6 show the 5 relevance options. Column 7 and 8 show the order of importance ranking and totals.

	Actions required at project phases 1	Answers in percentages (%)					Importance	
		2	3	4	5	6	7	8
		Would do at this phase	Don't use at this phase but consider good idea	Don't use at this phase too early	Don't use at this phase too late	Don't use at all as not a good idea	Order of importance	Total = 259
A	Establish all cladding interfaces	94		3	3		1	42
B	Establish all cladding interface responsibilities	61	32	7			2	72
C	Establish a standardisation strategy	61	29	7	3		3	73
D	Establish cladding fixing zones	83	3	14			2	72

Table 6.4: Review point 3 validation results

The results show that 93 percent “would as a matter of course” *Establish all the cladding interfaces* at this stage. Therefore it was expected it would rank highest in importance. However 3 percent think this is too early and a further 3 percent too late (1 respondent for each). If the respondents predominantly use the construction management procurement method then possibly this may account for their response. With this method the design is developed as the project progresses; therefore they may presume the interfaces are in this development time zone.

The remaining three points produced some interesting results. (B) *Establish the interface responsibility* and (C) *Standardisation strategy* had virtually identical results. However, (C) 3 percent (one respondent) considered it was too late to establish a standardisation strategy. The encouraging results for the research both ranked “don’t use but consider a good idea” quite high. This indicates that the research has produced information that will be used by industry.

(D) For *Establish the cladding fixing zones*, 82 percent “would do as a matter of course” but 14 percent thought it was too early. The author can only presume that this result signifies some respondents think that this is the responsibility of the frame contactor to detail this. Traditionally this would be achieved later in the process.

In terms of importance ranking B, C and D returned virtually identical results therefore no significant difference can be drawn between the three and they are all as important as each other. However, (A) *Establish all cladding interfaces* is the most important outcome of the review point.

6.2.11 Phase 6 co-ordinated design, procurement & full financial authority

Figure 6.10 shows the issues for the cladding process and interface management for phase six.

<p>Main Project Process Protocol Actions & Decisions</p>	<p>PHASE 6 Co-ordinated design, procurement & full financial authority Produce product model (co-ordinated design) Prepare work packages Continue cost plan Revise project brief, business case, project/process execution plan, procurement plan, maintenance plan & CDM</p>	<p>Cladd:ISS review 4</p>
<p>Cladding Process CP Actions & Decisions</p>	<p>Agree testing regime Complete detailed project specific design Full cladding costs established Develop outline product production drawings Risk assess the availability and type of specialist cladding contractor (if not already appointed) Design team agree project is statutory compliant Agree strategy for material incompatibility Agree full design freeze Agree programme for production drawings Agree/review critical Supply chain (e.g. glass)</p>	
<p>Interface Management IM Actions & Decisions</p>	<p>Agree upon cladding work packages Co-ordinate interfacing designs such as frame and roof designs Agree cladding fixings Manage interface responsibilities with workpackages and agree their warranties Develop workpackage method statements Agree strategy for plant implications with interfacing workpackages Agree interface warranties Agree Interface testing</p>	

Figure 6.10: CP and IM issues for phase 6 (taken from CladdISS)

At this phase there are eight interface actions and decisions.

- Agree upon cladding workpackages
- Co-ordinate interfacing designs such as frame and roof
- Agree cladding fixings
- Coordinate interface responsibilities with workpackages and agree their warranties
- Develop workpackage method statements
- Agree strategies for plant implications with interfacing workpackages
- Agree interface warranties
- Agree interface testing

1 Agree upon cladding workpackages

At this stage the cladding workpackages must be agreed. Traditionally this is the phase where the tender documents are sent out to contractors. Failure to fix workpackage content will incur additional, unplanned costs.

Irrespective of the chosen procurement route, at this point in the project there will be a high specialist contractor involvement. If the specialists are bidding for the workpackages they must know what they entail. During the data collection (5.2.15) the term 'by others' was identified as a major problem for the interfaces. If the workpackages are agreed this can help reduce this problem.

2 Co-ordinate interfacing designs such as frame and roof

The detailed design will generally be the responsibility of the specialist contractors (5.2.15). The specialists will need to see other specialist's details, especially those that interface with their own. A method of coordination needs to be put in place. Modern technology facilitates effective information transfer; drawings can be accessible to the design team for approval and revision using this method. These techniques need to be explored further by the design team, however this is outside the scope of this thesis.

3 Agree cladding fixings

The cladding fixings should be agreed at this stage especially whether they are going to be cast in or site applied. *Case study C* never resolved this issue until late in the design, fortunately as the project fell behind schedule this did not become an issue.

4 Coordinate interface responsibilities with workpackages and agree their warranties

Once the interface responsibility has been agreed it needs to be coordinated. Probably the specialist contractor who has the interface responsibility will detail the interface drawing (5.2.15). Therefore the other contractors will need to view the details so they can finalise their drawings.

5 Develop workpackage method statements

Continuing points 1 and 4; once the workpackages have been agreed and the coordination process is in place the method statements need to be developed. The health and safety file for the project must include the installation methods for all the contractors. Table 5.7 in chapter 5 shows that health and safety

involvement becomes less prevalent as the project progresses, if the method statements are developed at this phase the involvement should remain constant throughout. Also the principal contractor will need to review the method statements to enable efficient programming.

6 Agree strategies for plant implications with interfacing workpackages

This will be principal contractor driven from this point forward. The design team will have considered and developed a strategy in the previous phases. The principal contractor will need precise information from the workpackages as to their requirements for plant. This will then be put in place within an agreed programme.

7 Agree interface warranties

Phase 6 mainly involves agreement of design before the production of the systems. Therefore all the designs need to be complete at this phase. This will mean the workpackage contractor responsible for the interface agreeing the design with the other workpackage contractor so they can agree the warranty. A contractor should not make a formal agreement of the warranty until the design is complete.

8 Agree interface testing

Once the designs have been agreed then a decision can be made on the interface testing process. The development of the testing regime will assess the level of the test required. It is recommended that all bespoke projects have off-site testing, also standard systems with complex interfaces (*case study c*) (It is recommended that the CWCT testing document is consulted). However a project with standard systems and designs may not need the thorough off-site test. The design team should make this decision unless the client states otherwise.

6.2.12 CladdISS review point 4

Review point 4 precedes phase 7. Figure 6.11 shows the outcomes from the review.

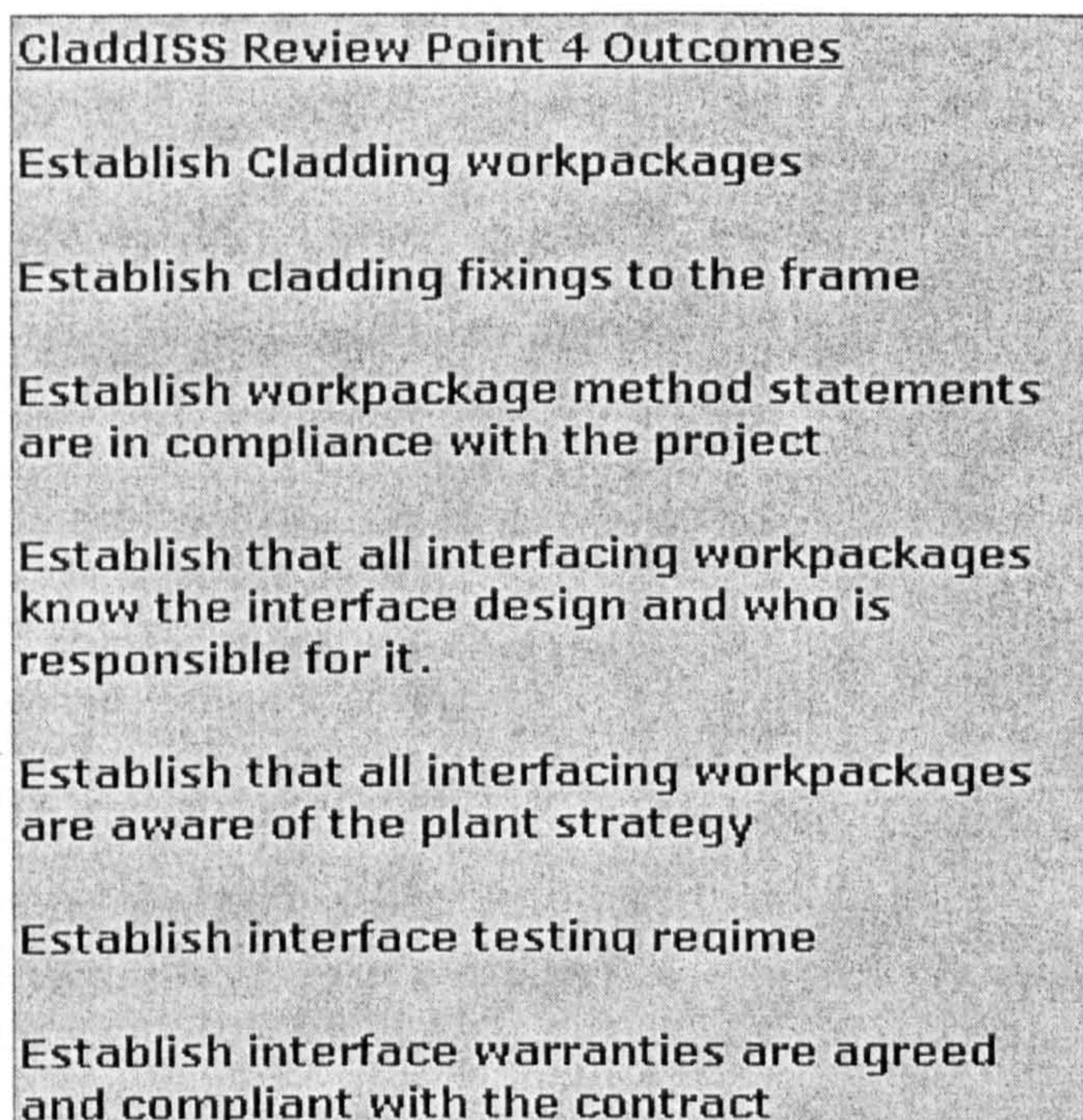


Figure 6.11: Review point 4 outcomes (taken from CladdISS)

The review shows that there are seven outcomes;

- Establish cladding workpackages
- Establish cladding fixings to the frame
- Establish workpackage method statements are in compliance with the project
- Establish that all interfacing workpackages know the interface design and who is responsible for it.
- Establish all interfacing workpackages are aware of the plant strategy
- Establish interface testing regime
- Establish interface warranties are agreed and compliant with the contract

Table 6.5 shows the results from the validation survey for the review point 4. Columns 2-6 show the 5 relevance options. Column 7 and 8 show the order of importance ranking and totals.

	Actions required at project phases	Answers in percentages (%)					Importance	
		2	3	4	5	6	7	8
	1	Would do at this phase	Don't use at this phase but consider good idea	Don't use at this phase too early	Don't use at this phase too late	Don't use at all as not a good idea	Order of importance	Total = 739
A	Establish cladding workpackages	80	13		7		1	47
B	Establish cladding fixings to the frame	83	13		3		2	86
C	Establish workpackage method statements are in compliance with the project	60	13	23	3		4	118
D	Establish that all interfacing workpackages know the interface design and who is responsible for it.	43	37	7	13		2	85
E	Establish all interfacing workpackages are aware of the plant strategy	40	47	7	7		7	138
F	Establish interface testing regime	60	33	3	3		5	132
G	Establish interface warranties are agreed and compliant with the contract	37	57		7		5	133

Table 6.5: Review point 4 validation results

The results show that the majority either “do as a matter of course” or “do not use but consider a good idea”. There are a small minority that consider those actions too late and a few, still too early.

(A) *Establish cladding workpackages* was ranked as most significant and 80 percent of the samples “do this as a matter of course”. Generically this is probably true, for example the cladding package will be established, however it is common to separate some of the elements into smaller packages such as sun shading (if applicable). If this is the case the workpackages are not fully established. In addition this can produce problems later in the project (*case study B*).

(C) *Establish that all interfacing workpackages know the interface design and who is responsible for it* ranked second. 43 percent are in agreement, also 37 percent “don’t use but consider a good idea” again highlights the benefit of the research. Of the remaining answers, the too late and the too early comments could be procurement related. As the procurement route will dictate the appointment time of the workpackages.

(B) *Establish cladding fixings to the frame* was also ranked second. With 83 percent “doing as matter of course” it was expected this would rank number one. As the number is so high probably the fixings are established early within the cladding package. However this is still the interface between the frame and cladding (5.4.5), the hardest to manage and needs to be managed throughout having been thoroughly planned.

