Decision support to avoid collapses in structural refurbishment projects

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DECISION SUPPORT TO AVOID COLLAPSES IN STRUCTURAL REFURBISHMENT PROJECTS

MUKESH KASHYAP

A Doctoral Thesis submitted in partial fulfilment of the requirements of the Loughborough University for the award of Doctor of Philosophy

June 2007

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ABSTRACT

Safety management to avoid collapses during structural refurbishments of buildings has been of great concern to site professionals and management involved in structural refurbishments. The problems hindering safety in refurbishment projects were identified as: process bottlenecks, absence of a structured refurbishment process and limitations in the use of decision support tools. The aim of the research was to develop a Safety-Integrated Refurbishment Process Model (RPM) and establish its viability as the basis for a Decision Support System (DSS) to avoid structural collapses in refurbishment projects.

Approaches to avoiding structural collapse on refurbishment projects are highly variable and depend, to a large extent, on the decision making ability, availability of information, expertise and competence of the project team. Refurbishment projects involving partial demolition activities and/or structural alterations require competent and qualified professionals who can ensure the integrity of the structure right from the feasibility stage to the actual refurbishment execution stage. Project participants require decision support that is relevant not only to their particular context but, which also gives them the flexibility to be kept informed of the responsibilities of the other team members. There are not many decision tools available for structural refurbishment projects, and existing general purpose tools do not live up to the requirements and expectations of the site personnel. Lack of communication and information flow were identified as other major concerns during site operations.

The research methodology adopted consisted of several methods. A literature review on structural refurbishment and site practices was first undertaken. This was followed by two sets of case studies: the first set of five case studies of refurbishment projects sought to identify management practices and problems associated with structural refurbishments; while the second set of five historic case studies focused on cases where collapses had occurred during structural refurbishments. Case studies also sought to identify areas where decision support could help in preventing structural collapses. The findings from literature and review of current practices supported by case studies were used to develop a new safety-integrated refurbishment process model for refurbishment projects. The validation of
the process model was carried out in three workshops by industry practitioners, academics and researchers to assess the usefulness and appropriateness of the refurbishment process. The case studies and interviews with industry practitioners helped in identifying the key stages of decision making, identifying major activities during refurbishment and establishing end-user requirements for a decision support system. They also stressed to improve the decision-making process in refurbishment projects by providing information on structural safety and integrity. These requirements informed the need to develop a decision support system. The evaluation of the DSS and feedback received from the end users indicated that the DSS is a useful tool for streamlining site operations and ensuring safety during structural refurbishment projects.

It is concluded that structural refurbishment can be much safer if the refurbishment process model, which provides for a structured sequence of activities during the project life-cycle and incorporates multiple feedback processes at the various stages, is adopted. The use of the DSS can assist the project participants during the decision making process by identifying the roles and responsibilities of the various participants, and providing context-specific guidance on issues to consider during the refurbishment process. The proposed DSS is a practical, simple, and effective tool for supporting decision making and addressing safety requirements during structural refurbishments.
DEDICATION

I dedicate this thesis to my Father (Shri Yograj Kashyap) and my Mother (Shrimati Saroj Kashyap).
ACKNOWLEDGEMENTS

I wish to express my sincere thanks to all those who have contributed to the successful completion of my PhD research. I express my sincere thanks to my supervisors, Professor Chimay J. Anumba and Professor Charles O. Egbu for providing guidance, various sources of information and intellectual guidance throughout the research. My special thanks to Professor Anumba for being a mentor, providing constant motivation and for his patience. Professor Egbu was a constant source of encouragement and inspiration. I owe a deep debt of gratitude to both of them.

I am grateful to the Health and safety Executive (HSE) for providing the funding and access to case studies to undertake the research. I am also grateful to the Centre for the Built Environment, Glasgow (CBE) and Glasgow Caledonian University for providing the necessary facilities and computing equipments to conduct workshops. I am very much indebted to a number of people from construction/consultancy firms for allowing me to conduct interviews, utilise the findings from interviews, willingly participating in the evaluation workshops and providing useful feedback.

I like to thank my colleagues in the department of Civil and Building Engineering, for participating in validation workshop. My sincere thanks to Harshal Galgale who provided constant feedback and support during the testing and evaluation of software.

I express my sincere appreciation to my wife Susan for her understanding, patience and support throughout my research period, and to my lovely daughters Ayushi and Ananya for providing the welcome distractions when they were needed most.

Finally, my profound gratitude to Almighty God, who enabled me to carry out this research.
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<td>ACoP</td>
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<tr>
<td>BRE</td>
<td>British Research Establishment</td>
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<td>CDM</td>
<td>Construction (Design) and Management) Regulations 1994</td>
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<td>CIRIA</td>
<td>Construction Industry Research and Information Association</td>
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<td>DBMS</td>
<td>Database Management System</td>
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1.1 Introduction

This chapter introduces the research reported in this thesis. It gives a brief summary of the background to the research and justification for undertaking it. It also outlines the research aims and objectives, research methodology, and provides a guide to the contents of the thesis.

1.2 Research Background

There are ever-present health and safety risks in construction; these are greater on refurbishment projects involving structural alterations, facade retentions and partial demolition. There is evidence that the construction industry lacks effective management systems to cope with refurbishment safety risks and hazards (Egbru et al., 1996). In 1991 the European Foundation for the Improvement of Living and Working Conditions in their study on fatal accidents in the construction industry showed that 37% of accidents were due to the failure of site management and workers, 28% to poor planning and 35% to unsafe design. An important conclusion drawn from these statistics is that over 60% of accidents were due to poor decisions made even before the work began. Research presented by Behm (2005)
suggests that designers can have strong influence on construction safety. Among fatal accidents, the HSE in their study (HSE, 1988) has identified that 75% of fatal accidents are caused by lack of effective management actions. Construction refurbishment remains one of the least understood (Quah, 1988; Egbu, 1994) and most under-researched sectors of construction, especially with regard to the management and health & safety areas (Egbu, 1994; CIRIA, 1994). Refurbishment work is less well-planned and more difficult to control than new-build (Egbu, 1996; Egbu, 1999). Furthermore, it is widely acknowledged that refurbishment projects are complex, risky and uncertain (HSE, 1988; BRE, 1990; Quah, 1992; Egbu, 1994; Egbu, 1995).

The renovation and refurbishment market is growing faster and rapidly expanding in comparison to the new construction market (Van Leeuwen et al 2000; Kincaid, 2002). The UK refurbishment market increased two-folds from 22.5% (£1,109m) of the total construction output in the 1970s (DOE, 1981) to 42.9% (£18,743m) of the total construction output by 1990 (DOE, 1995). The maintenance repair and refurbishment (MRR) sector further grew up to 46.6% (37,441m) by 2004 in the UK (DTI, 2005). Statistics from planning permission applications showing refurbishment to be about 10% of all building activities could be misleading as large-scale refurbishment projects are often designated under new building category, for example where housing is converted to other uses. The refurbishment sector is close to the new build as shown in Building Maintenance Information Report (BMI report, 2004). According to BMI report, the repair and maintenance sector which comprises 45.7% of the total output of the UK construction industry does not include improvements, alterations work as these have been included in the new work.

This growth in refurbishment work and its increasing importance, acknowledged by the 1995 Technology Foresight exercise (OST, 1995), is not matched by comparable empirical research on the subject. Gibb (2001) pointed out the build type bias for research in refurbishment compared to the market share of MRR sector and advocated for further underpinning and application research. For example MRR sector attracts only 3% of the
funding for research in pre-assembly in comparison to nearly 53% secured by residential and major commercial projects (Gibb, 2001).

1.3 Justification for the Research

The most recent HSE statistics show that, while the number of fatalities in the construction sector generally dropped in 2001-2002, the number of fatalities in the refurbishment sector remained unaffected, therefore accounting for a greater proportion than hitherto of the total fatalities count. Although no official statistics exist on the current proportion of refurbishment work, the maintenance and repair sector including refurbishment is thought to constitute nearly 47% of the total UK construction output and accounts for about 43% of the total number of fatal accidents in the building and civil engineering industry in the UK (see Figure 1.1).

![Figure 1.1 Construction Worker Fatalities by Site Activities (HSE, 2002)](source: Revitalizing Health and safety in Construction, HSE Document 2002)

Out of the total building refurbishment activities housing sector accounts for 56% while the rest 44% is taken up by the commercial sector. Lamont (2005) identified refurbishment of domestic premises among type of activity,
where industry professionals most need to act to reduce risks. Refurbishment projects are dangerous, as demonstrated by the recent collapses in Hull, Stoke, Elland (2005), London (2006), Middlesbrough (2007), East London (2007) in the UK, Mumbai (2007) in India and Istanbul (2007) in Turkey. The Health and Safety Executive (HSE) in the UK has categorised collapses into two categories:

1. collapse or partial collapse of any building structure which involve a loading of over 5 tonnes of materials on any floor or wall of a building under construction or used as a place of work; and
2. complete or partial collapse of scaffolds or temporary structure over 5.0 m height.

There are no statistics available on 'building collapses during refurbishments'. However, facts from the dangerous occurrences data from HSE (2005) do show the incidences of collapses (see Figure 1.2).

![Figure 1.2 Structural Collapses During Construction in The UK (HSE, 2005)](image)

Source: Health and Safety Statistics 2004/05, Table DO1, Dangerous occurrences, HSE document, 2005.
A basic requirement for any building structure is that it does not collapse, causing death, injury or economic loss, yet this cannot be made absolute as structures do collapse. Overloading during the life-span of a building and/or the alteration of load paths can seriously undermine the structural integrity of a building. Similarly, additional loads during refurbishment, change of use, additions, alterations to the structure can aggravate an under-designed building and contribute to its eventual collapse. The results of the research work carried out by Egbo et al (2002) and Anumba et al (2004) pointed out the need for greater care to improve health and safety in the management of refurbishment projects involving demolition and structural instability.

The construction industry has been criticised for under-achievement (Carpenter, 1981; Egan, 1998). The reasons for this situation have been attributed to inefficient construction processes and temporary multi-organisations (Tucker and Ambrose, 1998; Low, 1998). Some of the earlier research by Walker (1985), Sanvido and Norton (1994), and Karhu and Lahdenpera (1999) focused on modelling the construction process. Most of the modelling studies were geared towards new construction and highlighted the importance of capturing information and indicated the significance of integrating project information.

The research work carried out by Anumba et al (2004) highlighted the need for greater care in the management of refurbishment projects to improve industry practices and emphasised on the importance of improving communication and information exchange between project team members during the various stages of the refurbishment project lifecycle. Many challenges in current construction processes arise from poor access to the right information at the right time for timely decision-making and from the lack of communication between project participants (Kondratova et al, 2003). Thus, the quality, quantity and timing of information and effective communication are important as they can either hinder or facilitate successful results (Garza et al, 1998). There has been an absence of any such process model for the refurbishment sector.
Anumba et al (2004), highlighted that there is a shortage of decision support tools in the refurbishment and demolition sectors. The research also highlighted the need for a practical decision support system that organisations and individuals involved in refurbishment projects could use to ensure the safer completion of structural refurbishment projects. The literature review drew on the findings of the previous studies conducted by BRE (1990), Quah (1992), and Egbu (1994) and found that refurbishment projects are complex and that most of the existing decision support systems are geared towards the needs of new-build construction or aspects of the project delivery process rather than safety (John et al., 1999; Anumba and Scott, 2001). Although the industry recognises the importance of a structured process model and a decision support system, many are uncertain about the actual benefits it can provide. McGee (2004) states that the capture and presentation of information is crucial in preventing mishaps from happening owing to the capability to share knowledge and lessons learned.

Consequently, this research sought to address the need through an investigation of how refurbishment projects involving structural alterations, modifications, removal and/or structural instability should be managed to prevent accidents, especially those due to structural collapses. In particular it focussed on the development of a structured refurbishment process model and a decision support system. The aim and objectives of the project are presented in the next section.