(C) *Establish that workpackage method statements are in compliance with the project* ranked fourth. This outcome produced a result that possibly contests this finding with 23 percent ranking it too early. However 60 percent “do as a matter of course”. Those that considered it too early maybe unaware of health and safety implications which appear to become less important as the project nears the construction phase (table 5.4).

(F) *Establish interface testing regime* and (G) *Establish interface warranties* ranked joint fifth. 60 percent do (F) “as a matter of course”, however 33 percent “do not use but consider a good idea”. Therefore it is possible that the testing is considered but it is the cladding systems that are tested and the interfaces are not. It is quite easy to obtain testing results for a cladding system. These can be supplied by systems companies or from previous projects. The interfaces are always bespoke and need to be tested (case study C).

Table 5.4 shows that *Establish interface warranties* is one of the three issues that are not resolved until handover. With 57 percent responding with “do not use but consider a good idea” further endorses the earlier results. This clearly shows that the interface warranty is not considered enough or is too late. Hopefully the use of CladdISS will help this issue.

(E) *Establish all interfacing workpackage contractors are aware of the plant strategy* ranked seventh, however there was very little between E, F and G so they can be considered as important as each other. This could be misconstrued as a site issue (phase 8) and maybe why it was ranked so low. However 47 percent responded “do not use but consider it a good idea” which is an encouraging result indicating that the outcome is considered a design issue and not a construction issue.

6.2.13 Phase 7 production information

Figure 6.12 shows the issues for the cladding process and interface management for phase seven.

Main Project Process Protocol Actions & Decisions	Phase 7 Production Information Procure package suppliers Monitor cost & quality Start enabling works Finalise project brief, business case, project/process plan, cost plan, co-ordinated product model and H&S plan
Cladding Process CP Actions & Decisions	Cladding production drawings completed
Interface Management IM Actions & Decisions	(If applicable) Co-ordinate off-site testing, including interfaces with other materials or building elements. Agreement between all interfacing workpackages on the programme (e.g. are they all in the there correct work zones and time scales) Co-ordinate all interfacing work package method statements Agree surveying options with interfacing contractors (cladding/frame/roof - who takes responsibility)

Figure 6.12: CP and IM issues for phase 7 (taken from CladdISS)

At this phase there are four interface actions and decisions.

- (If applicable) Co-ordinate off-site testing, including interfaces with other materials or building elements.
- Agreement between all interfacing workpackages on the programme (e.g. are they all in the correct work zones and time scales)
- Coordinate all interfacing workpackage method statements
- Agree surveying options with interfacing contractors (cladding/frame/roof - who takes responsibility)

1 (If applicable) Co-ordinate off-site testing, including interfaces with other materials or building elements.

If there are complex interfaces off-site testing should happen. In the UK there are limited testing facilities therefore the testing needs to be coordinated within the production time. Sufficient time should be allowed for the test to be arranged; generally this will include a 'mock up' of the cladding types and materials (flashings and DPM's) at the particular interface. Too often the test happens when production is in operation. If the interface fails then design revisions may occur, potentially changing the design of the production items.

2 Agreement between all interfacing workpackages on the programme (e.g. are they all in the correct work zones and time scales)

The principal contractor should take the initiative with this issue. The best method to reach this agreement is to have pre construction meetings with all interfacing workpackages and the principal contractor. The meetings should ascertain when and where the workpackages are scheduled in the programme and if there are any specific requirements relating to other workpackages.

3 Coordinate all interfacing workpackage method statements

This issue will be coordinated in parallel with issue two. If a meeting is going to be convened between the interfacing parties then the method statements can also be discussed. The method statements should include working practices such as trade overlaps and zones (if applicable).

4 Agree surveying options with interfacing contractors (cladding/ frame/roof - who takes responsibility)

Section 5.3.12, post tender problems identified setting out of the structure and façade as problematic especially dealing with manufacturing and construction tolerances. If incorrectly surveyed; the end panel may have to be altered due to failure to allow for cumulative tolerances.

During the interviews (5.2.24), the question was asked whether the frame, cladding contractor and the principal contractor ever surveyed and 'signed off' the frame together. Invariably the answer was no but the idea was considered advantageous. It would however need all the parties to be contracted at the same time, which rarely happens.

Question 10 (5.4) validated this with varying responses. The majority (61%) agreed with it, however 31 percent of the cladding contractors disagreed. The author is suggesting that this is a method of overcoming some of the construction problems and should be considered in a project if there is sufficient time and resources allowed.

6.2.14 Phase 7a manufacture

Figure 6.13 shows the issues for the cladding process and interface management for phase seven (A).

Main Project Process Protocol Actions & Decisions	Phase 7A Manufacture Produce design for manufacture Manufacture and pre-assembly Deliver components and units to site
Cladding Process CP Actions & Decisions	Co-ordinate manufacture of the cladding system Co-ordinate critical supply chain (e.g. glass)
Interface Management IM Actions & Decisions	Audit of manufacturing QA

Figure 6.13: CP and IM issues for phase 7a (taken from CladdISS)

At this phase there is one interface action and decision.

- Audit of manufacturing quality assessment (QA).

1 Audit of manufacturing quality assessment (QA).

The manufacturing time for cladding is one of the longest in construction with lead times of up to 35 weeks for certain types. Section 5.2.15 highlighted managing lead times for materials especially glass as a problem. Section 5.3.12 suggested that the lead times were too short thus causing construction problems. Therefore an audit system needs to be administered to prevent manufacturing problems.

6.2.15 Phase 8 construction/ assembly

Figure 6.14 shows the issues for the cladding process and interface management for phase eight. At this phase there are three interface actions and decisions:

- Continued co-ordination of interface responsibility
- Co-ordinate testing of completed cladding and interfaces
- Co-ordinate protection and cleaning down of interfacing workpackages

Main Project Process Protocol Actions & Decisions	PHASE 8 Construction / Assembly On-site work Practical / Final Completion Complete CDM File	Cladd:ISS review 5
Cladding Process CP Actions & Decisions	Manufacture continued and co-ordinated Co-ordinate cladding construction tolerances Co-ordinate cladding protection (include material cleaning incompatibility) Co-ordinate all method statements Co-ordinate deliveries and storage Co-ordinate preparation of cladding "as built" drawings for CDM file All cladding site operatives may need induction training prior to work commencement	
Interface Management IM Actions & Decisions	Continued co-ordination of interface responsibilities Co-ordinate testing of completed cladding and interfaces Co-ordinate protection and cleaning down of interfacing workpackages	

Figure 6.14: CP and IM issues for phase 8 (taken from CladdISS)

1 Continued co-ordination of interface responsibility

Section 5.3.12 stated that often there is no design input given at site level and the design intent can change due to the lack of information passed down to the site operatives. If the design team, prior to construction, agreed the interface responsibility then this information needs to be transferred to the principal contractor enabling coordination between the interfacing contractors.

2 Co-ordinate testing of completed cladding and interfaces

If the decision was made to site test the interfaces then this needs to be coordinated with the cladding contractors. If site tests have been arranged then they should occur before the commencement of the main cladding works. If leaks occur then the problem can be rectified before the main work is started.

Therefore the cladding contractors need to be programmed so that their systems are assembled ready for testing. If the cladding works are sequential then it would be prudent to assemble the test 'mock up' in the same sequence. The principal contractor needs to coordinate this operation related to the construction programme.

3 Co-ordinate protection and cleaning down of interfacing workpackages

Section 5.3.9.4 stated that, being realistic, damage will happen to cladding so it must be reduced wherever possible. A holistic approach should be taken and sufficient allowances should be made for the cladding contractor to protect their works.

In addition if a cladding package has been completed and following trades need to work in close proximity to the completed works then they must be protected. The principal contractor should ensure sufficient money has been allowed for the protection. Furthermore they also need to ensure that the contractor protects their works as agreed in their tender.

6.2.16 CladdISS review point 5

Review point 5 precedes phase 9. Figure 6.15 shows the outcomes from the review.

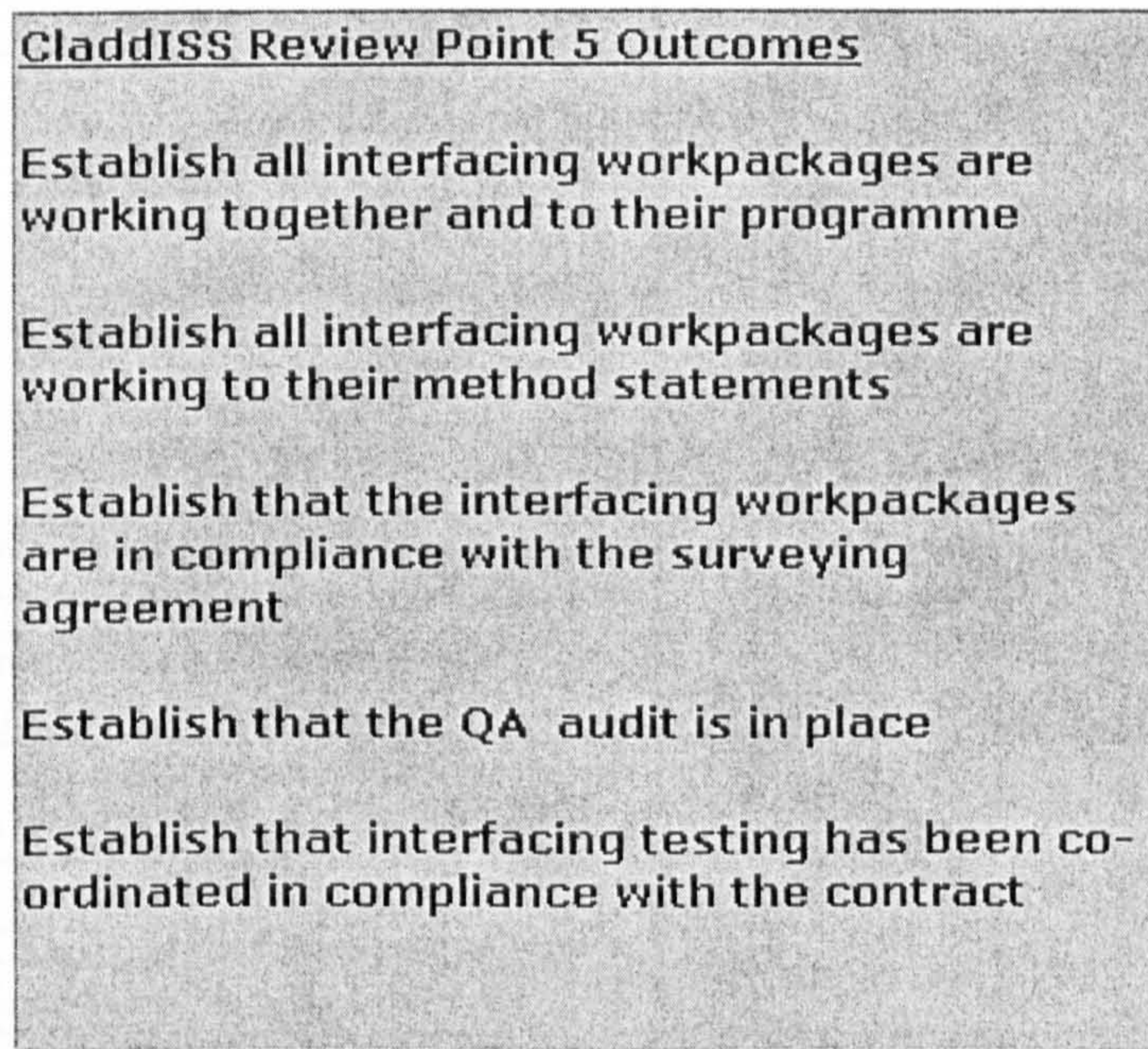


Figure 6.15: Review point 5 outcomes (taken from CladdISS)

The review shows that there are five outcomes;

- Establish all interfacing workpackages are working together and to their programme
- Establish all interfacing workpackages are working to their method statements
- Establish that the interfacing workpackages are in compliance with the surveying agreement
- Establish that the QA audit is in place
- Establish that interface testing has been co-ordinated in compliance with the contract.

Table 6.6 shows the results from the validation survey for the review point 5. Columns 2-6 show the 5 relevance headings. Column 7 and 8 show the order of importance ranking and totals.

	Actions required at project phases	Answers in percentages (%)					Importance	
		2	3	4	5	6	7	8
	1	Would do at this phase	Don't use at this phase but consider good idea	Don't use at this phase too early	Don't use at this phase too late	Don't use at all as not a good idea	Order of importance	Total = 398
A	Establish all interfacing workpackages are working together and to their programme	86	14				1	57
B	Establish all interfacing workpackages are working to their method statements	86	11		3		2	64
C	Establish that the interfacing workpackages are in compliance with the surveying agreement	54	43		3		3	84
D	Establish that the QA audit is in place	68	25		7		4	93
E	Establish that interfacing testing has been co-ordinated in compliance with the contract	69	21	3	7		5	100

Table 6.6: Review point 5 validation results

The results show that it appears all the outcomes are managed satisfactorily "as a matter of course". With the exception of *the interfacing workpackages are in compliance with the surveying agreement* (whose responsibility is it to survey the frame prior to the cladding be installed), where 45 percent responded with "don't use but consider good idea". This indicates that the surveying issue is a problem (5.3.12) and methods of resolving the problem would be accepted.

The five outcomes had the following ranking in order of importance;

- 1 Establish all interfacing workpackages are working together and to their programme.
- 2 Establish all interfacing workpackages are working to their method statements.
- 3 Establish that the interfacing workpackages are in compliance with the surveying agreement.
- 4 Establish that the QA audit is in place.
- 5 Establish that interface testing has been co-ordinated in compliance with the contract.

6.2.17 Phase 9 maintenance / facilities management

Figure 6.14 shows the issues for the cladding process and interface management for phase nine.

Main Project Process Protocol Actions & Decisions	PHASE 9 Maintenance / Facilities Management Handover and user occupation Defects liability period - Release of retention etc.	Cladd:ISS review 6
Cladding Process CP Actions & Decisions	Co-ordinate cladding manufacturers and installers information included in Health & Safety file Co-ordinate O&M manual completion Test certificates included in Handover Co-ordinate defects liability and warranties period with contracted parties	
Interface Management IM Actions & Decisions	Co-ordinate all parties involved with the handover periods, may include partial handover before total completion of cladding packages Co-ordinate and review output from end users/clients feedback process and identify items regarding interfaces and advise relevant parties. Co-ordinate interface maintenance	

Figure 6.16: CP and IM issues for phase 9 (taken from CladdISS)

At this phase there are three interface actions and decisions:

- Co-ordinate all parties involved with the handover periods, this may include partial handover before total completion of the cladding packages
- Co-ordinate and review output from end users/clients feedback process and identify items regarding interfaces and advise relevant parties
- Co-ordinate interface maintenance

1 Co-ordinate all parties involved with the handover period; this may include partial handover before total completion of cladding packages.

If there are two or more cladding types in the façade and one is completed whilst the others are still being assembled then handover to the principal contractor has to be coordinated. This may include the protection of the completed cladding

remaining until the whole façade is complete. Also if partial handover to the client is required a method of handover has to be coordinated between the cladding contractors, principal contractor and the client.

In addition at handover the cladding contractors must supply information to the principal contractor of their installed cladding systems especially if there has been a complicated interface detail between the systems or building elements. Furthermore there should be precise references to who is responsible for the interface warranties.

2 Coordinate and review output from end users/clients feedback process and identify items regarding interfaces and advise relevant parties.

Following the completion of the project there needs to be an end user feedback system. This should include all the interfacing parties (cladding contractors, principal contractors and frame contractor etc) and the end users. The purpose of this is to establish where the process went wrong or was improved during the building development and how it has affected the completed building.

This information should be coordinated by a design team member and a method of knowledge transfer put in place. This will allow information to be passed to future projects so that the mistakes are designed out and the benefits are introduced.

3 Coordinate interface maintenance

At the handover stage the maintenance information is given to the client. If there have been unique interface designs and joints between cladding systems these will also have to be maintained within the facade maintenance plan. This information needs to be coordinated by the cladding contractor, principal contractor and the client.

This may include methods of access to the interface and techniques of dismantling and reassembly. Furthermore there may be specific details of specialist suppliers for the materials.

6.2.18 CladdISS review point 6

Review point 6 precedes phase 10. Figure 6.17 shows the outcomes from the review.

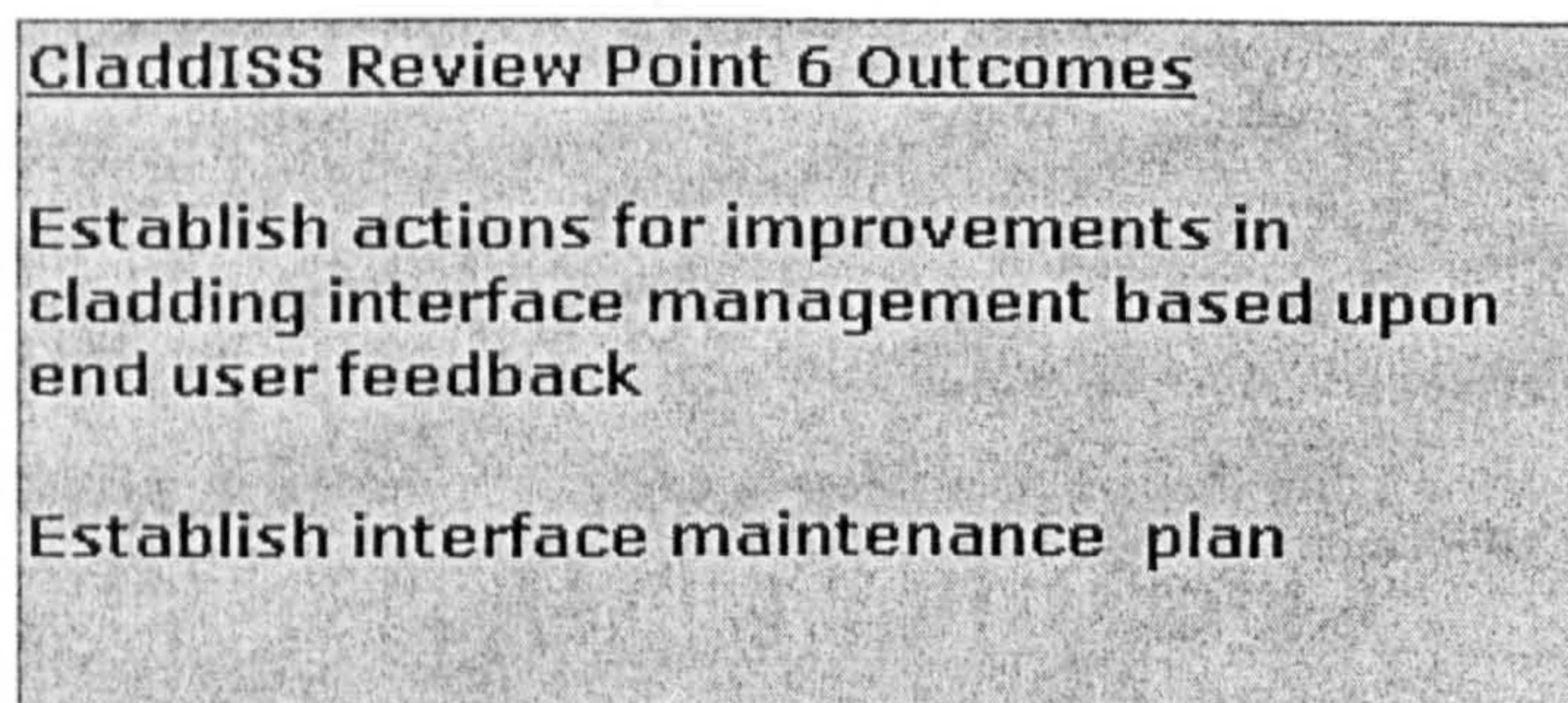


Figure 6.17: Review point 5 outcomes (taken from CladdISS)

The review shows that there are two outcomes;

- Establish actions for improvements in cladding interface management based upon end user feedback
- Establish interface maintenance plan

Table 6.7 shows the results from the validation survey for the review point 6. Columns 2-6 show the 5 relevance headings. Column 7 and 8 show the order of importance ranking and totals.

	Actions required at project phases 1	Answers in percentages (%)					Importance	
		2	3	4	5	6	7	8
		Would do at this phase	Don't use at this phase but consider good idea	Don't use at this phase too early	Don't use at this phase too late	Don't use at all as not a good idea	Order of importance	Total = 85
A	Establish actions for improvements in cladding interface management based upon end user feedback	21	72		7		1	47
B	Establish interface maintenance plan	39	34	3	24		2	38

Table 6.7: Review point 6 validation results

Out of the six review points this has given the highest score for a "don't use but consider a good idea". Establish actions for improvement in cladding interface management based upon end user feedback achieved 72 percent. This

exemplifies the need for methods for improving the construction process. For this to happen requires improved integration of the whole process. Also this outcome was ranked first in order of importance.

Twenty-four respondents considered that it was too late to *Establish interface maintenance plan*. If this is when it is considered then the author agrees. However the full interface management plan includes all relevant details for maintaining the interface and how this is achieved and therefore cannot be fully established until this stage.

6.2.19 Phase 10 demolition / decommission

Figure 6.18 shows the issues for the cladding process and interface management for phase ten.

Main Project Process Protocol Actions & Decisions	PHASE 10 Demolition Decommission Manage user decant Decommission and demolition Redevelop site
Cladding Process CP Actions & Decisions	Co-ordinate cladding demolition (in accordance with CDM) Provide specific information in the contract on requirements (if any) for demolition of the cladding Co-ordinate contract with demolition company and cladding contractor wherever applicable
Interface Management IM Actions & Decisions	Consider reusing or recycling cladding materials when demolished Consider all adjacent works prior to demolition, may need meetings and surveys on adjoining buildings

Figure 6.18: CP and IM issues for phase 10 (taken from CladdISS)

At this phase there are three interface actions and decisions.

- Consider reusing or recycling cladding materials when demolished
- Consider all adjacent works prior to demolition, may need meetings and surveys on adjoining buildings

1. Consider reusing or recycling cladding materials when demolished.

With the introduction of the CDM regulations there is a need to consider demolition. Cladding is an element that consists of numerous parts, in which the materials, such as aluminium and glass could be recycled. Therefore a consideration should be given to these materials for reuse, if and when the product is dismantled. Therefore interfacing contractors need to establish procedures for dismantling their systems.

In the cladding design, awareness should be included for dismantling and reusing the materials after demolition. Obviously for this to come into fruition the cladding contractor has to have a major design input.

2 Consider all adjacent works prior to demolition- may need meetings and surveys on adjoining buildings.

Section 5.3.7 identified this interface as a problem and it is sometimes not considered enough. To avoid legal repercussions when adjoining to an existing building, a strategic method should be considered in the initial design.

6.3 Validation of the results

6.3.1 Introduction

It is important to be sure of the validity of the research and the framework. This was achieved by a questionnaire. The validation questionnaire had two parts;

- General impact of the framework
- Specific impact of the review points

The framework was shown to 32 construction industry experts. The general impact section had eight questions; the results of these are covered here.

6.3.2 How easy is CladdISS to use and navigate?

Table 6.8 shows the results for ease of use, (throughout, all the results are shown as percentages).

very easy	easy	moderate	difficult	V difficult
13	38	44	6	

Table 6.8: CladdISS ease of use results

The results show that the majority found CladdISS “very easy/ easy” to navigate (51%), followed by “moderate” (44%). Only six percent found it difficult.

6.3.3 How useful is the information in the upper tier (chapter 4.5.2) of the matrix at the following phases?

Table 6.9 shows the results for usefulness of the upper tier and table 6.10 displays it graphically.