1.4 Research Aim and Objectives

1.4.1 Aim

At the commencement of this research, key gaps in knowledge regarding structural refurbishments were identified, which further strengthened the need to address the problems and risks involved in structural refurbishments.
The identification of these key gaps and literature research allowed the overall aim of this research to be formulated, as follows:

'To develop a Safety-Integrated Refurbishment Process Model and establish its viability as the basis for an Decision Support System (DSS) to avoid collapses in structural refurbishment projects'.

1.4.2 Objectives

In order to achieve the overall project aim, the following specific objectives were set:

1. To review current practices adopted for managing health and safety on refurbishment projects with a view to adopting best practice and identifying opportunities for improvement;
2. To identify the different stages of involvement of key functionaries under given circumstances and situations and their effect on decision-making during refurbishment;
3. To identify areas that need support for health and safety management during structural refurbishment projects and establishing end-user requirements;
4. To develop a Safety-Integrated Refurbishment Process Model (RPM) to ensure that safety considerations are taken into account from the earliest stages in the planning and design of refurbishment works;
5. To develop a Decision Support System (DSS) to avoid structural collapses during structural refurbishments through appropriate system development;
6. To evaluate the resulting prototype decision support system with industry practitioners and then to refine the system based on the feedback received.
A combination of research methods (literature review, case studies, interviews, questionnaires, prototyping) were utilised to achieve the research objectives. The relevant chapters addressing the research objectives are illustrated in Figure 1.3.

**Research Objectives**

**Research Methods**

**Literature Review**
- Chapter 2: Refurbishment in Construction
- Chapter 4: Case Studies in Refurbishment

**To review current practices adopted for managing structural refurbishment with a view to adopt best practices, and establish the end-user requirements.**

**Case studies and Interviews**
- Chapter 2: Refurbishment in Construction
- Chapter 4: Case Studies in Refurbishment

**To identify the different stages of involvement of key functionaries and their effect on decision making during refurbishment.**

**Questionnaire/Workshops**
- Chapter 4: Case Studies in Refurbishment
- Chapter 5: Development of RPM
- Chapter 6: Development of DSS

**To identify areas that need support for effective decision making in refurbishment projects and develop functional specification.**

**Develop a safety-integrated refurbishment process model for structural refurbishment and a conceptual framework for decision support system.**

**Encapsulate the developed methodology into a prototype decision support system.**

**Evaluate the resulting prototype system and refining of the system**

**Figure 1.3 Research Objectives and Methods**
Figure 1.4 presents the research input, research activities and expected outcome at each stage of the research. The successful completion of these tasks has led to the realisation of the research objectives.

<table>
<thead>
<tr>
<th>Input</th>
<th>Research Activities</th>
<th>Output</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compilation of Knowledge</td>
<td>Literature Review</td>
<td>• Critical review of structural refurbishments practices</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Identification of Knowledge gap</td>
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<tr>
<td></td>
<td></td>
<td>• Review of various DSS</td>
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<tr>
<td></td>
<td></td>
<td>• Review of Process Modelling in construction</td>
</tr>
<tr>
<td>Industry input</td>
<td>Case studies and Document Investigation</td>
<td>• Problems associated with structural refurbishment</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Identify areas that need support</td>
</tr>
<tr>
<td>Industry Input</td>
<td>Interviews</td>
<td>• End user requirements</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Identification of roles and involvement of key functionaries</td>
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<tr>
<td></td>
<td></td>
<td>• Development of functional requirements</td>
</tr>
<tr>
<td></td>
<td>Development of Refurbishment Process Model and Validation</td>
<td>• Safety-Integrated Refurbishment Process Model (RPM)</td>
</tr>
<tr>
<td></td>
<td>System Architecture of DSS</td>
<td>• Conceptualisation of the DSS</td>
</tr>
<tr>
<td>Industry Input</td>
<td>DSS Software Development and System Evaluation</td>
<td>• Software programme</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Coding</td>
</tr>
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<td></td>
<td></td>
<td>• DSS End product</td>
</tr>
</tbody>
</table>

**Figure 1.4 Research input, Research activities and Expected outcomes**

Next section outlines the research methodology adopted and justification for the research methods used.
Chapter 1  Introduction and Background to the Research

1.5 Research Methodology

This section outlines the research methodology adopted for the research and justifies the research methods used for the research. The details are as follows:

An extensive literature review was conducted mainly on health and safety in refurbishment projects, problems with structural refurbishment and existing decision support tools available within the industry. The literature review drew on the findings from the previous research on health and safety in refurbishment and the literature available from Building Research Establishment (BRE), Construction Industry Research and Information Association (CIRIA), Health and Safety Executive (HSE), Standing Committee on Structural Safety (SCOSS) and the Institute of Demolition Engineers, UK (IDE) to establish the causes of structural collapse during refurbishment. The search of the available and relevant literature was carried out through the Loughborough University Library Catalogue (OPAC), Loughborough University Metalib (an integrated search engine that facilitates searching across different databases and journals available electronically) and Internet search engines such as Google and Dogpile.

The case study approach was selected because it provided an in-depth insight into the current approaches for structural refurbishments. The case studies involved:

(a) semi-structured interviews with nine senior staff from five companies to ensure that a comprehensive overview was obtained (see Section 4.3).

(b) five historic case studies along with a review of documents where collapses had actually occurred (see Section 4.5).

The case studies highlighted the shortcomings in current practices and causes of structural collapses during structural refurbishments.
The findings from the case studies revealed that the industry lacked a structured process model for refurbishment and lack of a decision support system.

The next stage was the development of the refurbishment process model. The knowledge gained from the literature review, existing practices in structural refurbishments and interviews with experts were used to develop a refurbishment process model. This was considered essential for the development of the decision support system. Process modelling technique, based on the Process Protocol (Kagioglou et al., 1999) were used to develop the refurbishment process model, which outlines the various stages and project participants involved in refurbishment projects. The process model was validated by 49 participants in three workshops and during interviews which included academics, researchers and practitioners working in the industry.

Case studies also helped in identifying end-users' requirements and the functional specifications of the decision support system. Based on the findings of the literature review, case studies and interviews, the prototype DSS was developed on a personal computer using Microsoft™ Visual Basic 6.0 and MS Access. The evaluation of the DSS was carried out by 34 industry experts and potential end-users in two separate workshops to evaluate its appropriateness and usefulness. The first workshop involved a presentation to 27 participants, which was followed by another hands-on evaluation of the system by 7 experts, who provided useful feedback via an evaluation questionnaire.

A summary of the research objectives and the research methods used to achieve them is illustrated in Table 1.1.
A brief description of the research methods has been given in this section. The research methodology adopted and its justification is described in detail in Chapter 3, Section 3.5.

1.6 Research Scope and Output

The research addresses the need to develop a safety-integrated refurbishment process model that provides decision support to avoid...
collapses during structural refurbishments. The system offers guidance and decision aid during various stages of the refurbishment project through evaluation by project participants at a particular stage and producing a printable report to maintain a record of evaluation and identify when the evaluations were made and by whom. While conducting and establishing the research work, the various constraints encountered were as follows:

- The definition and types of refurbishment works are varied and complex. It is therefore difficult to classify all refurbishment works as they can differ from mere architectural/cosmetic works to works involving structural modifications, and alterations. It is difficult to develop a system which will cater for the management of refurbishments in general. As a consequence, the research project focussed on problems associated with structural refurbishments only.

- The detailed information about technical aspects and causes of collapses during refurbishment was difficult to obtain as some of these were subject to legal proceedings. Thus, case studies could only be undertaken for historic cases which were accessible for research purposes and where sufficient information could be obtained;

- It was difficult to speak to people who were involved with collapses to identify major causes and concerns. Although many Health and Safety Executive (HSE) officials were more than willing to share their experiences and insights, they were not involved in any way with the site management and project decision-making. However, they provided information and knowledge based on projects that they had investigated following unintentional collapses.

Based on the above constraints, the scope of this thesis can be described as follows:
• Identification of the roles of key project participants and their involvement in decision-making on a refurbishment project;
• The development of a Safety-Integrated Refurbishment Process Model;
• The development of a Decision Support System (DSS) to enhance safety by providing context-related information at tactical and operational level;
• Although occupational health and safety considerations such as the presence of asbestos, noise and dust during partial demolition and refurbishment have been broadly studied, these have not actually been implemented in the prototype DSS.

1.7 Original Contribution

The work presented in this thesis imparts the following original contributions to the research field:

• It provides a critical review of the existing practices and problems associated with structural refurbishment projects;
• It provides an insight into decision-making and the gaps in knowledge while undertaking structural refurbishments;
• It constitutes one of the first attempts to formalise the refurbishment process through the development of a model that provides greater clarity on the key stages, major activities, sub-activities, and roles and involvement of project participants in refurbishment projects;
• It adds to the Process Protocol by modelling the ‘Refurbishment Management Activity Zone’ and provides the framework for the development of a Decision Support System for structural refurbishment projects;
• It developed a decision support system for structural refurbishment projects that can be effectively used by project participants during structural refurbishments to reduce the incidence of structural collapses.
1.8 Thesis Layout

The thesis structure reflects the approach followed to achieve the objectives of the study and the stages of development of the DSS. Each chapter presents independent subject matter to substantiate the chapter theme with appropriate cross-referencing which was necessary in drawing together the various threads. The thesis is divided into the following chapters (see Figure 1.5).

Chapter 1: Introduction and Background to the Research
Chapter one introduces the subject matter of the research project and briefly describes its background. It justifies the need for the research and explains its aim and objectives. This chapter also outlines the research scope and contribution to the research field. The final section presents a brief account of the research methodology and the structure of the thesis.

Chapter 2: Refurbishment in Construction
Chapter three provides an overview of the refurbishment and difficulties in managing refurbishment projects. It reviews the concept of decision-making in general and highlights the process of decision making could be made effective when tackling structural refurbishments. It then reviews the various decision-making and decision support tools available for refurbishment projects and concludes by establishing the need for decision support to avoid structural collapses during structural refurbishments.

Chapter 3: Research Methodology
This chapter provides an introduction to general research methodologies. It introduces the types of research methods and presents a description of the research methodology used to achieve the aim and objectives of this project. It also justifies the methodology adopted.
Chapter 1 Introduction and Background to the Research

Chapter 2 Refurbishment in Construction

Chapter 3 Research Methodology

Chapter 4 Case Studies in Refurbishment

Chapter 5 Refurbishment Process Model

Chapter 6 Decision Support System

Chapter 7 Conclusions

Figure 1.5 Thesis Structure
Chapter 4: Case Studies in Structural Refurbishments
Chapter four presents the findings from case studies and describes the problems with structural refurbishments and possible solutions to avoid structural collapses during refurbishments.

Chapter 5: Development of Refurbishment Process Model (RPM)
Chapter five examines details of the construction process, project team involvement and various process models developed for the construction industry. This work was essential for developing a suitable process model for refurbishments since there is no previous work on, or study of, a refurbishment process model. It then presents the development of the process model for refurbishment projects. It fully describes the validation of the process model, the validation objectives and the evaluation method used. An evaluation of the evaluation results is presented along with the limitations of the model.

Chapter 6: Development of Decision Support System (DSS)
Chapter six describes the design and development of software for the decision support system. It presents the system's architecture, creation of database and development and operation of the system. The evaluation of the prototype system is also presented together with an analysis of the evaluation results. This chapter also summarises key findings, benefits and limitations of the system.

Chapter 7: Conclusions and Recommendations
This last chapter, summarises the whole project, evaluates it against the original aim and objectives, and presents the conclusions drawn from the research. It discusses the contributions made by this research and makes recommendations for future research.
Accompanying CD-ROM: There is a CD-ROM containing IDS software, developed as part of the research, which is an installable software and attached at the end of this thesis.