Phase no	very useful	useful	moderate	poor	no use
0-3	31	59	6		
4-6	50	47	3		
7-8	38	50	9	3	
9-10	19	44	31	6	

Table 6.9: Usefulness of the matrix upper tier

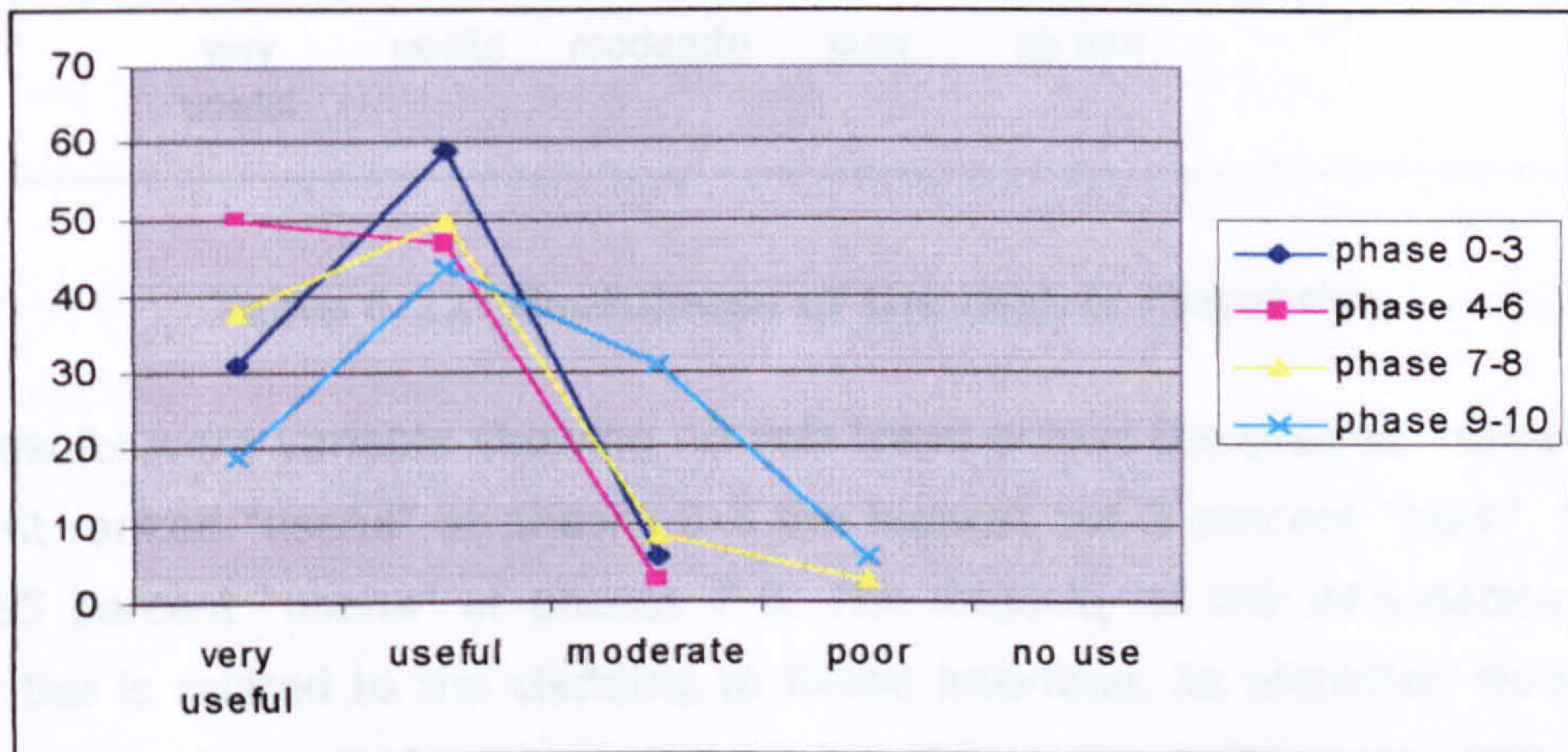


Table 6.10: Usefulness of the matrix upper tier

The results show that the information is most beneficial in phases 4-6 with 50 percent of the respondents indicating 'very useful'. However it appears to lose its importance at phases 9-10. As the upper tier is predominantly technical design information this is not unexpected.

6.3.4 How useful is the information in the lower tier (chapter 4.5.2) of the matrix at the following phases?

Table 6.11 shows the results for usefulness of the lower tier table 6.12 shows it graphically.

Phase no	very useful	useful	moderate	poor	no use
0-3	19	65	13	3	
4-6	45	48	6		
7-8	29	55	16		
9-10	13	48	32	6	

Table 6.11: Usefulness of the matrix lower tier

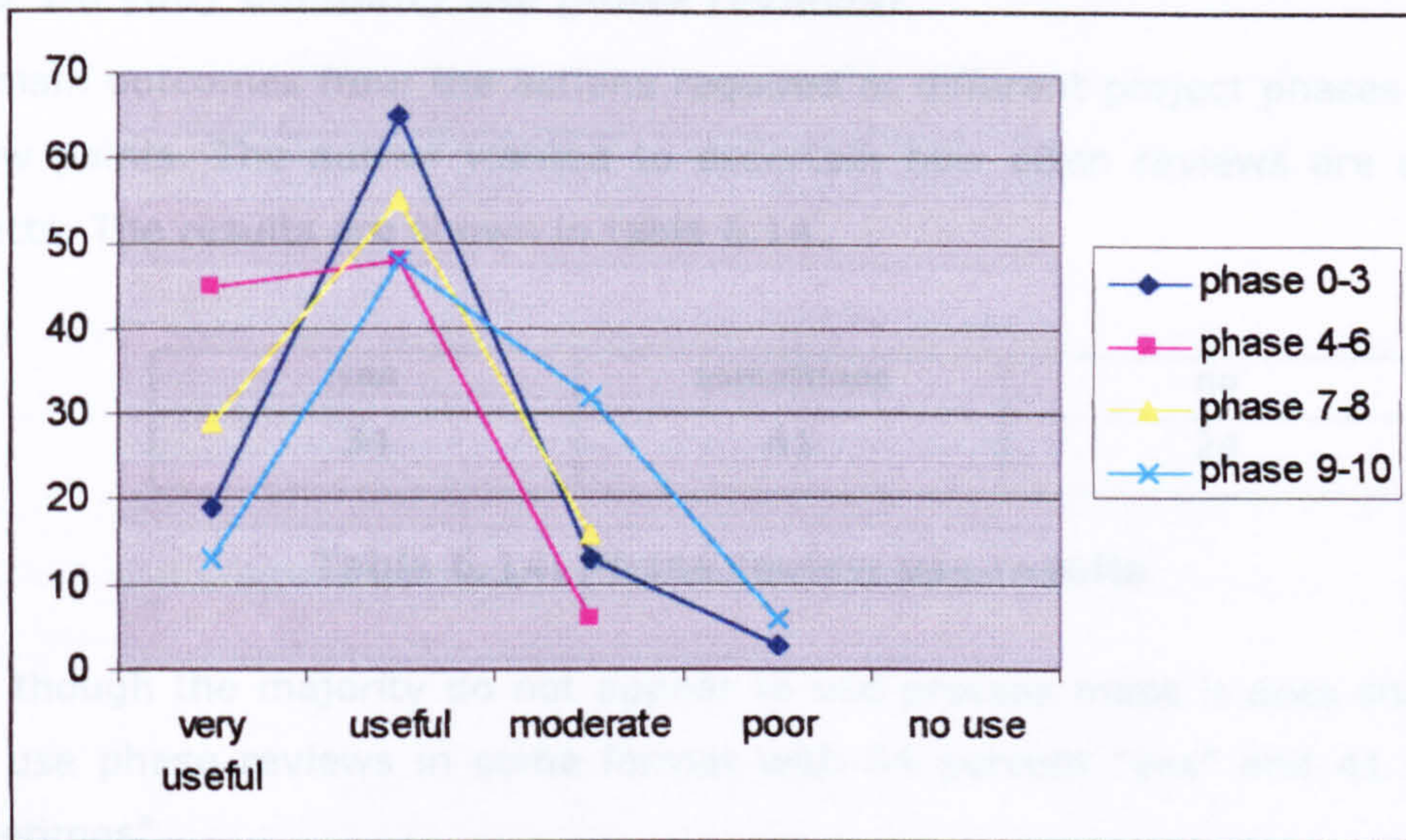


Table 6.12: Usefulness of the matrix lower tier

The results were variable showing no real trend across the phases. However, 65 percent ranked “useful” at phases 0-3 the highest but 3 percent “poor”. Second was 55 percent “useful” at phases 7-8. The majority of the information in the lower tier is related to the cladding to frame interface. As identified throughout this thesis, this interface appears to be the most problematic generically. Therefore it is not surprising that the information is considered useful throughout the whole project.

6.3.5 Do you recognise the project phases shown in CladdISS?

The framework was based on the process protocol, a process mapping method. For future work it was decided to investigate what knowledge, if any, the construction industry has of the process and to see what extent it is being used. Table 6.13 shows the results.

Used on projects	considering implementing	recognise	aware but never seen	no knowledge
11	4	46	18	21

Table 6.13: Project phase recognition results

The results show that only 11 percent are using this or a similar method of process mapping on their projects, with 4 percent considering implementing which appears to be quite low especially as 46 percent recognise it. 21 percent had no knowledge, which implies that an improved method of promoting process mapping in the industry has to be implemented for it to have any real impact.

6.3.6 Do you/ company use phase reviews?

The main outcomes from the actions required at different project phases are the review points. The author wanted to ascertain how often reviews are used on projects. The results are shown in table 6.14.

yes	sometimes	no
34	41	24

Table 6.14: Phase review use results

Even though the majority do not appear to use process maps it does show that they use phase reviews in some format with 34 percent “yes” and 41 percent “sometimes”.

6.3.7 How useful did you find the information in the management section of CladdISS?

The management section of CladdISS is the basis of this thesis therefore the result for this question could be considered the most significant. The results are shown in table 6.15.

very useful	useful	moderate	poor	no use
16	66	18		

Table 6.15: Usefulness of the management section results

The results are very encouraging with 81 percent “useful” or “very useful”.

6.3.8 Is CladdISS a useful tool for the production of cladding on a project?

Table 6.16 shows the results for the usefulness of CladdISS for the production of cladding on a project.

very useful	useful	moderate	poor	no use
34	53	13		

Table 6.16: Usefulness of CladdISS as a cladding tool results

This question is related to question 6 in the respect that the research aim was to produce information for improved management of cladding interfaces. With 53 “useful” and 34 “very useful”. This further validates the impact of the research findings.

6.3.9 Will you or your company use CladdISS after seeing this demonstration?

Table 6.17 shows the results for the respondents using CladdISS after seeing the demonstration, again suggesting a good potential future implementation of CladdISS.

yes	unsure	no
63	28	9

Table 6.17: Will CladdISS be used by you/company results

6.3.10 Summary of validation survey

The validation of any research is important. It makes sure that there is confidence in the research findings. The validation survey has shown that:-

- CladdISS is easy to use and navigate.
- The upper tier of the matrix is useful across all the project phases.
- The lower tier of the matrix is useful across all the project phases.
- A high proportion (46%) recognises the process protocol project phases.
- The majority (75%) either regularly or sometimes use phase reviews.
- The majority (82%) thought the management information was useful.
- The majority (87%) thought CladdISS was a useful tool for the production of cladding on a project.
- 63 percent of the people surveyed would use CladdISS after seeing the presentation.

6.4 Summary

Utilising the information identified in the previous five chapters, this chapter produced a framework which provides assistance for improved interface management for cladding and critical building elements.

To achieve successful interface management there must be an understanding of the project structure and procurement plan. For instance management forms of contracting and the resulting workpackaging can cause complex interface management issues. Also the added involvement of the specialist contractors can potentially produce greater management problems concerning the interfaces.

With these issues in mind there is a need for improved management and guidance. The framework is a tool that addresses these problems. It is applicable to the whole construction process so that the issue of interface management becomes part of the construction process from inception through to handover (Pavitt and Gibb, 2002).

Chapter 7 Conclusions and Recommendations

7.1 Introduction

The first four chapters of the thesis presented the theoretical and methodological framework for the research with chapter four providing a generic overview of the results. This enabled qualitative and quantitative data analysis in Chapter five. Chapter 6 presented the research results by producing a framework for improved management of cladding interfaces. Finally validation results were shown and discussed. This chapter concludes the thesis, summarising the findings and the main conclusions from the research. Further discussion is made of the implications the framework has on the construction industry. Finally recommendations for continued research in interface management are reflected upon.

7.2 Achievements of the objectives

The objectives of the research, developed in chapter one of the thesis are re-stated in table 7.1. Each objective is individually discussed in the following subsections.

Research objectives	
O1	Review and establish present interface management within the construction industry via current literature
O2	Review and establish interface problems that occur in the construction industry, in particular the cladding sector
O3	Establish the most problematic interfaces within the cladding sector
O4	Produce a standardised strategy for managing cladding interfaces
O5	Establish specific areas for improved interface management
O6	Validate and disseminate the research findings

Table 7.1: Research objectives re-stated from chapter one

7.2.1 Interface management within the construction industry (O1)

This objective is satisfied in the literature review of chapter three. The literature search identified that there was very little published literature on interface management within the construction industry. Relating to the research topic

there only appears to be one major author Gibb. Gibb (1994) states that there are three ways of classifying interfaces, as follows:

Physical interfaces, which are physical joints and connections between elements or components. These may be unavoidable or may be brought about by the intricacies of the detailed design.

Management or contractual interfaces, where the parcelling of work into discrete packages to suit logistics or design information availability creates interfaces between works by several specialist contractors.