1.9 Summary

This chapter has given an introduction to the thesis, the aim and objectives of the project, the justification for the research, a brief research methodology and guide to the thesis. The next chapter will elaborate on the research methodology adopted for the project.
2.1 Introduction

The construction industry is continually faced with hazards. The hazards during refurbishment are more complex, difficult to observe and evaluate than the hazards on new build (CIRIA 1994; Egbu, 1994, 1997). This chapter presents an overview of the refurbishment sector, recent trends, problems associated with structural refurbishments and identifies the causes of structural collapses. It also aims to develop an understanding of the decision making process in refurbishment works and identifies areas for decision support. It also reviews the various process models, modelling techniques and available decision support systems for refurbishment. Lastly, this chapter provides the foundation for the need to develop a process model for refurbishment and a decision support system for avoiding structural collapses.

2.2. Defining Refurbishment

Building work can be classified as either new build or refurbishment. New build is an easy concept to grasp, as the term is applied to any work that starts from the scratch. Refurbishment, however, is a more difficult concept to define. Refurbishment works can take many forms and may be undertaken for a variety of reasons. This can be with the purpose of essential rearrangement of an existing building in order to eliminate its physical,
architectural/aesthetic, functional, comfort, and other kinds of deterioration, from minor maintenance to major structural alterations. Various definitions of refurbishment exist and several authors have tried to put forward refurbishment as:

Riley and Cotgrave (2005) put forward a very broad definition of refurbishment as:

‘Work undertaken to an existing building’

They define refurbishment as work, ‘that extends the useful life of existing buildings through the adaptation of their basic forms to provide a new or updated version of the original structure’.

Johnstone (2001) defines refurbishment as work which reverses the economic depreciation of dwelling services and extends the life of a dwelling through alterations, replacement and reconstruction. The refurbishment of existing buildings enables aging infrastructure to fulfil modern technical, operational and economic demands while continuing to guarantee safety.

Kirby (1979) cited Bagby’s (1973) clarification on what refurbishment means to a home owner, which could be from changing a light bulb to change in use of the facility. Marcus (1979) defined refurbishment as extending the beneficial use of an existing building by providing cost-effective alternatives to redevelopment. Seeley (1987) believes that rehabilitation, which in many texts is simultaneously used with refurbishment has further evolved a whole new range of terms (see Egbu, 1996) for terms such as conversion, modernisation. Bone (1987) provided a range of words that are synonymous with refurbishment, but which are in reality sub-categories of the refurbishment process.

Egbu (1996) considers refurbishment to encompass rehabilitation, alteration, extension, improvement, and modernisation carried out on an existing
building to permit its re-use for various specific purposes. Aikivuori (1996) suggests that refurbishment projects may be initiated because of profound damage to the physical structure of a building, or alternatively may be planned in advance depending on the rate of deterioration.

Quah's (1988), comments that refurbishment was apparently indistinguishable from other specialist activities and routine tasks were refuted by Mansfield (2001; 2002), who felt that refurbishment has a specific meaning, which needs to be preserved to prevent a loss of clarity. Hardcastle et al (1997) commented that refurbishment of buildings is a process which reflects the ethos of urban regeneration. Their amended definition previously used by Industrial Market Research comes closest and has been adopted for defining refurbishment in this research as:

"..... work which involves the structural alteration of buildings, the replacement of main elements or finishes and/or the improvement of the floor space, associated repair works, including rebuilding work behind the facade and new building works in an existing building."

2.3 Terminologies Used For Refurbishment

Johnson and Wilson (1982) attempted to define various terms used in renovation and restoration of buildings and tried to 'map' the different terms used in upgrading of facilities. Rosenfeld and Shohet (1999) adapted the map, and associate maintenance and repairs to keep the constructed facilities operable and in a satisfactory appearance. Restoration, is associated with conservation of monuments and buildings of historic significance and associated rehabilitation to prolong the effective life of the facility, without changing the original characteristics, although it may include some repairs and modifications. When these substantial modifications are done with new
installations, the entire operation fits better in the *renovation* category. Major renovation may include addition and expansion to existing facilities. Finally, in the upgrading spectrum is reconstruction, which involves demolition or building of a completely new facility (see Figure 2.1).

![Figure 2.1 Terminologies for Upgrading of Constructed Facilities](Source: Rosenfeld and Shohet, 1999)

In the overall picture, lack of timely maintenance would mean the facility would require rehabilitation, and if the timely rehabilitation is not taken up at the right time, it might lead to reconstruction works. The above topological representation however, does not clarify the term refurbishment.

It is commonly thought that refurbishment is located towards the end of a property's life cycle and typically follows a series of increasing expenditure in the form of maintenance, repairs, restoration and replacements. Yet the conventional methods and models are unable to assess exactly at which time a particular building would be ready for refurbishment or redevelopment (Mansfield, 2002). As such it can be assumed that refurbishment could be taken up during any stage of the lifecycle of a building (see Figure 2.2).
By recognising refurbishment as a physical process, one of the key problems is with accurately identifying the boundaries between the processes in the cycle (e.g. maintenance, repair, restoration, renovation, replacement and redevelopment). This is important as the levels of project participants’ involvement, expertise, risk involved and their decision making abilities play a crucial role in refurbishment works.

2.4 Focus On The Refurbishment Industry

There are numerous reasons why this research project has chosen to focus on refurbishment works. Firstly, the incidence of health and safety problems in refurbishment works is higher than in new construction works. The most recent HSE statistics show that, while the number of fatalities in the construction sector generally dropped in 2001/2, the number of fatalities in the refurbishment sector remained unaffected, therefore accounting for a greater proportion than hitherto of the total fatalities count.
Furthermore, it is widely acknowledged that refurbishment projects are complex, risky and uncertain (BRE 1990; Quah, 1992; Egbu, 1994). Refurbishment work is dangerous, as demonstrated by the fairly recent collapses in Hull, Bootle, Stoke and Tottenham, and confirmed by the latest Health and Safety statistics. The value of all construction work excluding maintenance in 2000 was about £60 billion. Out of this refurbishment accounted for 51.4% of the total work in the UK (see breakdown of activities in Figure 2.3).

![Figure 2.3 Breakdown of New build and Refurbishment](Source: Riley and Cotgrave 2005)

The interesting fact which comes to light from the above graph is that the refurbishment sector exceeds new build in all sectors except in the commercial private sector. The heterogeneous nature of each refurbishment project and the lack of projects of sufficient size and scope has prevented the refurbishment industry from attaining the economies of scale needed for lowering the resource requirements per unit of refurbishment. Without the opportunity for standardisation and repetition, the opportunities for greater usage of prefabricated parts/industrialisation are limited, thus leaving refurbishment sites even more hazardous.
Chapter 2 Refurbishment in Construction

The problem is compounded by the fact that refurbishment contractors have hitherto in the main, been small and lowly capitalised; however larger-sized contractors are rapidly moving into this market in response to the shrinking new-build market and the higher technological demands of large scale refurbishment projects. The current literature demonstrates that refurbishment is generally performed inefficiently and at correspondingly higher costs. Other contributory causes are higher off-site costs regulatory requirements, and inefficient procurement methods coupled with inherent higher risks of the unknown nature of work in refurbishments.

There is strong evidence that the refurbishment industry lacks appropriate management strategies for coping with refurbishment safety risks and hazards (Egbu, et al, 1996). In fact, one specific problem particularly with refurbishment activities, is the necessity to manage the increasing information flow not only from within the project team, but also from inter-organisational participation. This introduces further complications due to the fact that the project team is in a decisional environment in which the highly interdependent processes are entrusted to people and organisations while operative methods which pose more risks often remain independent (Crichton, 1966). In such a context there is strong demand for adequate management and information tools to support the professionals on complex building refurbishment projects (Costantino and Sivo, 1999).

The Construction (Design and Management) Regulations, CDM - 2007, which cater for health and safety works in construction projects do apply to any refurbishment works which involve a change in use of the facility or full or partial demolition. These, however, are generally geared towards new construction works and do not adequately cover many small repair and refurbishment projects, apart from the design element.
2.5 Characteristics Of Structural Refurbishment Works

Structural refurbishment involves structural alterations and partial demolition work and, often, refurbishment projects are started without the benefit of condition surveys to determine the 'as built' information. It is even more difficult to mechanise, plan and efficiently organise refurbishment work due to the small, labour intensive, adhoc and dynamic nature of the work. Refurbishment works have characteristics that sharply distinguish them from new build construction projects. Young and Egbu (1993) in their study listed structural constraints, spatial constraints, site access and programming and scheduling of refurbishment works as five most difficult characteristics. They further suggested there is a correlation between characteristics rated most difficult and their frequency of occurrence. Bridges et al (1996) further investigated the frequency of occurrence and degree of difficulty, of refurbishment characteristics. One of the major problems with most of the refurbishment projects is the absence of original drawings and design calculations. Absence of unrecorded alterations and modifications during the building's life and deterioration may be far worse than assumed (Okoroh, 1992).

There may have been many unrecorded alterations and modifications during the building's life, and deteriorations behind the scenes may be far worse than assumed. Another unique problem is the virtual impossibility of defining the exact scope of work at feasibility stage (Okoroh, 1992), which can alter further if there are some works which were not thought of earlier or planned earlier, for example, the removal of some weak member or redundant services. The noise, dust and disruption of major building services are often assumed to be more tolerable alternatives to the problem of temporarily relocating the premises especially if the job has been envisaged to be of shorter duration.
2.6 Structural Collapses in Structural Refurbishment

The most notable structural collapses in the world have occurred under catastrophic conditions such as major earthquakes, floods, hurricanes and tornadoes. Other types of collapses occur sporadically during construction, refurbishment, under heavy snow loads, or more often as a result of faulty design. Structural collapses can occur for a variety of reasons. They can result from a major structural fault, construction fault or design fault, but, any seemingly minor faults can contribute to a chain of events that inevitably may lead to a collapse. Collapses can be classified under three categories:

**Localised collapse**: This relates to collapses that are confined to a small part of the building, without any induced damage occurring on other parts. The key feature distinguishing localised collapse from progressive collapse is that the resulting damage is disproportionate to the local damage (Ellingwood, 2005).

**Progressive collapse**: Progressive collapse occurs when a key member, or members of a structure fails. The isolated failure of this key member then initiates a sequence of events, causing failure of the entire structure, as most buildings are susceptible to progressive collapse to varying degrees (Taylor, 1975; Ellingwood and Leyendecker, 1978).

**Disproportionate collapse**: Disproportionate collapse occurs if, accidentally or by mistake, removal of one supporting member, causes damage beyond the locus of the failure. That means the building must not be damaged to an extent disproportionate to the cause of the damage (Douglas, 2002).

Some of the major problems associated with structural refurbishments and causes of occurrences of collapses as identified after literature review, SCOSS reports, HSE Report 204 (2004) on structural instability are:
• Absence of structural appraisal of the existing structure
• Lack of detailed risk assessment to reduce potential risks
• Failure to controlling demolition and unplanned collapses
• Non-Compliance With Statutory And Regulatory Requirements
• Failure to appoint a competent and experienced team
• Errors in design and during execution
• Lack of communication and flow of information
• Misunderstanding about the load path

2.6.1 Absence Of Structural Appraisal Of The Existing Structure

The structural engineer should make a detailed structural evaluation of the existing building to determine the adequacy of all the structural systems that are affected by any removal, alteration, modification or addition during change of use or during any repair of damages. The original design documents and all available construction and operation records must be carefully reviewed to obtain a thorough appreciation of the original design principles and the structural integrity of the existing building. The structural appraisal should report on the condition and strength of the load-bearing members along with remedial measures and supporting calculations necessary to satisfy the requirements of the Building Regulations. It should also address the risk and provision of robustness and consequences of the damage it may suffer on account of any collapse. A structural appraisal should aim at assessing the actual condition of an existing building. Such assessment should be able to highlight the actions essential to ensure the structural adequacy of the building for its intended use at present or in the future (HSE Investigation Report, 1999). This should also identify the vulnerability of such buildings and recommend actions to be taken to reduce the potential risk during structural alteration, rehabilitation or repair works to existing structures or facilities. This entails that any building being refurbished must go through a detailed initial inspection as it may have been exposed to the risk of abnormal loading and instability (SCOSS, 2003). The provision of safety measures should be based on simultaneous consideration
of the risk (probability of the building being exposed to abnormal loading) and the consequence of failure caused by such loading (HSE Investigation Report, 1999). It should also study the interaction between structural elements to be removed and those being retained so as to develop the demolition methods to avoid premature or unplanned collapse. Building Research Establishment (BRE Digest 366, 1991) provides guidance on the structural appraisal of existing buildings for change of use. The Institution of Structural Engineers’ publication, Appraisal of Existing Structures (IStructE, 1996) also provides guidance on the structural appraisal of existing buildings.

2.6.2 Lack Of Detailed Risk Assessment To Reduce Potential Risks

During document investigations and case studies provided by HSE, detailed risk assessment was found to be missing. Before commencing detailed design for any refurbishment work, those sections of the works that need to be modified should be carefully surveyed and documented. All buildings undergoing building works for change in the use of the building, having floor slabs spanning one way or roof components supported on load-bearing masonry walls and/or without any provision for peripheral or internal horizontal ties, would be required to comply with Building Regulations Part A (structures). The consequences of failure of a small building may not be as significant as those with the failure of a medium-sized public building. However, there may be circumstances where the probability of failure may be high on account of the inadequacy of robustness of 'key' vertical load-bearing elements or where an explosion (e.g., unventilated voids) could occur, as with Case # 4 and as highlighted in the HSE Investigation Report (1999).

2.6.3 Failure To Controlling Demolition And Unplanned Collapses

Structural refurbishments involving structural alterations/ modifications could be very tricky and troublesome depending on the size and type of project and could include:
(a) Removal of structural elements;
(b) Partial demolition of the building with a view to making extensions; or
(c) Creation of new openings or enlargement of existing openings.

Unfortunately, more accidents and fatalities occur during partial demolition than during total demolition works especially while carrying out small demolition activities. This is mainly due to the fact that instability of demolished part and stability of the retained part of the structure is not ensured. Interaction between site workers and the people occupying such buildings need to be fully considered because accidents during demolition works are mainly caused by partial or total collapses. Partial demolition involves carrying out works only on portions of the structure and maintaining structural stability for all the remaining parts during and after execution. Structural stability would depend on analysing the structural requirements and providing adequate temporary supports, and deploying proper demolition methods.

There may also be issues with the appointment of non-specialist contractors and the inadequacy of co-ordination and supervision of activities on small demolition activities. BS 8110 as referenced in the Approved Document Part A, recommends provision for all buildings, to have a minimum level of robustness, (e.g. design against a notional horizontal load, provision of horizontal ties, etc). As a result, buildings are expected to have measures to make them reasonably robust against large scale collapse on account of a local accident, damage to a small area, or due to the failure of a single structural element. The same holds true for buildings undergoing structural refurbishments. Pre-1970 buildings did not have any such provisions in design and it might be necessary to equip such building for their life after refurbishment as recommended in HSE investigation report (1999). Any measures for improving a building’s robustness should be practical and effective. Structural strengthening could be considered as an option for some buildings. One way to achieve this would be to improve the continuity (tying)
between individual structural components, so that the structure could bridge over a zone of local damage (HSE investigation report, 1999). Alternatively, the 'key' vertical load-bearing components could be adequately strengthened to resist the accidental loads to which they may be subjected.

2.6.4 Non-Compliance With Statutory And Regulatory Requirements

Building codes and structural standards specify minimum loads and safety factors and contain detailed rules embodying the best structural knowledge available at the time of writing. Except for small, conventional structures, which are covered by empirical rules, structural standards must only be applied by competent engineers. The basic idea is to make the structure sufficiently strong to withstand the loads that will be applied to it. Loads and structural strength are, however, to some extent unpredictable and this is where the risk comes in. To reduce the risk of collapse to an acceptable level, safety factors; ratios between calculated strength and applied loads are introduced and stipulated in building codes. Refurbishment and adaptation of buildings is to some extent a function of legal regulations and the ways in which they have been interpreted /applied in the past and the way they are being applied today (Kincaid, 2002). The practical legislation in the UK is complex, with more than 150 statutory measures for regulating the built environment. Some of the major areas of legislation particularly relevant to the refurbishment of buildings are:

- Building Act 1984
- Building Regulations 2000
- Fire Precaution Act 1971
- Control of Asbestos at work Regulation 1987 (Asbestos regulations)
- Planning Act 1990 (Listed Building and Conservation Areas)
- Town and Country Planning Act 1990
- Health and Safety at Work Act 1974
Chapter 2 Refurbishment in Construction

- Environmental Protection Act 1990.
- Control of Substances Hazardous to Health Regulations 1994 (COSHH).
- Party Wall Act 1996.

All the above mentioned Acts have a set of regulations which focus on specific issues from a legal point of view. The Building Regulations 2000: Part II, Control of Building Work, clarifies and provides legal requirements to be adhered to, for change in the use of a building. This can be change from one use class to another, for example from a commercial property to a residential use or within the same use, as in the case of division of a commercial property into a set of separate units. The Health and Safety Executive introduced the Construction (Design and Management) Regulations in 1994 to improve safety on construction sites and issued an Approved Code of Practice (ACoP) to give practical advice on how the law is to be complied with when applying CDM regulations. The new CDM regulations 2007 have advocated the role of CDM co-ordinator in place of planning supervisor with more powers assigned to him.

2.6.5 Failure To Appoint A Competent And Experienced Team

One of the most important considerations during structural refurbishment is the appointment of a competent and experienced team (e.g., planning supervisor and temporary works co-ordinator), including checking the competency and proficiency of the designer, contractor and other key professionals involved in the project, and identifying their actual responsibilities. Clancy (1994) has listed specific skills and knowledge required for the structural engineer to perform structural investigations. He advocated that a competent structural engineer should have pragmatic
knowledge of structural theory and knowledge of historic form of construction and about the behavior of materials. Competent specialist contractors and workers on site and their experience is vital for safety in the refurbishment, yet it is recognised that the construction industry tends to employ many occasional workers with limited technical skills and, quite often, poor knowledge of communication language and understanding of safe practices. The workforce has to be properly trained and qualified to carry out refurbishment works (Egbu, 1994). (Anumba et al, 2004) strongly recommend that workers are assessed for their ability to understand procedures and safety instructions that are communicated to them. The project participants involved in refurbishment works have also to be specifically trained on each aspect of the work they are undertaking, for example, structural assessment, design risk assessment, demolition etc..

2.6.6 Errors In Design and During Execution

Errors leading to structural collapse are made by those who design, build or use the structure, or by those who demolish it, refurbish it, or excavate near it. It is essential that these people should have the best information available and the experience to make use of it. Structural engineers responsible for design must understand how the structure works, and this requires a fundamental knowledge of statics, dynamics, material behaviour, structural strength and ductility. There are many chances for mistakes, especially where certain building elements cannot be replaced with exactly the same dimensions and weight to fit the existing space and support the structure (Daoud, 1997). There should always be an independent assessment of a design, assessment of risk as sometimes people responsible overlook sufficient details, consideration of adequate anchorage or bearing distance to allow for construction tolerances. Similarly there are ample evidences where the loads have not been adequately taken into account or because of inadequate understanding of structural behaviour. Unwanted collapses during demolition usually occur. There have been many collapses of walls and other parts of buildings into adjacent excavations. Usually the fault is
obvious, but with some old buildings it is difficult to know what the existing foundations are like. Some of the errors during refurbishments are due to change in dead load or partition loads, possible effects of temperature change, shrinkage, differential settlement, wind uplift or overturning which might lead to progressive collapse. This applies not only to the main structure but also to the temporary supports, and complicates structural refurbishments. Some catastrophic failures during demolition especially of temporary supports, have occurred because previously successful designs have been transferred to new situations or modified on sites, without realising that this may cause a fundamental change in the over-all structural behaviour, for example; collapse of walkway at Hyatt (1981).

2.6.7 Lack of Communication and Flow of Information

Communication of information (particularly risk information) is critical for health and safety management on refurbishment projects. The communication of all the relevant information relating to the existing structure is vital for the development of an accurate structural design (including temporary structures) as well as the selection of demolition methods and the preparation of demolition programmes (Anumba et al, 2004). Similarly the communication of all the information gathered during preliminary investigations is fundamental to understanding the structure and interpreting structural behaviour during adverse situations which might lead to a collapse. Health and safety issues and instructions need to be communicated to workers; this is a particular challenge with foreign workers whose first language is not English. The communication of information through drawing-based method statements and instructions given to workers during site inductions and regular toolbox talks need to be clear and concise especially to overcome language barriers and should be able to capture the attention of the audience (Anumba et al, 2004). Drawings and pictures to represent method statements and work methods have been strongly suggested at various forums. The most important aspect is the continuous flow of information which needs to be maintained between all the project participants.
involved in the refurbishment process. This also includes the need for feedback on unexpected discoveries about the structure and materials as the work progresses.

2.6.8 Misunderstanding About The Load Path

Loads play an important role in how a building is designed and what materials and methods are used in its construction. The identification of how these loads are transferred to various structural components during any structural alterations and structural refurbishments is even more important. There are three main types of loads, known as static, dynamic, and hidden loads. As described below:

**Static Loads**: The first of these, static loads, are more or less constant and consist of both dead load and live load. Dead load is the weight of the building itself, including walls, floors, and roof. Live load is the sum total of what is put onto the building such as snow, people, furniture, equipment etc. (Levy and Salvadori, 2002). If an existing building is being refurbished for a different use or a structural element is altered, the live load may increase, raising the risk of a collapse.

**Dynamic Loads**: Dynamic loads can be described as those acting suddenly, such as those due to high wind and earthquakes (Wearne, 1999; Levy and Salvadori, 2002). The collapse of a adjacent building, explosion in a nearby building, or vehicular impact can also be categorised as dynamic loading, which may cause a sudden change in the load paths or structural capacity of the building’s elements and ultimately result in structural collapse (Building Collapses, 2004).

**Hidden Loads**: Hidden loads, which may not be sudden, can be experienced by buildings due to climatic changes or sudden change in temperature. Steel, concrete and other building material expand from the heat of direct sunlight, and contract when cold (Building Collapses, 2004; Levy and Salvadori, 2002). Humidity can cause adverse changes in the
chemical composition of the building materials. Similarly, fluctuations in the water table beneath a building and variations in ground water level may alter the soil composition and undermine the building’s stability.

Detailed structural investigation to identify the load path is essential before removing any part of buildings to avoid distress to any key elements that might lead to progressive and catastrophic collapse. Buildings components have to deal with these three types of loads and hidden loads and any misunderstanding/miscalculation about load path can lead to structural collapse. The concept of reducing the sensitivity of a building to disproportionate collapse came after the Ronan Point incident of 1968 and the subsequent investigations. The work should include provision of measures to reduce the sensitivity of the building to disproportionate collapse, to ensure that it is suitable for refurbishment and during its intended use after refurbishment.

2.7 Decision Making
2.7.1 Introduction

Decision making is an important aspect of management activity (Mintzberg, 1973) as decision makers are limited in their cognitive abilities to process complex information (Taylor, 1975). Decision making involves the resolution of competing interests between different groups within the client body, and between the professionals with diverse perspectives (Kamara and Anumba, 2000) and are usually the result of discussions and negotiations between those involved. The solutions to problems can be far more accurate, fast and correct if the essential information and data are available to the right people at right time. It has been established that right people with adequate experience and knowledge are often available but the right decision which will then trigger the right responses are not taken at the right times; either because the decision maker could not get complete and correct information or the correct
information was not available/made available to decision maker (Kashyap et al 2005). Making decisions seems a difficult task and thus, people generally believe it is the making of the decision that presents the real problem. Yet the fact is, it is not the decision that is difficult, the difficult part is getting the information on which the decision is based and having certainty that the information is from the reliable source and in correct order of importance. Decisions are mainly taken by the design group consisting of the owner (client), designer, structural engineer, project manager, and site personnel (Alanne and Klobut, 2003). The decision making during refurbishment projects depends on the needs and requirements of the occupants and state of the building. The project participants involved want the authenticity and certainty about the information to be able to make accurate and timely decisions.