Organisational interfaces, which are the interactions between the various parties involved in a construction project.

7.2.2 Interface problems within the cladding sector (O2)

The factors identified in achieving objective 1 were also used to attain objective 2 and during the data collection. These have been separated into the three subdivisions; design, manufacture and installation.

Design

- Interface responsibility should be determined early enough in the design phase. However it is not determined early enough, sometimes not until site installation.
- Contactors are not appointed early enough to aid the design.
- There can be too much "over specification" of the cladding, causing complicated and sometimes impossible designs.
- There is a lack of understanding of the different materials.
- There is a lack of communication throughout the design stage.
- There is a lack of importance given to the interfaces.
- There is incomplete design, especially of the interface.
- There is insufficient design expertise from the specialist contractors.
- With standard systems you can never speak with the actual designer- this system was probably designed five years ago.
- There is a lack of design coordination.
- Often there is insufficient money allowed for the design of the interface because of this complexity.

Manufacture

- There is a lack of understanding of tolerances in manufacture and design. However, "the tolerance issue is not really a problem; it only

becomes a problem when the interfacing specialists do not know the tolerances of the other products”.

- Managing the lead times for materials. “Glass invariably will be on the critical path, as it can take up to 14 weeks for delivery.
- A cladding system will be complete in manufacture but has to be altered due to insufficient design of the interface.

Installation

- There is a lack of training for site installation staff.
- There is a Problem in getting the interfacing workpackages to talk to each other.
- Often contactors are not there when they should be- invariably this is due to the procurement route chosen by the client.
- Sequence in which the trades are programmed causes problems.
- The term *by others*. “Most contractors, to win work, especially with traditional procurement detail their own standard work and ignore anything over and above quoting by others”.
- Frame to cladding interface. Invariably the two contractors are not formally contracted at the same time so assumptions have to be made. Exact fixing zones on the frame cannot be identified. So, often, revisits or reworks are required.
- Sealants at the interface tend to be overlooked because there is no clear identification as to whose package they are in.

7.2.3 Most problematic cladding interfaces (O3)

This objective was achieved in the data collection. The factors were initially identified in the interviews and focus groups and finally validated in the questionnaire. There are numerous construction interfaces but in the cladding sector there appears to be six main interfaces, defined as;

- Frame/cladding interface
- Cladding/cladding interface
- M&E services/cladding interface
- Internals/cladding interface
- Roof/cladding interface
- Secondary components/cladding interface

- **Frame/cladding interface**

This is possibly the most complex interface. The cladding must be designed so that the frame can accommodate the cladding weight and differing panel sizes. This will vary significantly between cladding types.

- **Cladding/cladding interface**

This is an interface that brings together two dissimilar cladding types, whereupon the junction must be designed so the cladding types can accommodate movement and tolerance of each other and still maintain the integrity of the building envelope.

- **M&E Services/cladding interface**

This is an interface that details M&E works such as flues and louvres that may pass through or be connected to the cladding panels.

- **Internals/ cladding interface**

This is an important interface, which concerns the internal design layout, especially the positioning of internal walls. It is possible that the cladding brackets will protrude into the building thus imposing a design restriction on the internal walls, floors or ceilings. Furthermore, the level of raised floors and suspended ceilings will impact on the cladding layout.

- **Roof/cladding interface**

This is one of the hardest interfaces to design and manage. This is because the interface involves more than two elements; frame, cladding and roof. Site management and programming for this is crucial as the building is often required to be made water-tight as soon as possible. Thus three or four different trades have to work in an organized sequence.

- **Secondary components/cladding interface**

This is an interface that is sometimes considered late in the process. It deals with the various features that are secured to the cladding such as sun-shades, cleaning cradles, handrails, signs and flagpoles.

The most problematic interface out of the six was shown to be the cladding to frame interface. Table 7.2 shows how the different disciplines ranked the interface in the validation questionnaire.

subject types	consultants	designer	system designer	principal contractor	cladding contractor	Total
easiest	2		1	2	3	8
2	2		2	1	1	6
3		1	1	1	1	4
4	5	2		2	1	10
5		4		3	3	10
most difficult	5	7	1	6	3	22
Total	14	14	5	15	12	60

Table 7.2: Results – cladding to frame interface

7.2.4 A standardised strategy for managing cladding interfaces (O4)

This objective was satisfied using the literature, data collection and the resources from the CladdISS project. It is presented as a process map that identifies significant cladding interface management actions and decisions in a project, from its inception through to facilities management.

The process map was adapted from the Process Protocol (Sheath et al 1996). In total there are twelve phases, from phase 0 "demonstrating the need" to phase 10 "demolition/decommission". The information has been divided into 3 sections for each phase;

- **Cladding Interface Management (IM).** Advises on crucial cladding interface management issues at particular stages within the project.
- **Cladding Process (CP).** The cladding process has been included to show how the interface management issues relate to stages in the cladding process. (The cladding process shown is generic and would need to be developed to represent the particular project circumstances).
- **CladdISS Review Points.** These are situated at the end of crucial project phases. They advise that, before progression to the next stage, the review point outcomes must have been established. Figure 7.1 shows the project phases and the location of the six review points

Phase 0: Demonstrating the need	
Phase 1: Conception of need	Cladd:/SS Review 1
Phase 2: Outline feasibility	
Phase 3: Substantive feasibility study and outline financial authority	Cladd:/SS review 2
Phase 4: Outline conceptual design	
Phase 5: Full conceptual design	Cladd:/SS review 3
Phase 6: Co-ordinated design, procurement & full financial authority	Cladd:/SS review 4
Phase 7: Production information	
Phase 7a: Manufacture	
Phase 8: Construction/ Assembly	Cladd:/SS review 5
Phase 9: Maintenance/ facilities management	
Phase 10: Demolition decommission	Cladd:/SS review 6

Figure 7.1: The twelve phases of the process map

7.2.5 Specific areas for improved interface management (O5)

This objective was achieved principally through the CladdISS research and the validation questionnaire. From the problems uncovered during the research investigation the following conclusions have been realised that enable improved interface management (ranked in order of importance);

1. Identify the interface responsibility as early as possible
2. Appoint the specialist contractor earlier
3. Ensure there is a greater understanding of all tolerances
4. Ensure there is a greater understanding of buildability
5. Develop tools that identify and aid interface management
6. Appoint cladding and frame contractors at the same time
7. Standardise interface designs
8. Reduce adversarial effects within the process
9. Risk assess designers knowledge of cladding from past projects
10. Improve programming and sequencing at site level
11. Eliminate the term 'by others'
12. Ensure all installers have attended approved training courses

7.3 Addressing the research question

The research set out to concentrate on the following research question, stated in section 1.2.1.

How can interface management in the building façade be better understood and managed to improve construction projects?

The major problem with the literature search, emphasised in section 1.5.2, was the lack of published literature or research into interface management. Furthermore, a thorough understanding of interface management was scarce in construction, let alone in the cladding sector of the industry. Therefore the need for the research was obvious from the outset. The research addresses this need by firstly finding out the most problematic interfaces associated with the building façade.

Secondly, the research provides more specific details of when the interfaces are actually considered in a project. Also it shows which if any of the interfaces appear to be prioritised over others.

Thirdly, the research defined the specific problems and solutions occurring at the interfaces. The author identified that the cladding process is divided into three main sections, design, manufacture and installation. Therefore, wherever possible the problems and solutions are shown within the three groups.

Finally the research has significantly contributed to the understanding of interface management for construction of façades, culminating in a strategy for managing the interfaces. Furthermore it has provided a basis for further research into the broader subject area.

7.4 Implications for theory

The research confirms that interfaces will always continue to cause problems within the construction process, particularly interfaces with the complex façades of a building. Therefore there is a need to acknowledge and understand the problems as early as possible. Furthermore, it has identified that if a building is going to leak, invariably it will be at an interface. Therefore a significant change is required so that the interfaces are addressed properly.

Throughout recent years there has been a need for change in construction not just in ways of building projects but the methods by which the projects have

been developed. This is due in part to the fragmentation in the industry, which perpetually provokes serious problems. Therefore there is a need to consider the concepts and methods used in other industries, particularly the ones with manufacturing processes. Both Latham (1994) and Egan (1998) have emphasised the need for change in construction and recommended that existing work on supply chains and partnered arrangements is continued.

This thesis has also contributed to the methodological body of knowledge within construction management research. It has shown that qualitative and quantitative methods can be employed together producing successful results. Furthermore it has shown the benefits of using case studies in construction management. However they were used merely as verification instruments for the main data collection.

In addition it has shown that industry funded research projects in association with universities can be successful in producing valuable research (CladdISS). All EPSRC funded research projects have to be critically reviewed on completion. The CladdISS project attained a very high assessment rating; Appendix C shows the full judgement from the assessment panel. This further emphasises the importance and success of the research.

Finally it has shown that the research design and methodological approach undertaken were both strong and appropriate to the subject under examination. Providing a positive contribution of knowledge to construction management research.

7.5 Implications for practice and industry

Although the research has produced findings with theoretical propositions, it has also shown it has an industrial function. Objective six stated, "Validate and disseminate the research findings". It is important to be sure of the validity of the research and the framework. This was achieved by the author trialling the CladdISS CD to a cross section of professionals from the construction industry including cladding contractors, architects and construction managers. During this time they completed a questionnaire. The validation survey showed that:-

- CladdISS is easy to use and navigate.
- The upper tier of the matrix is useful across all the project phases.
- The lower tier of the matrix is useful across all the project phases.

- A high proportion (46%) recognises the process protocol project phases.
- The majority (75%) either regularly or sometimes use phase reviews.
- The majority (82%) thought the management information was useful.
- The majority (87%) thought CladdISS was a useful tool for the production of cladding on a project.
- 63 percent of the people surveyed would use CladdISS after seeing the presentation.

CladdISS is a tool that addresses the interface problems. It is intended to be useful to the whole construction process so that the issue of interface management becomes part of the construction process, from inception through to handover (Pavitt and Gibb, 2000). The validation results clearly show that it has achieved its objective and its application will help industry with the interface problems.

7.6 Limitations

As with all research, the findings have limitations. Two main limitations are apparent and produce areas for further research (see section 7.7).

The first limitation was the lack of specific guidance for the interfaces across the different procurement options. From the outset of the research the issue of procurement route and its implications became apparent. It was the intention of the author to map the framework generically across the different procurement routes. Following advice given by members of the project steering group this was omitted due to its complexities and time constraints. Furthermore it was clear that non-specific procurement information could be detrimental rather than informative. However, this issue was addressed using the Process Protocol, as this process map is intended to be procurement neutral.

The second limitation is the investigation of programming the interfaces. Similar to limitation one, programming has manifested itself as a separate research topic. The research identifies in depth the problems occurred when traditional programming issues are employed, however not enough specific programming was produced; this should encompass best practice and Latham and Egan principles.

7.7 Reflections

Generally the research has been a fulfilling and interesting time for the author, it has allowed him to gain further, broad knowledge of the construction industry and its processes. Furthermore it has allowed him the opportunity to understand and gain research skills and techniques, such as qualitative and quantitative data collection methods and analytical skills. However, specifically, the research has surprised the author in terms of how the industry works and its apparent reluctance to change.

It was interesting to discover that the interfaces are very rarely addressed or managed effectively on a project. This is further endorsed by the scarcity of literature published on the subject. Furthermore the companies that claim to have an interface strategy really do this in an ad hoc way, which is really not planned. The author observed that the industry's attitude to interfaces is almost blasé due, in part, to the interface responsibility never being assigned.

Therefore it is often considered as the responsibility of others, culminating in its importance being overlooked, which realistically is 'passing the buck'. In addition the industry appears to follow a 'head in the sand' approach hoping the interface problem will resolve itself or go away at best. However CladdISS does appear to have provoked interest and hopefully will produce a positive attitude within the industry.

7.8 Recommendations for further research

The following recommendations are made for future research into interface management within construction.

- Extend the research to identify all the major interfaces within construction not just cladding interfaces.
- Extend the CladdISS process map and review points into all building interfaces.
- Investigate further what effect the different procurement options have on cladding and building interfaces.
- Investigate more specifically the six major cladding interfaces providing greater solutions to the generic issues identified, such as tolerances and movement.
- Implement CladdISS into new projects from inception through to completion and produce evidence of its success and benefit, making comparisons with projects working without it.
- Investigate further methods for improving the programming for cladding interfaces.
- Investigate how the different procurement options have an effect on the appointment of specialist cladding contractors and their role within projects.