2.7.2 The Decision Making Process In Refurbishment

Decision making depends on the process of decision-making itself. Some of the factors responsible for the difficulty in making decisions include: complexity of the choices and environment, multiple and conflicting objectives, the different perspectives of those involved, flexibility and sensitivity to changes, and information flow constraints. Decision making involves the resolution of competing interests between different groups within the client body and between the professionals with diverse perspectives and is usually the result of discussions and information flow between those involved (Yang et. al., 2000). Adding further to the complexity and difficulty in decision making is the lack of certainty that the decision will lead to the desired outcome and results. It is difficult to predict accurately what an individual person will do in a specific hazardous situation. The situation, environment, options available and characteristics of a person can all influence the eventual decision. Young et al (1996) identified three issues for understanding the decision making process in refurbishment:

- Ascertain the major variables that affect effective decision making;
• Ascertain the degree of involvement of key functionaries in the decision making process;
• Ascertain if there are identifiable stages in the process of decision making.

Decision making is not always an easy task particularly with the management of health and safety on a refurbishment project. The decision making process comprises five steps as shown in Figure 2.4.

Renovation and refurbishment are typical forms of construction activities, where an existing situation has an important impact on the planning of the work process (Van Leeuwen et al, 2000). The planning stage offers the widest scope for decision making in comparison with the later phases of the project. Decisions taken at this stage are of particular importance as failure to plan at the early stages would mean 'planning to fail'. Information about structural behaviour needs to be established early and can be obtained from tests and visual inspections. Refurbishment decisions are also influenced by many micro-level factors such as deterioration and obsolescence of a building, indoor environmental quality as well as social and economic factors (Kaklauskas and Gikys, 2003). The problems with the quality of the indoor environment have considerable impact on the refurbishment plan and strategy (Bluyssen, 2000). Decisions taken as part of the planning process are of particular importance as knowledge of the material and information about the structure play a major role in the decision making and offer the widest scope for decision making compared to later phases. Design decisions affect the entire life cycle of a building as they not only affect the construction but also the energy consumption, maintenance and recycling potential and running costs. Design decisions have a large (though mostly
indirect) effect on the entire life cycle of a building as they affect the maintenance and recycling ability as well as the energy expenditure required to run the building. The decisions that are taken during the planning of repair or renovation activities have a direct impact on health, safety and environmental management of projects.

Decisions taken during the construction process have an impact on the overall construction, health and safety and the level of quality achieved. But, with each consecutive stage in the decision-making process, the freedom of choice decreases and the degree of definition and detail increases. Similarly, knowledge of the material and information about the structure play a major role in decision making in refurbishment. There are several factors that need to be considered; the uncertainty and incompleteness of information, the need for engineering judgement, knowledge about the structure, experience with the behaviour of structure, and engineering knowledge to interpret the data and information. During the project life-cycle of a building, different project participants (planners, investors, construction managers, users etc.) make decisions that have direct and indirect consequences on the overall management of the project. The decisions on refurbishment projects pose greater concern and are more difficult to observe and evaluate than the major hazards of the new build as pointed out by Egbru (1996b).

2.7.3 Risk-Based Decision Making Process in Refurbishment

Risk-based decision making (RBDM), also referred to as risk-informed decision making, relies on timely incorporation of important risk related information into an organisation's decision-making processes (Macesker et al, 2003). Traditional management techniques tend to over-strengthen some aspects of the system and insufficiently address others. Risk-based decision making on the other hand, allows to address the uncertainties associated with the process and identify those areas that may be over or under-designed. The analysis of safety levels of new and unique situations can be made and compared with those termed as safe earlier. With these increased insights
into the strengths and weaknesses, comes the ability to prioritise attention on those areas that have the lowest safety levels. Doheny and Fraser (1996) collaborated with psychologists to develop a model of decision making in emergency and proposed that experience, knowledge of the domain and nature of activity will largely determine what course of action will one take.

Risks and uncertainty are inherent in all types of construction (Thompson and Perry, 1992). The field of risk-based decision-making was developed in order to deal with these uncertainties by allowing the uncertainties to be characterized, and integrated into activities such as; planning, design, mitigation of risks, crisis prevention and management. The recent development in the field of risk analysis and risk management, define risk as the exposure to the chance of loss, or the combination of the probability of a hazard occurring and the significance of the consequence of the hazard occurring. Mathematically, this can be interpreted as shown in the following equation:

\[
\text{Risk of a specific Hazard} = \text{Probability of that Hazard} \times \text{Consequence of that Hazard}
\]

Risks can be characterised in terms of probability, consequence and sensitivity to counter-measures susceptibility to risk management measures. and can be rated either qualitatively e.g., low, medium or high or quantitatively. Hazards are potential undesirable events in a given system along with their associated consequences and are characterised in terms of their associated consequence risks, as they incorporate the likelihood of experiencing that hazard. The risk-based decision making process supports the decision maker with source of information, supplying not only the optimal solution, but also insight regarding the situation, including uncertainties involved, objectives, and various other value judgments and assessments of the project partners involved. and is composed of five major components. Risk-based decision making processes have been the subject of a great deal of interest in industry recently, with their ability to encode and incorporate the uncertainties inherent in today's highly complex and variable situations. This
is an iterative, process and may seem to be different, however, after understanding the process and familiarising with the philosophy of risk-based decision making this may appear like another decision making process. Figure 2.5 shows the risk communication throughout the project life cycle between various project participants.

Some of the factors responsible for the difficulty in making good decisions include, complexity of the environment, multiple project participants, different perspectives of those involved, flexibility and sensitivity to changes, information flow, and uncertainty etc. The first step in risk based decision making process is the identification and delineation of a goal. This step, as with every step, should be a group effort, endorsed by group consensus. The critical steps in the process of risk based decision making are discussed next:
Assess the situation: This first essential step requires a thorough understanding of the working environment. Individuals at every level who can make a useful contributions should be involved in the process at the earliest opportunity and specialist advice may be obtained in complex and high risk situations. This requires the identification of potential sources of hazard. This may be done involving designers, contractors and demolition contractors to identify the potential hazards.

Identification of risk: One of the first steps before undertaking risk-based decision making is to understand the fundamental notion about the risk itself. Potential sources of risk on a refurbishment project should be identified and ranked. The information available from the database for relevant and accurate data should be investigated. Difference in education, experience and personal outlook could result in divergent perceptions to risk as suggested by Mansfield and Reyers, (2001).

Risk assessment: Risk Assessment is the process of assessing risks arising from identified risks and ranking them (and/or their components) in terms of risk characteristics. It attempts to provide answers to some questions like, what can go wrong, what is the likelihood that it will go wrong, and what could be the consequences. The risk assessment process in risk based decision making minimises the possibilities and degree of surprises encountered, due to thorough study of the problem and can provide consistent decisions for best outcomes over time.

Risk management: Once a screened and prioritized list of risks has been developed, a risk management action plan can be developed. As the risk countermeasures will vary widely for different situations, no comprehensive list of potential management actions is possible. Generally, risk management attempts to provide answers to the questions like, what can be done, what options are available, what are their associated risks and consequences and what are the effects of current decisions on future options. In order to provide
input for future risk assessments and goal setting and selection, an assessment of the effect of the countermeasures used must be conducted.

**Risk communication**: Effective risk communication is a two-way process that must take place throughout the decision making process. It starts in the assessment process incorporating all risks and not only provides complete set of information for the analysis, but also improves awareness, understanding and subsequent management activities. After identifying risks, it must then be communicated to all the project participants, and urgent items should be forwarded for informational and action/decision purposes. The various team members should then discuss the assessment results and communicate by providing input to management system. The process of communicating risks depends on level of risk, decision making method and its subsequent effect in a particular situation.

The two most important aspects during risk based process is understanding of concept of probability and uncertainty.

**Probability**: The probability of an event can be defined as:

- The ratio of the number of outcomes to the total number of equally likely and different ways;
- The probability of an event is given by the limit of its relative frequency as the number of samples becomes large;
- The probability of an event is the measure of the degree of belief that one holds for that event.

**Uncertainty**: Uncertainties affect every aspect of the refurbishment from design, demolition, construction and maintenance strategies. The variations in material properties, demolition techniques, construction techniques, and methods affect refurbishments to a very great extent. Table 3.2 lists and describes the three types of uncertainties that are typically encountered in structural refurbishment works.
Table 2.1 Three Types of Uncertainties During Structural Refurbishment  
(Adapted from Mascesker et al, 1995)

<table>
<thead>
<tr>
<th>Type</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inherent</td>
<td>• Load pattern</td>
</tr>
<tr>
<td></td>
<td>• Structural Strength</td>
</tr>
<tr>
<td></td>
<td>• Quality and type of material</td>
</tr>
<tr>
<td>Process based</td>
<td>• Availability of Information</td>
</tr>
<tr>
<td></td>
<td>• Quality of information</td>
</tr>
<tr>
<td></td>
<td>• Flow of information</td>
</tr>
<tr>
<td></td>
<td>• Organisational procedure</td>
</tr>
<tr>
<td>Human/Organisational</td>
<td>• Difference in Skill level</td>
</tr>
<tr>
<td></td>
<td>• Ability in decision making</td>
</tr>
<tr>
<td></td>
<td>• training</td>
</tr>
</tbody>
</table>

Risk-based decision making should be incorporated into everyday management activities during all major activities as refurbishments do have inherent risks. The risk-based decision making methods form a process by which decisions can be made regarding safety, stability and maintenance during refurbishment of old structures. With increased group involvement there may be many benefits, such as acceptance of the common goals, better understanding of the goals and increased ability to effectively support goal-related activities. Some of the other benefits from using risk-based methods, are, ability to optimise procedures, regulations, process and resources for a given scenario and set of conditions.

2.8 Decision Support Systems

2.8.1 Definition

Decision support systems (DSS) is the area of information systems (IS) devoted to supporting and improving decision-making. Decision support systems (DSS) are tools that provide support to individuals or teams of people that need to make decisions in a given situation (Arnott, 2006). The concept of DSS were first articulated by Scott Morton in the early 1970s under the term 'management decision systems' (see Scott Morton, 1971).
The classical definition of DSS, provided by Keen and Scott-Morton (1978) describes DSS as:

"Decision support systems couple the intellectual resources of individuals with the capabilities of the computer to improve the quality of decisions. It is a computer-based support system for management decision makers who deal with semi-structured problems".

These definitions were accepted by practitioners and researchers throughout the 1970s. However, by the end of the decade, new definitions started to emerge. Freyenfeld (1984) defined Decision support system as:

"An interactive data processing and display system which is used to assist in a concurrent decision-making process".

Turban (1995) defined such systems as:

"Interactive computer-based systems, which help decision makers utilise data and models to solve unstructured problems".

According to Sprague and Carlson (1982) DSS assist decision makers to confront uncertainties, ill-structured problems, through direct interaction with data, which are able to draw upon a well established pool of knowledge about a given domain to offer advice on how to deal with a technical or business problem. Moore and Chang (1983) disagree about the use of problem structure for defining DSS. They argue that the concept of structure in a problem is not meaningful, because it depends on the user's perception of the structure of a problem. It is unfortunate that the definitions of DSS in literatures do not provide a consistent view, because most of the authors try to put it in a different way, and there seems to be a retreat from the consideration of outputs (e.g., decision quality) to focus on the input instead. To provide a consistent background for the discussion in this thesis a working
definition of DSS has been developed from those provided by Finlay (1994) and Turban (1995) as follows:

"An Decision Support System (DSS) is a flexible and adaptable computer based system that aids the process of decision making capable of providing management information and intelligence. It utilises information, provides a friendly user interface and allows for the decision maker's own insights."

Sprague and Watson (1989) summed up the characteristics to define DSS as:

- That which tend to aim at less well structured, under-specified problems that management face;
- That which can be easily used by non-computer literate people in an interactive mode;
- That which attempt to combine the use of models or analytic techniques with data access and retrieval functions;
- That can be flexible and easily adaptable to address changes in the environment and the decision making approach of the user;
- Being selective in provision of information and avoiding information overload to the user(s);
- User-friendly and able to display information in a format and terminology which is familiar to the user(s).

An important role of a decision support system is to provide information to end users to analyse situations, make decisions and do their job more effectively (Poe et al, 1998; Chau et al, 2002). The DSS are able to draw upon a well established pool of knowledge about a given domain to offer advice on how to deal with a technical or business problem (Sprague and Carlson, 1982; Power 1996). Decision support systems assist decision makers to confront uncertainties, ill-structured problems, through direct interaction with data and information and provide support to individuals or teams of people to make decisions in a given situation. Figure 2.6 presents a generic architecture of a DSS.
2.8.2. Classifications of Decision Support Systems

The taxonomy to classify DSS cannot be exactly pinpointed and thus it is difficult to classify DSS into only one classification. There are several ways to classify decision support systems depending on the design, process, implementation process and types of DSS, and might overlap with another (Turban, 1995). Accordingly DSS can be classified as:

- Institutional versus adhoc DSS (Donovan and Madnick, 1977);
- Data oriented versus model oriented (Alter, 1980);
- Personal, group or organisational support systems (Hackathorn and Keen, 1981).

According to Finlay (1994), the most well-known and widely accepted classification is that of Alter (1980) in which the output of the system is classified with the degree of implication of input or action.
At the system level, Power (1997) classified DSS as Enterprise-wide DSS which are linked to large data warehouses and serve many managers in a company or desktop DSS which are PC based, single-user support systems. Different authors propose different classifications. At the user-level, Hattenschwiler (1999) differentiates DSS as:

**Active DSS:** An active DSS can bring out such decision suggestions or solutions.

**Passive DSS:** A passive DSS is a system that aids the process of decision making, but that cannot bring out explicit decision suggestions or solutions.

**Cooperative DSS:** A cooperative DSS allows the decision maker to modify, complete, or refine the decision suggestions provided by the system, before sending them back for system validation.

At the conceptual level, Power (2002) differentiates DSS as:

**Model-driven DSS:** These type of DSS use data and parameters provided by DSS users to aid decision makers in analyzing a situation, and may not necessarily be data intensive (Gachet, 2004).

**Communication-driven DSS:** These type of DSS support more than one person working on a shared task, for example, integrated tools like Microsoft's NetMeeting or Groove (Stanhope 2002).

**Data-driven DSS:** Data-oriented DSS emphases access and manipulation of internal or/ and external data.

**Document-driven DSS:** These type of DSS manage, retrieve and manipulate unstructured information in a variety of electronic formats.

**Knowledge-driven DSS:** These type of DSS provide specialised problem solving expertise stored as facts, rules or procedures.
Eom (1999) in his longitudinal study about trends and research concluded that influence of organisational science has been diminishing while cognitive science and psychology have emerged as the more influencing contributing disciplines.

2.8.3 Components of Decision Support Systems

Although there is no consensus on a universal definition or classification of the DSS. Many authors (e.g., Sprague and Carlson, 1982; Finlay, 1994; Dixon and Sharda, 1990; Turban, 1995) accept that computer based DSS must contain at least three integrated components: user interface, data management system, and model management system (see Figure 2.7). There can be additional components such as knowledge management system depending on requirements and type of the decision support system.

Figure 2.7 Components of a Decision Support System
(Source: Finlay, 1995; Turban, 1995)

Based on the Figure 2.7 shown above, each component can be briefly elaborated as follows:
• User Interface (i.e. Human-computer Interface) provides communication between user the system. The design of user-interface is a very important aspect of the software development because this affects the user-friendliness of the system.

• Data management provides the core for the registration of problem data. It further includes database(s), which manage storage, modification, retrieval and presentation of relevant data (Turban, 1995). These data may come from different sources such as; internal data (e.g., engineering, information, external data (e.g., information from external source like designers, contractors or from any specific authority) or personal data (e.g., rules for specific decision making)

• Model Management includes quantitative models that provide the systems' analytical capabilities. Finlay (1994) provides a definition of the term 'model' as a representative of reality. These models could be mathematical model, financial model or statistical model.

2.8.4 Application of DSS in Construction/Refurbishment Sector

Project participants need significant resources to ensure the safety of structures while taking up refurbishment jobs. Numerous decision support systems have been developed for use in the construction industry and have been deployed in such areas as design, estimating, costing, defects diagnosis, interpretation of geotechnical data, and the selection of foundation types. Some other areas where expert system have been developed are on management training in the construction industry (Saoud 1996) and decision support system for prequalification of contractors developed by Ng and Skitmore (1992). Table 2.3 tabulates some of the potential areas where DSS could be deployed.
Table 2.2 Areas of Application of DSS/ES/KBS in Construction
(Source, Okoroh, 1992)

<table>
<thead>
<tr>
<th>Application Field</th>
<th>Application Areas</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Estimating</strong></td>
<td>• Cost management</td>
</tr>
<tr>
<td></td>
<td>• Estimation and cost prediction</td>
</tr>
<tr>
<td></td>
<td>• Plant selection advice</td>
</tr>
<tr>
<td><strong>Planning</strong></td>
<td>• Crane selection advice</td>
</tr>
<tr>
<td></td>
<td>• Demolition/De-construction techniques</td>
</tr>
<tr>
<td></td>
<td>• Critical path analysis</td>
</tr>
<tr>
<td></td>
<td>• H&amp;S Planning</td>
</tr>
<tr>
<td></td>
<td>• Plant suitability</td>
</tr>
<tr>
<td><strong>Design</strong></td>
<td>• Assess design options</td>
</tr>
<tr>
<td></td>
<td>• Material selection</td>
</tr>
<tr>
<td></td>
<td>• Energy requirements</td>
</tr>
<tr>
<td><strong>Procurement</strong></td>
<td>• Prequalification of contractors and sub-contractors</td>
</tr>
<tr>
<td></td>
<td>• Selection of Contractors</td>
</tr>
<tr>
<td></td>
<td>• Bid management</td>
</tr>
<tr>
<td><strong>Construction</strong></td>
<td>• Materials management</td>
</tr>
<tr>
<td></td>
<td>• Resource management</td>
</tr>
<tr>
<td></td>
<td>• Site layouts/site logistics</td>
</tr>
<tr>
<td><strong>Building monitoring</strong></td>
<td>• Defect diagnosis</td>
</tr>
<tr>
<td></td>
<td>• Energy consumption</td>
</tr>
<tr>
<td></td>
<td>• Post project monitoring</td>
</tr>
<tr>
<td><strong>Training</strong></td>
<td>• Training requirements</td>
</tr>
<tr>
<td></td>
<td>• Skill enhancement and expertise</td>
</tr>
</tbody>
</table>

Some of the recently developed decision support systems exclusively for refurbishment sector are EPIQR, TOBUS, INVESTIMMO, XENIOS, MoPMIT (see Table 2.4) are discussed below:

The main objective of EPIQR (Energy Performance and Indoor environment Quality Retrofit) was to develop an evaluation tool to assess retrofitting needs, costs and planning needs with respect to optimisation of energy consumption for refurbished facility. It is a computer based multi-media program primarily for existing apartment buildings to be used at inception as well as during the retrofitting and refurbishment process.

TOBUS (A decision-making Tool for selecting Office Building Upgrading Solutions) is another decision support system which aims to provide decision
support for; costs for strategic facility planning, compliance with laws and regulations, predictions for future retrofit needs.

INVESTIMMO (A decision-making tool for long term efficient investment strategies in housing maintenance and refurbishment for residential buildings) is another decision support tool to assist users in decision making process for long-term financial investment strategies to owners of large stock of apartment buildings. The software provides support to decide which buildings and components should get priority for investments.

XENIOS (An audit tool for promotion of renewable energy sources (RES) and rational use of energy (RUE) for hotel buildings) is a multimedia software for making assessment about the most cost-effective energy efficient renovation practices. Some of the other decision support system recently developed in construction/refurbishment are tabulated in Table 2.4.

Table 2.3 Recently Developed DSS for Construction and Refurbishment Sector

<table>
<thead>
<tr>
<th>Author / Researcher</th>
<th>DSS Tool</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cacavelli et al (2000)</td>
<td>INVESTIMMO – A Decision-Making Tool For Long Term Investment Strategies For Maintenance And Refurbishment (For Housing)</td>
</tr>
<tr>
<td>Dascalaki et al (2001)</td>
<td>XENIOS – A Decision Making Methodology And Software For Refurbishment Scenario (For Hotels)</td>
</tr>
<tr>
<td>Kumaraswamy and Dissanayaka, (2001)</td>
<td>DSS For Building Project Procurement</td>
</tr>
</tbody>
</table>
Chapter 2 Refurbishment in Construction

<table>
<thead>
<tr>
<th>Authors</th>
<th>Decision Support System</th>
</tr>
</thead>
</table>

2.9 Justification For A Decision Support System For Structural Refurbishment

During the building project life cycle, different stake-holders such as clients, construction consultants, designers, planners, contractors, and site workers make decisions on everyday matters based on their knowledge and expertise. Experience and expertise can be captured and encapsulated in a decision support system that provides a sound technical framework for decision making. This is supported by Mattila et al, (1994) who highlighted the need to develop techniques and tools that management can use to prove their commitment to safety and company’s information system. This affects the degree of confidence the end user can have for ensuring structural stability during the refurbishment activities. The quality of the existing environment has considerable impact on the refurbishment plan and strategy (Bluyssen, 2000). The user’s professional activities in office space, the flexibility and capacity to modify, compliance with regulations, safety of the existing and adjacent structures play a decisive role during refurbishment (Caccavelli,
Refurbishment decisions are influenced by many micro-level factors such as deterioration and obsolescence of a building, indoor environmental quality as well as social and economic factors (Kaklauskas and Gikys, 2003).

The domain of refurbishment projects is ideal for the deployment of a decision support system for many reasons. First, it is an area in which there are numerous safety problems as several collapses over last five years suggest that the management and technical solutions often adopted in these projects are inadequate. The explanations presented by earlier research by Levitt and Samelson (1987), Landeweer et al (1990), Okoroh (1992), Egbu (1996) reveal lack of experience, knowledge, training, organisational factors, type of job, lack of decision support and management strategies. Secondly, avoiding structural collapse in refurbishment projects requires a considerable degree of expertise and experience that is often not readily available, particularly on small scale projects.

Other reasons for seeking to develop a DSS for this domain include: the need to build on the findings of Anumba et al (2004) and the need to develop a practical tool that both clients and industry practitioners can readily utilise to improve safety in refurbishment projects. It is intended that the proposed decision support system would assist project participants by providing proactive measures and timely information for decision making and serving as a useful training tool for inexperienced workers involved in structural refurbishment projects.

2.10 Summary

The chapter highlighted the problems associated with structural refurbishments and causes for structural collapses. The notion of decision making and the nature of decisions themselves are changing due to the requirements and implementation of new technologies. If the prospective
team members have all the required information the decision can be made easily and correctly. The complexities associated with refurbishment works can be resolved, through a decision support system that can be used by project team members to help them decide on courses of action in situations where there is uncertainty either before or during the refurbishment works. The chapter highlights the absence of any standard process model and need to have a decision support system to tackle the problem of collapses during structural refurbishments.
CHAPTER 3

RESEARCH METHODOLOGY

3.1 Introduction

This chapter provides an introduction to general research methodologies and presents an overview of the methodology used for this research. The first part of the chapter examines the philosophical perspective and underlying principles of the research process. The second part presents a critical review of the research methods used in the field of construction management and information systems studies. It also describes different research methods to justify the choices that have been made in the selection of an appropriate research strategy. The chapter ends with a description of the research methods adopted and demonstrates how it justifies to achieve the research objectives.