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APPENDIX A

The Questionnaire used for the research validation

Questionnaire (Loughborough University) "An experts view of managing cladding and window interfaces"

A Which of the following best describes your organisation's function in the construction industry (Please tick where applicable)

- A Overall Project Design
- B Cladding Systems Design
- C Management of construction
- D Fabrication
- E Installation
- F Other (Please state)

B What is your position in the company (e.g. Contracts Manager, Designer)

(1- Easiest, 6- most difficult)

1 Rank the 6 interfaces regarding difficulty to manage

- Clad/Frame (steel, concrete, precast)
- Clad/ Roof
- Clad/Internals (walls, floors, ceilings)
- Clad/Building services
- Clad/Secondary components (signs, flag poles)
- Clad/Cladding

2 If the 6 interfaces are managed *incorrectly* what significance does this have on the project

No sig'cance	Little s'cance	significant	very s'cant	no comment

3 Who should be involved in the design of the interfaces between two different cladding systems. Please score as follows;

- 1 No design involvement
- 2 Some deign input
- 3 Shared design responsibility
- 4 Main design responsibility
- 5 Complete responsibility

- Architect/designer
- Cladding Consultant
- System designer
- Fabricator
- Cladding contractor
- Other (please state)

4 Who should be involved in the design of the interfaces between the cladding system and other building elements (e.g. frame, roof) Please score as follows;

- 1 No design involvement
- 2 Some design input
- 3 Shared design responsibility
- 4 Main design responsibility
- 5 Complete responsibility

- Architect/designer
- Cladding Consultant
- System designer
- Fabricator
- Cladding contractor
- Building element contractor
- Other (please state)

5 The lack of buildability understanding by project designers/ architects causes more than 10% extra cost to the project

Strongly Disagree	Disagree	Uncertain	Agree	Strongly Disagree

6 If the specialist cladding contractor had design input at concept design phase the interfaces would be easier to manage and co-ordinate

Strongly Disagree	Disagree	Uncertain	Agree	Strongly Disagree

Added comments

	Strongly Disagree	Disagree	Uncertain	Agree	Strongly Agree
7 The responsibility for completing the interface on site should be agreed by the project team at scheme design stage					
8 Cladding contractors <i>often</i> overestimate resources and underestimate programming time during tender negotiation					
9 Clients or their advisers should risk assess the design team's knowledge of proposed cladding systems prior to appointment					
10 At detailed design stage there should be a "buffer" zone between the cladding and the interfacing elements to allow for manufacturing and construction tolerances (see page 3 for details)					
11 The "as built" position of the frame should be surveyed concurrently by the frame installer, cladding contractor and principle contractor					
12 The "as built" drawings of the frame should be used to adjust the cladding installation (see page 3 for details)					
13 The drainage design of the cladding system is always poorly detailed at the interfaces					
14 There should be greater design input to the drainage detail by the systems designers					
15 There is insufficient allowance made in the project costs for protecting the cladding during and after installation					
16 Changing the sequence of erection to suit the programme causes repercussions to the design concept of the cladding					
17 There should be a strategy developed to standardise interface design details					
18 The "closing" or end panel for each elevation should be manufactured based on the "as built" drawings of the frame					
19 The cladding fixings should be designed to accommodate the worst possible combination of tolerances					
20 The lack of buildability understanding in design causes more than 10% extra time to be added to the construction programme					
21 Principle contractors <i>often</i> make ambitious claims for the progress of preceding workpackages during and after negotiating the tender with the cladding contractor					
22 If a strategy was developed between the principle contractor and the cladding contractor to agree a realistic programme for installation with agreed resources the project would have less delays					
23 The cladding design, from concept to detail, should be carried out by one design team.					
24 The lack of supply chain management in the cladding industry prevents effective interface management					

25 Rank the 4 different project procurement options on their effective influence on management of construction interfaces (1 Best, 4 Worst)

- A Design and build type
- B Traditional/lump sum type
- C Management type
- D Partnering type
- E Procurement route has no effect

26 Please rank the following 12 statements in order in which you think would improve interface management (1 Best - 12 Worst)

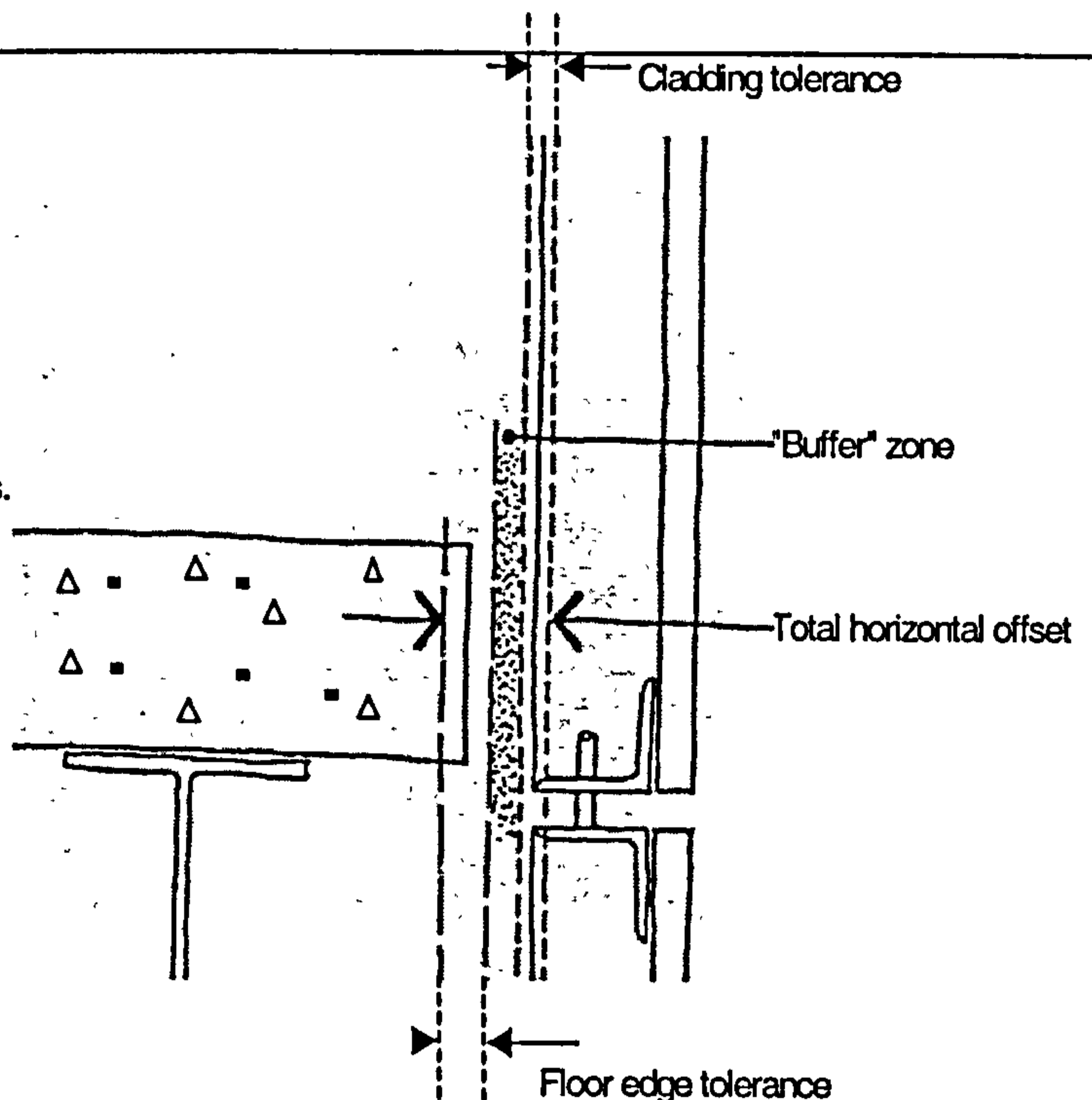
- A Eliminate the term "by others"
- B Identify the interface responsibility as early as possible
- C Ensure there is a greater understanding of buildability
- D Improve programming and sequencing at site level
- E Ensure there is a greater understanding of all tolerances
- F Ensure all installers have attended approved training courses
- G Appoint cladding and frame contractors at the same time
- H Appoint the specialist contractor earlier
- I Develop tools that identify and aid interface management
- J Standardise interface designs
- K Reduce adversarial effects within the process
- L Risk assess designers knowledge of cladding systems from previous projects

Question 10: Tolerance "buffer zone"

Shown is a cross section view of a cladding interface with a structural frame and the floor slab. This shows a horizontal "buffer" zone.

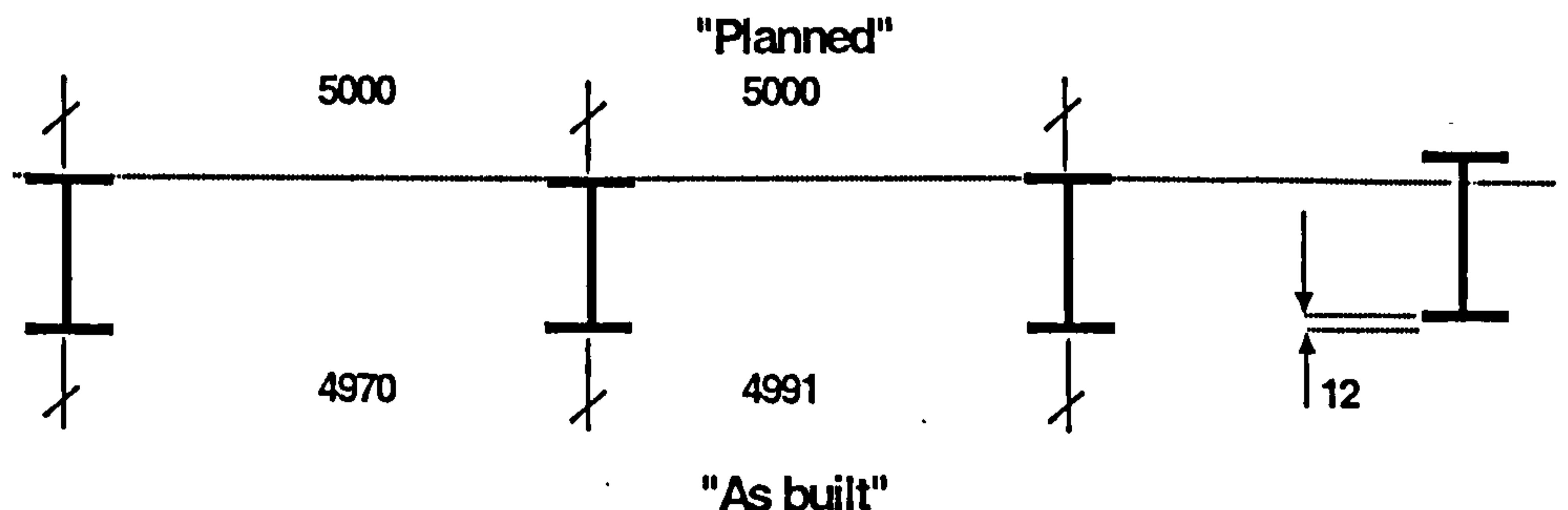
In practice, frames sometimes exceed specified tolerances and buffer zones are an effective means of absorbing variations. They are an addition to other tolerances but are not intended to relax the specifications.

This detail and information has been extracted from "Curtain wall connections to steel frames" By the steel construction institute, (1992.)



Question 12: "As built" setting out

This shows how the "as built" frame could differ from the planned setting out drawings. This question advises that the cladding setting out should be carried out from the "as built" not the "planned" information.



"Thank you for your time in filling out this questionnaire"

Shown are the full results from the questionnaire. The answers are shown in percentages.