3.2 Research

Research can be defined as the way a researcher thinks about the development of knowledge (Saunders et al, 2003). Research can be generally divided into work which discovers and describes existing reality (exploratory research) or which aims at creating a new reality (e.g., new process or technology) that needs to be developed, evaluated and justified. According to Bourner (1996) and Phillips and Pugh (2000), the important characteristics of any research are that it is based on an open system of
thought, examines data critically and specifies the scope of research. It also limits generalisations. Saunders et al. (2003) clarified research as a 'research onion' and put forward the idea that there are various layers of the onion which need to be peeled off before finalising the research type, research process, research approach, research strategies and research methods (see Figure 3.1). Research philosophy, type, process, approach, strategy and methods for the present study are marked in blue as illustrated in Figure 3.1.
To achieve research objectives, the study should have a detailed design that can be used as a blueprint for collecting observations and data connected to the research as follows:

- Reviewing the field by conducting a literature survey about the field of study;
- Concept building to identify what the research is about and why it is being done;
- Theory testing which justifies the relevance and validity of the proposed solution of the research;
- Reflection and integration to evaluate the importance of contributions made to the discipline by research.

### 3.2.1 Research Philosophy

There are two philosophies that appear to dominate the research in construction management - the positivist approach and the interpretivist (otherwise known as Phenomenological) approach (Love et al, 2002). Weber (2004) examined how positivism and interpretivism supposedly differ in terms of their various theoretical assumptions. According to Weber (2004) positivists supposedly believe that reality is separate from the individual who observes it and generally, attempt to test theory to increase the predictive understanding of phenomena and to build knowledge of a reality that exists beyond the human mind (Myers, 1997). Then, there is post-positivist research which is a further development of positivist ideas where results are considered to be true when all procedures to establish validity are exhausted (Guba and Lincoln, 1994).

On the other hand, interpretivists believe that reality and the individual who observes it cannot be separated. Interpretive research assumes that reality can be constructed as human beings interpret reality through language, consciousness and shared meanings (Fellows & Liu, 2003). Boland (1985;
1990) defines *hermeneutics* and *phenomenology* as the philosophical base for interpretive research. Hunter (2001) relates hermeneutics to asking the question about what is missing and what is false, and recognising the human capacity to interpret in a variety of ways. Phenomenology research seeks to understand human experience and phenomena through description of live experiences using variety of methods such as: interviews, discussion and participant observation (Hunter, 2001). Weber (2004) believes the difference between the two methodologies lie more in the choice of research methods rather than any substantive differences at a theoretical level. Researchers employing positivist methodology utilise experiments, surveys, and field studies as research methods in their work. Interpretivists, on the other hand, tend to use case studies, ethnographic studies and phenomenographic studies as research methods.

### 3.2.2 Research Type

Within the broad definition, research can be categorised as *pure* research or *applied* research. These terms borrowed from the scientific lexicon, refer to two end of a linear continuum; ‘pure’ is closer to an idea, and ‘applied’, closer to application. Pure research is for the sake of curiosity and to advance knowledge for its own sake, while applied research is for the sake of technological advancements. Pure research generates new ideas and applied research takes these ideas to create new inventions and develop commercially viable goods or processes (Alberta Online Encyclopaedia, 2006).

### 3.2.3 Research Process

Research process could be classified as *cross-sectional* or as *longitudinal*. Cross-sectional research involves the measurement of all variable(s) for all cases within a narrow time span so that the measurements may be viewed as contemporaneous. Essentially, data are collected at only one point in time, on several variables (Baltes *et al*, 1988; Creswell, 1994). In contrast,
longitudinal research involves study of one or more groups of participants studied at several points in time, generally following a cohort to investigate developmental variables and data are collected in a forward direction over time on one or more variables (Powers and Knapp 1995).

3.2.4 Research Approaches

Two types of research approaches could be adopted, which can be classified as *deductive* or *inductive*. Deductive research moves from general ideas/theories to a specific situations, while inductive research moves from particular situations to make broad general ideas/theories. Seymour and Rooke (1995) suggested that much of the research undertaken in the construction management field till early nineties was formulated on deductive theory testing. However, there has been a trend towards inductive research methods, which has been advocated by Brensen (1986) and Parke (1993). Parke (1993) argues that distinguishing deductive from inductive is untenable and unnecessary as the process of on-going theory advancement requires continuous interplay to lessen the gap between what is already known and which can be known through research. Miles and Huberman (1984) also state that inductive and deductive research approaches are dialectical and not mutually exclusive.

3.2.5 Research Strategy

Greenfield (1996) defines research as an art aided by skills of enquiry, experimental design, data collection, measurement and analysis, interpretation and presentation. The research strategy is a plan of how to answer the research question and contains clear objectives derived from the research question (Saunders *et al.*, 2003) and paves the way to achieve research objectives (Naoum, 1998). It could be based either on *qualitative* or *quantitative* methods or a combination of both, called the *triangulation* method (Denzin, 1978).
The choice of a research strategy depends on the purpose of a given study and the availability of the required information. The following section briefly describes the main characteristics of these three research strategies.

3.2.5.1 Qualitative Research

Qualitative research method seeks to understand how people interact with the world (Fellows and Liu, 2003). This strategy was developed in the social sciences to enable researchers to study social and cultural phenomena (Myers, 1997). Qualitative research involves the use of qualitative data, from case studies, interviews, to understand and explain a phenomenon. It is concerned with the development of concepts rather than applying pre-existing concepts (Wilson, 2000). It can be found in many disciplines and fields, using a variety of approaches, methods and techniques (Myers, 1997). Its data sets are relatively small scale (O’Leary, 2004) and mainly non-numeric, such as in the form of text and image (Punch, 1998). This is because qualitative research aims to investigate and gain insight into the beliefs, understanding, views and opinions of the people involved in depth rather than in breadth (Fellows and Liu, 2003). The tools for qualitative research are action research, case study, ethnographic research and grounded theory (Myers, 1997). Different types of qualitative research methods such as grounded theory, action research, case study research and ethnography are discussed in more detail in Section 2.3. The information gathered during qualitative research can be further classified under two categories, namely, exploratory, and attitudinal research (Naoum, 1998).

Exploratory Research: The central feature of exploratory research is the use of a hypothesis, where either a hypothesis is setup and tested or a complex array of variables is identified and hypotheses are produced to be tested (Fellows and Liu, 2003). Exploratory research is conducted for three inter-related purposes: diagnosing a scenario, screening alternatives and discovering new ideas (Zikmund, 2000).
Attitudinal Research: Attitudinal research is used to subjectively evaluate the opinion, view or perception of a person towards a particular object. The term 'object' refers to an attribute, a variable or a question (Naoum, 1998).

3.2.5.2 Quantitative Research

This type of research adopts scientific methods in which the initial study of theory and literature yields precise aims and objectives, with hypothesis to be tested. This is the most commonly encountered form of formal or conclusive research approach and seeks to gather factual data and studies relationships between facts and how such facts and relationships accord with the theories of previous research (Fellows and Liu, 2003). The quantitative approach essentially involves collecting data and builds upon the developed principles, theories from previous work to decide the data requirements of the particular research project. Different techniques are used to obtain quantified data which are evaluated in the light of existing knowledge (Bryman and Cramer, 1994) and often involving collection and analysis of a large amount of data sets in comparison to qualitative approach (O'Leary, 2001). The data collected in quantitative research are mainly in numeric form (Punch, 1998; Blaxter et al., 2006) and analysed using statistics (Creswell, 2002; O’Leary, 2001). The main approaches used in data collection typically involve questionnaires, structured interviews, carrying out experiments and surveys.

3.2.5.3 Triangulation

The combination of qualitative and quantitative methods is termed triangulation where theories can be developed qualitatively and tested quantitatively. Triangulation involves the use of a mixture of quantitative and qualitative research tools. According to Brewer and Hunter (1989) the fundamental strategy is to tackle the research problem with a combination of methods that have no overlapping weaknesses while complementing with their strengths (see Figure 3.2)
The combination of quantitative and qualitative methods has proved to be effective in many cases depending on the research objectives (Lee, 1991; Cavaye, 1996). Burns (2000) highlighted that the exclusive reliance on one method may bias or distort the researcher's perception about the facts and realities being investigated. Triangulation helps the researcher to eliminate bias in data collection (Creswell, 2002). The combination of methods reduces the disadvantages of one method, and has advantages of the other method (Fellows and Liu, 2003). Generally, triangulation reflects an in-depth understanding of the phenomenon and is usually adopted to clarify meaning, or verify the repeatability of an observation or interpretation (Stake, 2000). Fielding and Schreier (2001) identified three models of triangulation:

**Validity Model:** In this model, triangulation focuses on the validation of results obtained through different methods;

**Complementary Model:** In this model, triangulation means obtaining a large, more complete picture of the phenomenon under study;

**Trigonometry Model:** In this model, triangulation in its original trigonometrical sense indicates that a combination of methods is necessary to gain any (not necessarily a fuller) picture of the relevant phenomenon.

The combination of more than one research methodology in a single study adds rigor, breadth, complexity, richness, and depth to any inquiry (Denzin and Lincoln, 2000; Moore, 2000). The strengths of one method can compensate for the disadvantages of the other. The decision on whether to choose a quantitative or qualitative research method is a philosophical one. While some of these appear to be opposites, it should be clearly understood
that these are two different philosophies, which themselves are not necessarily polar opposites. Although most researchers do either quantitative or qualitative research work, some researchers have suggested combining two or more research methods to investigate a problem (Fellows and Liu, 2003). The combination of quantitative and qualitative research methods provides a multi-dimensional view of the subject, gained through synergy. Bowen (1996) suggested that triangulation could either be deployed simultaneously or in a sequential manner depending on the research design and method. There are four possible research designs that employ both research approaches (Miles & Huberman, 2002):

1. The first design involves both qualitative and quantitative data being collected at the same time;
2. The second design uses a multi-wave survey, conducted in parallel with continuous field work. The first survey wave may raise specific issues which the later field work may then modify;
3. The third design alternates the two methods, one after the other. The first stage employs exploratory qualitative data collection that leads to the adoption of a quantitative data instrument such as a questionnaire. The questionnaire results can be studied in more detail in a further round of qualitative research;
4. The fourth design uses an alternating style but in a slightly different way. First a survey is conducted to point the researcher to a specific phenomenon. Using qualitative research, the researcher develops a strong, conceptual understanding of how things work, supported by quantitative experiment to test the resulting hypotheses.

The distinction between qualitative and quantitative research is not clearly defined. While some writers regard these as fundamentally contrasting, others regard the distinction meaningless (Layder, 1993). According to Moore (2000), it is possible to take a quantitative approach to many issues
which are qualitative in nature or vice-versa; for instance, questions, their analysis and interpretations. Quantitative research differs from qualitative research in the following ways:

- The data is usually gathered using more structured research instruments;
- The results are based on larger sample sizes that are representative of the population;
- The research can usually be replicated or repeated, giving it high reliability;
- The results provide less detail on behaviour, attitudes and motivation.

Some of the other characteristics which differentiate between qualitative and quantitative research are listed in Table 3.1.