1 Score the 6 interfaces regarding difficulty to manage (1-Easiest, 6- most difficult)

Cladding to	Cladding Consultant	Cladding Contractor	Designer	Principal Contractor	Systems Designer	Overall
Frame	3.64	3.64	5.00	4.50	2.80	4.111
B/services	3.36	3.91	2.85	3.93	4.60	3.611
Cladding	3.91	3.45	3.62	3.29	3.80	3.574
Roof	3.36	3.27	4.15	3.00	4.80	3.574
Internals	3.91	3.27	3.62	2.79	2.80	3.315
S/components	2.82	3.64	2.08	3.43	3.20	3.000

2 If the 6 interfaces (question 1) are managed incorrectly what significance does this have on the project?

	Cladding Consultant	Cladding Contractors	Designer	Principal Contractor	Systems Designer	Overall
No Sig'cance						
Little Sig'cance						
Sig'cance	27	15	31	14	33	23
Very Sig'cant	73	85	69	86	67	77
No Comment						

3 The lack of buildability understanding by project designers/architects causes more than 10% extra cost to the project.

	Cladding Consultant	Cladding Contractors	Designer	Principal Contractor	Systems Designer	Overall
Strongly Disagree	9			8		4
Disagree	9			38	14	14
Uncertain	9			8	17	5
Agree	36	58		38	57	50
Strongly Agree	36	42		8	29	27

4 If the specialist cladding contractor had design input at concept design phase the interfaces would be easier to manage and co-ordinate

	Cladding Consultant	Cladding Contractors	Designer	Principal Contractor	Systems Designer	Overall
Strongly Disagree	9					2
Disagree	9					2
Uncertain				7		2
Agree	36	38	92	64	50	58
Strongly Agree	45	62	8	29	50	37

5 The responsibility for completing the interface on site should be agreed by the project team at scheme design stage

	Cladding Consultant	Cladding Contractors	Designer	Principal Contractor	Systems Designer	Overall
Strongly Disagree						
Disagree		8				2
Uncertain						
Agree	36	38	46	43	50	42
Strongly Agree	64	54	54	57	50	56

6 Cladding contractors often underestimate programming time during tender negotiation

	Cladding Consultant	Cladding Contractors	Designer	Principal Contractor	Systems Designer	Overall
Strongly Disagree	9					2
Disagree	9	46	23	29	17	26
Uncertain		8	15		17	7
Agree	55	38	54	43	67	49
Strongly Agree	27	8	8	29		16

7 Clients or their advisers should risk assess the design team's knowledge of proposed cladding systems prior to appointment

	Cladding Consultant	Cladding Contractor	Designer	Principal Contractor	Systems Designer	Overall
Strongly Disagree	9					2
Disagree			8	7		4
Uncertain		8	17	7	33	11
Agree	18	85	75	50	67	59
Strongly Agree	73	8		36		25

8 At detailed design stage there should be a "buffer" zone between the cladding and the interfacing elements to allow for manufacturing and construction tolerances

	Cladding Consultant	Cladding Contractor	Designer	Principal Contractor	Systems Designer	Overall
Strongly Disagree	9				17	4
Disagree				14		4
Uncertain						
Agree	64	77	77	43	33	61
Strongly Agree	27	23	23	43	50	32

9 The benefits of the "buffer" zone outweigh the advantages of the cost savings if it is not used.

	Cladding Consultant	Cladding Contractors	Designer	Principal Contractor	Systems Designer	Overall
Strongly Disagree	9					2
Disagree				7		2
Uncertain	9	15	15	21		14
Agree	64	69	85	36	60	63
Strongly Agree	18	15		36	40	20

10 The "as built" position of the frame should be surveyed concurrently by the frame installer, cladding contractor and principle contractor

	Cladding Consultant	Cladding Contractor	Designer	Principal Contractor	Systems Designer	Overall
Strongly Disagree						
Disagree	9	31		14		12
Uncertain		8	15	7		7
Agree	45	46	23	29	50	37
Strongly Agree	45	15	62	50	50	44

11 The "as built" drawings of the frame should be used to adjust the cladding installation

	Cladding Consultant	Cladding Contractor	Designer	Principal Contractor	Systems Designer	Overall
Strongly Disagree		8	8			4
Disagree	9	15	23	21	17	18
Uncertain	18		15	29		14
Agree	45	77	54	36	83	56
Strongly Agree	27			14		9

12 The drainage design of the cladding system is always poorly detailed at the interfaces (as defined in question 1)

	Cladding Consultant	Cladding Contractor	Designer	Principal Contractor	Systems Designer	Overall
Strongly Disagree		8				2
Disagree	18	31	15	29	50	26
Uncertain	18	15	23	21	17	19
Agree	45	31	54	43	33	42
Strongly Agree	18	15	8	7		11

13 At detailed design all the Interfacing parties should have a meeting to agree manufacturing and construction tolerances

	Cladding Consultant	Cladding Contractor	Designer	Principal Contractor	Systems Designer	Overall
Strongly Disagree						
Disagree	9	8	8	7		7
Uncertain				7		2
Agree	55	46	62	21	50	46
Strongly Agree	36	46	31	64	50	46

14 There is insufficient allowance made in the project costs for protecting the cladding during and after installation

	Cladding Consultant	Cladding Contractor	Designer	Principal Contractor	Systems Designer	Overall
Strongly Disagree				8		2
Disagree	18	8		31		13
Uncertain	36	8		23	17	16
Agree	18	62	77	15	67	46
Strongly Agree	27	23	23	23	17	23

15 Changing the sequence of erection to suit the programme causes repercussions to the design concept of the cladding

	Cladding Consultant	Cladding Contractor	Designer	Principal Contractor	Systems Designer	Overall
Strongly Disagree						
Disagree		23	15	21		14
Uncertain	45	15	19	21	17	24
Agree	55	31	58	36	50	45
Strongly Agree		31	8	21	33	18

16 There should be a strategy to standardise interface design details

	Cladding Consultant	Cladding Contractors	Designer	Principal Contractor	Systems Designer	Overall
Strongly Disagree						
Disagree	9	8	15		33	11
Uncertain	9	15	23		33	14
Agree	73	69	62	57	17	60
Strongly Agree	9	8		43	17	16

17 The "closing" or end panel for each elevation should be manufactured based on the "as built" drawings of the frame

	Cladding Consultant	Cladding Contractors	Designer	Principal Contractor	Systems Designer	Overall
Strongly Disagree		15				4
Disagree	20	23	23	57	33	32
Uncertain	10		8	7	17	7
Agree	70	62	46	29	50	50
Strongly Agree			23	7		7

18 Cladding contractors often overestimate resources during tender negotiation

	Cladding Consultant	Cladding Contractors	Designer	Principal Contractor	Systems Designer	Overall
Strongly Disagree		8		7		4
Disagree	36	77	31	21	17	39
Uncertain	27	8	46		67	25
Agree	18	8	23	50	17	25
Strongly Agree	18			21		9

19 The cladding fixings should be designed to accommodate the worst possible combination of tolerances

	Cladding Consultant	Cladding Contractors	Designer	Principal Contractor	Systems Designer	Overall
Strongly Disagree		8		7		4
Disagree	18	15		21	17	14
Uncertain	9		8		17	5
Agree	45	62	62	50	50	54
Strongly Agree	27	15	31	21	17	23

20 The lack of buildability understanding in design causes more than 10% extra time to be added to the construction programme

	Cladding Consultant	Cladding Contractors	Designer	Principal Contractor	Systems Designer	Overall
Strongly Disagree			8			2
Disagree	18	8	38	7	17	18
Uncertain		8	15	7	33	11
Agree	73	54	31	50	50	51
Strongly Agree	9	31	8	36		19

21 Principal contractors *Often* make ambitious claims for the progress of preceding workpackages during and after negotiating the tender with the cladding contractor

	Cladding Consultant	Cladding Contractors	Designer	Principal Contractor	Systems Designer	Overall
Strongly Disagree						
Disagree	27			29		12
Uncertain	9	8	31	29	33	21
Agree	55	46	62	36	50	49
Strongly Agree	9	46	8	7	17	18

22 If a strategy was developed between the principle contractor and the cladding contractor to agree a realistic programme for installation with agreed resources the project would have less delays

	Cladding Consultant	Cladding Contractors	Designer	Principal Contractor	Systems Designer	Overall
Strongly Disagree						
Disagree				14		4
Uncertain	9	8	23	7		11
Agree	73	38	46	64	67	56
Strongly Agree	18	54	31	14	33	30

23 The cladding design, from concept to detail, should be carried out by one design team.

	Cladding Consultant	Cladding Contractors	Designer	Principal Contractor	Systems Designer	Overall
Strongly Disagree		8		21		7
Disagree	9	23	23	14		16
Uncertain	9	8		7	17	7
Agree	55	31	54	21	50	40
Strongly Agree	27	31	23	36	33	30

24 The lack of co-ordinated supply chain management in the cladding industry prevents effective interface management

	Cladding Consultant	Cladding Contractors	Designer	Principal Contractor	Systems Designer	Overall
Strongly Disagree		8				2
Disagree	9	15	15		17	11
Uncertain	27	8	23	21	50	23
Agree	55	46	54	50	17	47
Strongly Agree	9	23	8	29	17	18

25 Rank the 4 different project procurement options on their effective influence on management of construction interfaces

		Cladding Consultant	Cladding Contractor	Designer	Principal Contractor	Systems Designer	Overall
A	Partnering type	1.333	1.62	1.33	1.33	1.2	1.12
B	Management type	2.222	2.46	2.42	2.25	2.2	2.333
C	Design and build type	3	2.46	2.42	2.00	3.4	2.54
D	Traditional/lump sum type	3.44	3.23	3.67	3.82	3.2	3.5
E	Procurement route has no effect	2		1	1	1	8%

26 Rank the twelve statements in order to improve interface management

	Cladding Consultant	Cladding Contractor	Designer	Principal Contractor	Systems Designer	Overall
B Identify the interface responsibility as early as possible	2.80	3.69	3.91	2.75	3.33	3.30
H Appoint the specialist contractor earlier	5.10	4.15	5.36	5.55	2.83	4.60
E Ensure there is a greater understanding of all tolerances	6.90	4.69	5.73	4.00	3.67	5.00
C Ensure there is a greater understanding of buildability	4.90	5.08	6.09	3.75	5.67	5.10
I Develop tools that identify and aid interface management	5.70	7.00	5.09	6.55	7.00	6.27
G Appoint cladding and frame contractors at the same time	6.30	4.15	7.45	7.64	5.83	6.28
J Standardise interface designs	7.70	7.00	5.91	4.55	8.00	6.63
K Reduce adversarial effects within the process	7.20	7.69	5.45	6.55	6.67	6.71
L Risk assess designers knowledge of cladding systems from previous projects	6.60	5.85	7.55	7.27	7.50	6.95
D Improve programming and sequencing at site level	8.00	6.77	8.18	7.82	5.67	7.29
A Eliminate the term "by others"	6.90	7.54	9.27	7.73	6.67	7.62
F Ensure all installers have attended approved training courses	7.90	7.69	8.09	9.09	7.00	7.95

APPENDIX B

Full SPSS results for cladding to six building elements.

		subject types					Total
		consultants	designer	system designer	principle contractor	cladding contractor	
clad/frame	easiest	2		1	2	3	8
	2.00	2		2	1	1	6
	3.00		1	1	1	1	4
	4.00	5	2		2	1	10
	5.00		4		3	3	10
	most difficult	5	7	1	6	3	22
Total		14	14	5	15	12	60

		subject types					Total
		consultants	designer	system designer	principle contractor	cladding contractor	
clad/roof	easiest	1	1		3	2	7
	2.00	3	1	1	2	2	9
	3.00	4	4		6	2	16
	4.00		2	1	2	3	8
	5.00	5	3		2		10
	most difficult	1	3	3		3	10
Total		14	14	5	15	12	60

		subject types					Total
		consultants	designer	system designer	principle contractor	cladding contractor	
clad/interiors	easiest	3	1		3	2	9
	2.00	1	3	2	3	1	10
	3.00	1	2	2	2	3	10
	4.00	3	4	1	2	4	14
	5.00	2	1		4	2	9
	most difficult	4	3		1		8
Total		14	14	5	15	12	60

		subject types					Total
		consultants	designer	system designer	principle contractor	cladding contractor	
clad/cladding	easiest	2	4	2	2	3	13
	2.00	2	1		4	1	8
	3.00		2		4	3	9
	4.00	1	2		3	1	7
	5.00	4	2	1	1	3	11
	most difficult	5	3	2	1	1	12
Total		14	14	5	15	12	60

		subject types					Total
		consultants	designer	system designer	principle contractor	cladding contractor	
clad/services	easiest		5			1	6
	2.00	6	1		3	2	12
	3.00	3	4		1	3	11
	4.00	1	1	2	4	1	9
	5.00	1	1	3	5	1	11
	most difficult	3	2		2	4	11
Total		14	14	5	15	12	60

		subject types					Total
		consultants	designer	system designer	principle contractor	cladding contractor	
clad/secondary	easiest	4	6	1	4	2	17
	2.00	2	6	1	2	3	14
	3.00	3		1	3	1	8
	4.00	3		1	1	1	6
	5.00		1		1	3	5
	most difficult	2	1	1	4	2	10
Total		14	14	5	15	12	60

Full SPSS results for procurement options design and build, management and partnering.

		subject types					Total
		consultants	designers	systems designers	principal contractors	cladding contractor	
design and build	best	2	1		4	2	9
	2.00	1	7		4	6	18
	3.00	4	2	3	6	4	19
	4.00	4	3	2		2	11
Total		11	13	5	14	14	57

		subject types					Total
		consultants	designers	systems designers	principal contractors	cladding contractor	
traditional	2.00	1	1	1	1	3	7
	3.00	3	2	2	3	5	15
	4.00	7	10	2	10	6	35
Total		11	13	5	14	14	57

		subject types					Total
		consultants	designers	systems designers	principal contractors	cladding contractor	
management	best	1	2	1	2	2	8
	2.00	7	4	3	6	5	25
	3.00	3	7		3	4	17
	4.00			1	3	3	7
Total		11	13	5	14	14	57

APPENDIX C

EPSRC assessment results for the CladdISS research project.

EPSRC

Engineering and Physical Sciences
Research Council

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20/12/2001

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E-mail chris.elson@epsrc.ac.uk
Grant Ref :GR/L39179/01

Dear Dr Gibb:

INDIVIDUAL GRANT REVIEW - GR/L39179/01
Grant Title: STANDARDISATION OF WINDOW AND CLADDING INTERFACES

The Individual Grant Review for GR/L39179/01, which you helpfully submitted on 02/01/2001 following the completion of the research, has now been assessed. A summary of the outcome, which stems from your self-assessment, from the comments of assessors and the judgement of the panel, is shown below:

<u>Criterion</u>	<u>Final Assessment</u>	<u>5-box Rating Scale</u>
Research Quality	Tending to internationally Leading	Unsatisfactory to Internationally leading
Research Planning and Practice	Tending to internationally Leading	Unsatisfactory to Internationally leading
Potential Scientific Impact	Nationally standing	Unsatisfactory to Internationally leading
Output of Research Staff	Outstanding	Unsatisfactory to Outstanding
Communication of Research Outputs	Tending to Outstanding	Unsatisfactory to Outstanding
Potential Benefits to Society	Tending to Outstanding	Unsatisfactory to Outstanding
Cost Effectiveness	Tending to Outstanding	Unsatisfactory to Outstanding

Overall Assessment : Tending to Outstanding

Yours sincerely



Mrs Chris Elson
Programme Operations Directorate

APPENDIX D

Proforma sheets used in the key expert interviews

INTERFACE MANAGEMENT MATRIX FOR CLADDING DESIGN, MANUFACTURE AND INSTALLATION													
KEY INTERFACE ISSUES	PLEASE RANK THE TIMING OF THE STAGES (Inception-Demolition) (1-6) FOR EACH OF THE KEY INTERFACE ISSUES						Project Name (If applicable):						Notes
	1	2	3	4	5	6	7	8	9	10	11	12	
	Inception	Client Brief	Concept Design/Performance Specification	Project Specific Design	Full Specification	Product Production Drawings	Manufacture of Product Parts	Deliver to Site	Installation on Site	Handover	Facilities Management/Maintenance	Demolition	
1	Cladding Type												
2	Frame/Cladding												
3	Cladding/Cladding												
4	Services/Cladding												
5	Internals/Cladding												
6	Roof/Cladding												
7	Features/Cladding												
8	Sealants at Interfaces												
9	Interface Tolerances												
10	Interface Warranties												
11	Interface Construction Sequences												
12	Maintenance of Interfaces												
13	Work package Contents												

INTERFACE MANAGEMENT MATRIX FOR CLADDING FIXING DESIGN, MANUFACTURE AND INSTALLATION																	
KEY INTERFACE ISSUES FOR CLADDING FIXINGS	PLEASE RANK THE TIMING OF THE STAGES (Inception-Demolition) (1-6) FOR EACH OF THE KEY INTERFACE ISSUES						Note: The type of procurement route may vary the responses to the Matrix. If this is the case please use the traditional method of procurement in this matrix. If you have time please copy the matrix and complete for other forms of procurement.						Notes				
	1	2	3	4	5	6	7	8	9	10	11	12		13			
	Inception	Client Brief	Concept Design/ Perform Specification	Project Specific Design	Full Specification	Product Production Drawings	Manufacture of Product Parts	Deliver to site	Installation on Site	Handover	Facilities Management	Demolition					
1																	
2																	
3																	
4																	
5																	
6																	
7																	
8																	
9																	
10																	

DATE: 26/01/1999
DRAFT: 3

APPENDIX F

Cladding test results from case study D

7. ADDITIONAL TESTING & ASSOCIATED REMEDIAL WORK

Prior to testing as detailed in section 6 above the sample was subjected to several tests with results and associated remedial work as follows:

7.1 PRE-TEST 2 MAY 2001

Water leakage was observed at several locations at window sill level and from pre-cast fixings below the frame.

Chamber temperature = 9°C
Ambient temperature = 7°C
Water temperature = 10°C

7.2 PRE-TEST 11 MAY 2001

Water leakage was observed at both ends of the window at sill level and from pre-cast fixings below the frame.

Chamber temperature = 18°C
Ambient temperature = 19°C
Water temperature = 14°C

7.3 PRE-TEST 14 MAY 2001

Minor water leakage observed between the window sill and glazing bead and beneath the window frame at a fixing screw.

Chamber temperature = 15°C
Ambient temperature = 14°C
Water temperature = 15°C

7.4 TEST 15/16 MAY 2001

7.4.1 Test 1 – Air permeability

The air flow results were within permissible values.

Chamber temperature = 18°C
Ambient temperature = 15°C

7.4.2 Test 2 – Static water

No water leakage was observed

Chamber temperature = 13°C
Ambient temperature = 12°C
Water temperature = 15°C

7.4.3 Test 3 – Wind resistance

No damage to the sample was observed.

Chamber temperature = 14°C

Ambient temperature = 12°C

7.4.4 Test 4 – Air permeability

The air flow results were within permissible values.

Chamber temperature = 15°C

Ambient temperature = 13°C

7.5 TEST 21 MAY 2001

7.5.1 Test 2 – Static water

At a pressure differential of 500 pascals water was observed dripping from a screw under the window frame.

Chamber temperature = 15°C

Ambient temperature = 14°C

Water temperature = 15°C

7.5.2 Test 3 – Wind resistance

No damage to the sample was observed.

Chamber temperature = 15°C

Ambient temperature = 14°C

7.5.3 Remedial Work

The window unit was removed from the test sample and a new unit fitted.

7.6 PRE-TEST 1 JUNE 2001

No water penetration was observed throughout the test.

Chamber temperature = 19°C

Ambient temperature = 17°C

Water temperature = 17°C

7.7 TEST 4 JUNE 2001

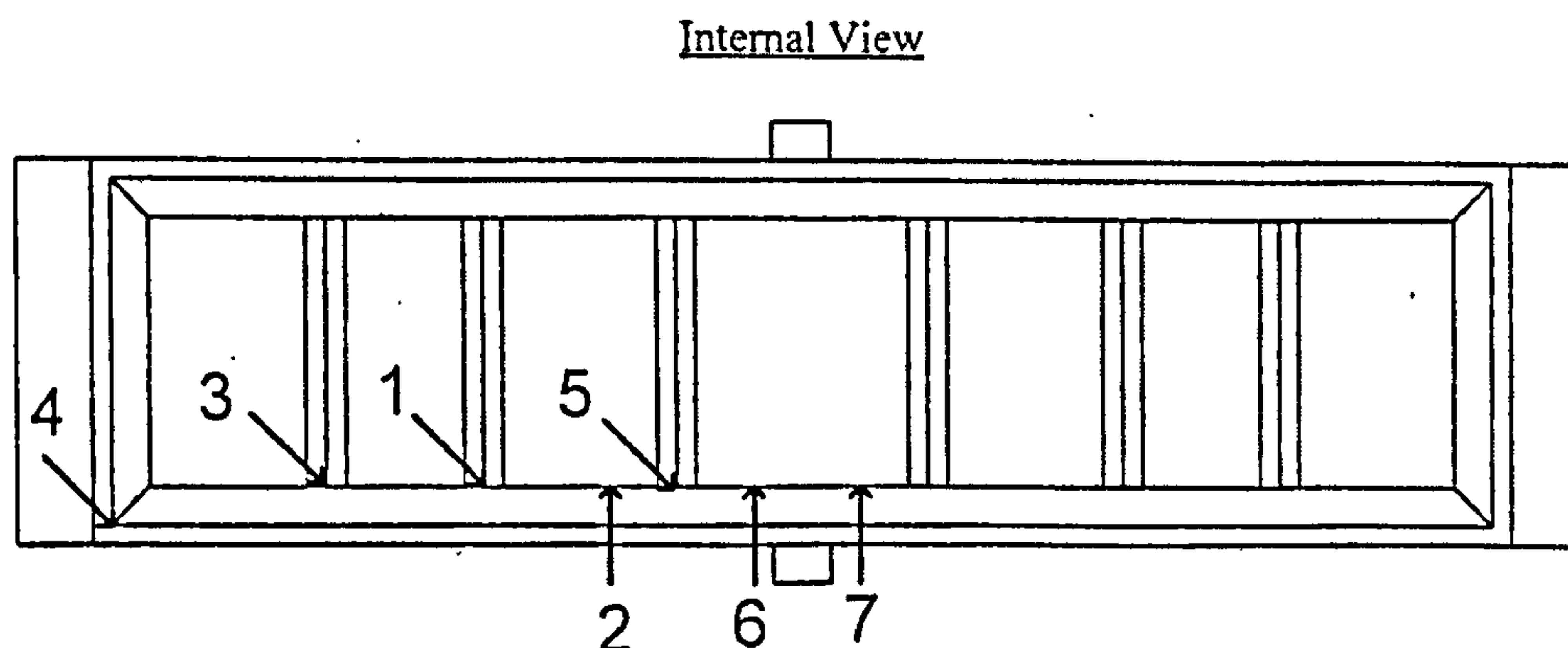
7.7.1 Test 1 – Air permeability

The air flow results were within permissible values.

Chamber temperature = 14°C

Ambient temperature = 11°C

FIGURE 4



The locations referred to in the following text are shown in Figure 4.

7.7.2 Test 2 – Static water

At a pressure differential of 100 pascals minor water leakage was observed from the bottom glazing bead at location 1.

At a pressure differential of 500 pascals minor water leakage was observed from the bottom glazing bead at location 2.

Chamber temperature = 16°C
 Ambient temperature = 14°C
 Water temperature = 15°C

7.7.3 Remedial Work

The glazing bead and gasket were removed and the toe bead sealant was cleaned away and replaced.

7.7.4 Test 2 – Static water (repeat)

No water leakage was observed.

Chamber temperature = 17°C
 Ambient temperature = 16°C
 Water temperature = 15°C

7.7.5 Test 3 – Wind resistance

No damage to the sample was observed.

Chamber temperature = 19°C
 Ambient temperature = 16°C



7.7.6 Test 4 – Air permeability

The air flow results were within permissible values.

Chamber temperature = 19°C

Ambient temperature = 16°C

7.7.7 Test 5 – Static water

At a pressure differential of 100 pascals two small pools of water were observed from beneath the glazing bead at location 3.

At a pressure differential of 200 pascals water was observed ponding on the sill at location 4.

Chamber temperature = 19°C

Ambient temperature = 17°C

Water temperature = 15°C

7.7.8 Remedial Work

The type of toe bead sealant was reviewed with Kawneer and Proglaze 550 was introduced at the sill and jambs.

7.8 PRE-TEST 6 JUNE 2001

At a pressure differential of 150 pascals minor water leakage was observed from the glazing bead at location 5.

Chamber temperature = 17°C

Ambient temperature = 15°C

Water temperature = 16°C

7.8.1 Remedial Work

The wedge gasket was removed from all the height and sill glazing beads. The toe bead was resealed and the glazing beads and gasket replaced.

7.9 PRE-TEST 15 JUNE 2001

At a pressure differential of 300 pascals two drops of water were observed from the bottom glazing bead at location 6.

At a pressure differential of 500 pascals three other areas of water leakage were observed from the bottom glazing beads at locations 1, 3 and 7.

Chamber temperature = 18°C

Ambient temperature = 16°C

Water temperature = 15°C



7.9.1 Remedial Work

Added Muntin sealer gasket to corners as per Kawneer details and bedded into Proglaze 550 sealant.

7.10 PRE-TEST 21 JUNE 2001

At a pressure differential of 500 pascals water was observed from the glazing bead at location 2.

Chamber temperature = 15°C

Ambient temperature = 18°C

Water temperature = 14°C

7.10.1 Remedial Work

The internal glazing beads and gaskets were removed. The Muntin sealer gasket was removed and the silicone cleaned away. The areas were resealed ensuring the blocks were fully bedded on sealant. The beads and gaskets were reinstated.

APPENDIX G

Site plan for case study E. Showing the site crane radius and limitations.