**Table 3.1 Comparison Between Qualitative and Quantitative Research**
(Source: Streubert and Carpenter 1995; Naoum 1998; Amaratunga et al, 2002)

<table>
<thead>
<tr>
<th>Qualitative research</th>
<th>Quantitative research</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soft Science</td>
<td>Hard Science</td>
</tr>
<tr>
<td>Primarily interpretive</td>
<td>Primarily Positivist</td>
</tr>
<tr>
<td>Inductive</td>
<td>Deductive</td>
</tr>
<tr>
<td>Subjective</td>
<td>Objective</td>
</tr>
<tr>
<td>Context dependent</td>
<td>Context free</td>
</tr>
<tr>
<td>Develops Theory</td>
<td>Tests Theory</td>
</tr>
<tr>
<td>Imperative</td>
<td>Measurable</td>
</tr>
<tr>
<td>Research questions</td>
<td>Hypothesis</td>
</tr>
<tr>
<td>Reasoning is dialectic</td>
<td>Reasoning is logistic</td>
</tr>
<tr>
<td>Literature review done simultaneously</td>
<td>Literature review done early in study</td>
</tr>
<tr>
<td>Report is narrative with personal interpretations</td>
<td>Report contains statistical analysis</td>
</tr>
<tr>
<td>Phenomenological, grounded theory, Ethnographic</td>
<td>Descriptive, Quasi-experimental</td>
</tr>
<tr>
<td>Nature of data is rich and deep</td>
<td>Nature of data is hard and reliable</td>
</tr>
<tr>
<td>Relationship between researcher and subject is close</td>
<td>Relationship between researcher and subject is distant</td>
</tr>
<tr>
<td>It is attitude measurement based on opinions and views</td>
<td>It is fact-finding based on evidence and records</td>
</tr>
</tbody>
</table>
The key difference between two approaches is that the quantitative research methods focus on quantifying data, while qualitative methods focus on gaining an understanding of the underlying attitudes.

### 3.3 Research Approaches in Information Systems in Construction Management

An information system (IS) is an 'arrangement of people, data, processes and information technology that provides information as output needed to support an organisation (Whitten et al, 2004). The research methods in construction management research attempt to answer real-life questions relating to aspects such as design management, procurement, execution or process of constructed facilities (Stewart et al, 1996). The approach to be adopted for conducting the research in IS in construction management depends on the nature of the investigation and type of data and information that are required and available and strategy of underlying philosophical assumptions about the research design and data collection (Naoum, 1998).

Orlikowski and Baroudi (1991) classified information system research as positivist research if there is evidence of quantifiable measures of variables, hypothesis testing and applying inferences about a phenomenon. Where as (Walsham, 1993; 1995) argues that information systems research could be classified as interpretive studies as it aims at producing an understanding of the context of the information system, and the process whereby the information system is influenced by the context. Various research approaches identified by Galliers (2002), which are used in the study of Information systems (IS) and their typical application in IS research is summarised in Table 3.2
Table 3.2 Approaches in Information System Research  
(Adapted from Orlikowski and Baroudi, 1991; Galliers, 2002;)

<table>
<thead>
<tr>
<th>Research Approach</th>
<th>Application in IS Research</th>
</tr>
</thead>
<tbody>
<tr>
<td>Action Research</td>
<td>• To obtain results of value from groups with whom the research has identified and adding to the base of theoretical knowledge.</td>
</tr>
<tr>
<td>Ethnography</td>
<td>• In designing, testing and evaluation of new information system</td>
</tr>
<tr>
<td>Experimental Research</td>
<td>• To improve the effectiveness of IS in practice.</td>
</tr>
<tr>
<td></td>
<td>• To study the shortcomings.</td>
</tr>
<tr>
<td>Survey Research</td>
<td>• To investigate IS failure or implementation strategies.</td>
</tr>
<tr>
<td></td>
<td>• To study impact of IT and IS on productivity and profitability.</td>
</tr>
<tr>
<td>Future Research</td>
<td>• To study impact of IT and IS in different situations and changing technology.</td>
</tr>
<tr>
<td>Case Study</td>
<td>• To study the benefits and barriers in implementations of IS.</td>
</tr>
<tr>
<td></td>
<td>• To study the impact of IT and IS on organisation and society.</td>
</tr>
<tr>
<td>Longitudinal Research</td>
<td>• To identify the changing relationships and their causes.</td>
</tr>
</tbody>
</table>

Before discussing the chosen research methodology for this study, research methods in IS in construction management research are reviewed and their advantages and limitations are explained as related to this study. In the following sections, each one of these research approaches are reviewed and discussed.

3.3.1 Action Research

Action research is defined as research that involves practical problem-solving which has theoretical relevance. Greenwood and Levin (1998) define action research as, “social research carried out by a team encompassing a professional action researcher and a member of an organisation seeking to improve their situation”. It usually involves not only gaining an understanding of the problem and generating ideas for improvement, but also the practical application of these ideas in a particular field (Humford 2001). In essence action research promotes stakeholder participation in the research process to
improve understanding of problematic events (Stringer 1996). The active involvement by the researcher is essential in order to identify, evaluate problems and find potential solutions in relation to variables based on the response presented (Foster 1972; Dane, 1988; Fellows and Liu, 2003). Action research frequently uses a number of different methods for the collection of data, therefore, a research project using action research methodology may last for several years where the roles of subject and researcher can easily be modified and reversed (Clarke, 1972). Using this type of methodology serves several purposes: it improves stakeholder knowledge and understanding; it enthuses willingness to implement any change arising from the research; it improves general practices within the organisation and it allows modifications of research ideas through direct input by the end-user (Oja and Smulyan, 1989). The advantage of using action research is that practical benefits are likely to accrue as the researcher's bias is made overt in undertaking the research (White, 1985).

3.3.2 Ethnography

This research methodology can also be classified as phenomenological research or the qualitative method of research. It is used to study an intact group over a prolonged period of time by collecting primarily observational data (Wallen and Frankel, 1991). The researcher using this methodology may need to spend a significant amount of time, sometimes months or even years, in the field to observe his/her subjects' behaviour, statements etc., in order to gain an insight into the forms of or reasons for pattern of their behaviour (Fellows and Liu, 2003).

Some researchers, not satisfied with the restrictions of traditional research techniques, often turn to ethnographic research as they consider this approach to be novel and innovative and thus allows them to research a given subject on their own terms. The strengths of ethnographic research lie in the new insights and innovative ideas but weaknesses may arise from the unstructured, subjective nature of the process.
3.3.3 Experimental Research

Experimental research measures the effect of manipulating one variable against another (Keppel, 1991). It is best suited to known problems or issues where the variables involved are identified or hypothesised with some confidence (Fellows and Liu, 2003). There are two approaches to experimental research: laboratory experiments and field experiments. The major strength of the laboratory experiment is the ability of the researcher to isolate and control the variables that can be studied in more depth. Field experiments are an extension of laboratory experiments but not conducted in a conventionally controlled laboratory (Dennis et al., 1991). There is always some difficulty in finding organisations or groups of people prepared to participate and to be experimented on in experimental study.

3.3.4 Survey Research

Survey research uses cross-sectional and longitudinal studies to collect data (Babbie, 1990) to investigate a particular phenomenon by means of a questionnaire or interviews (Leedy and Ormrod, 2001). Surveys are a good means of looking at more variables than is possible with experimental research methods (Gallier, 1992). Survey research operates on the basis of statistical sampling and it is not possible to involve everyone and get a complete picture. Statistical sampling is used to secure a representative sample as it saves money and time (Fellows and Liu, 2003), although other sampling methods e.g., theoretical sampling (Glaser & Strauss, 1967) to examine the pattern of relationship between variables are also possible (Dane, 1988). They can, therefore, provide a reasonably accurate description of a real-world scenario from a variety of viewpoints. However, there is the possibility of bias on the part of respondents as well as on the part of the researcher. The main methods gathering information and data during survey research are by face-to-face interviews or telephone interviews, by using questionnaire or a mixture of the two.
Interviews: An interview is the collection of data through direct verbal interaction between the researcher and the respondent. Interviewing is perhaps the most ubiquitous method of obtaining information from people. Interviews are ordinarily quite direct and a great deal of information is generally obtained from respondents by direct questioning (Emory, 1980; Kerlinger, 1985). It is an appropriate research tool when:

- There is a need for face-to-face contact;
- Immediate responses are desirable;
- There is adequate financial support and the researcher is dealing with a relatively small sample (Lang and Heiss, 1984).

Interviews vary in their nature and can be grouped as: structured, semi-structured, and unstructured (Moore, 2000; Fellows and Liu, 2003). Structured interviews are for large-scale interviewing and require an interview schedule that needs to be designed in the same way as a questionnaire. Semi-structured interviews also rely on an interview schedule, but here the interviewer introduces the topic briefly and then records the replies of the respondents. Lang and Heiss (1984) identify three ways of conducting interviews as:

- Individual interview (one interviewer and one respondent);
- Team interview (two or more interviewers and one respondent);
- Group interviews (a group of people being interviewed by one or more interviewers)

The main advantage of interviews over other research tools, apart from enabling greater communication, is the flexibility to deviate from a set pattern of questions if there is a need to probe other areas of interest instead of relying on routine responses. The drawbacks of interviews include the cost of interviewing in terms of money and time. The information obtained is often difficult to analyse and there can be difficulty in ensuring a high degree of consistency in the presentation of the interview and the interviewer’s bias.
**Questionnaire**: More often than not, the samples are surveyed through a questionnaire which is used for soliciting and recording responses from individuals (Lang and Heiss, 1984). The questionnaire survey is a flexible research tool which not only gives access to dispersed responses from a wide range of respondents, but is also quite accurate and cheap (Rothwell, 1993; Moore, 2000). The questionnaire is impersonal and can be completed by the respondent in his own time, and helps in avoiding any problems which may develop during interaction between the interviewer and the interviewee. The possible disadvantages are the delays in receiving replies, sending reminders and poor response rates (Rothwell, 1993). Another disadvantage is that questionnaire surveys lack qualitative depth to the answers and may result in superficiality.

**3.3.5 Future Research**

In this research method, scenarios and futures are postulated and impacts are identified under different situations (Delone and Mclean, 2003). Various approaches to the design of futures research are:

**Future extrapolation methods**: This method suggests that the future represents a logical extension of the past;

**Exploratory methods**: This method concentrates on identifying possible futures using qualitative descriptions;

**Participatory methods**: This method is based on experts' and stakeholders' opinions and their insight about the future;

**Scenario planning**: This method assumes that the future is unpredictable and modelling will not lead into one future, but rather to different futures, each of which can be described in the form of a scenario;

**Normative methods**: This method investigates what we want the future to be like and how to attain that future goal.
3.3.6 Case Studies

Case studies explore a single entity (‘the case’) and represent an intensive study of a phenomenon, using a variety of data collection sources and tools over a sustained period of time (Yin, 2002). The case study approach is problem-oriented and is applicable to an individual, a group of people, an institution, or a whole community (Lang and Heiss, 1984). Benbasat et al (1987) and Yin (2002) have categorised the case study method as a positivist research in qualitative research. It is quite different from action research as the researcher seeks to study an actual organisational phenomenon, unlike the action researcher who is often involved in planned organisational change (Avison et al, 2001). A selection of case studies may be carried out on the basis of their being representative of similar conditions to those encountered in statistical sampling in order to achieve a representative sample to demonstrate particular facets of the topic or to show the spectrum of alternatives (Fellows and Liu, 2003). They can be single or multiple. The single case study is analogous to a single experiment.

According to Yin (2002) and Creswell (2002), the design of case studies should include five components; (1) the research question, (2) its proposition (3) the analysis, (4) the logic for linking the data to the proposition and (5) the criteria for the data analysis. They are best used in studies that require a deeper understanding of how and why things happen (Yin, 2002) rather than testing the relationships between them (Gordon and Langmaid, 1988).

3.3.7 Longitudinal Studies

Longitudinal studies involve repeated measures on the same variable for the same group on an extended series of occasions (Robson 2002). Longitudinal research uses either discrete time design (in which cross-sectional data is collected on two or more occasions) and continuous time design (where data is collected continuously over a period). There can be three different types of longitudinal studies as suggested by Babbie (1990):
Panel studies: These studies examine the same set of people over time;

Cohort studies: These studies examine a specific sub-population over time;

Trend studies: These studies examine changes within the general population over time.

The key advantage of longitudinal studies is that they bypass the problems associated with a particular point in time. Yet some weaknesses exist, for instance when the same participants are unavailable during follow up measures. This emphasises the need to devise measures which can be repeatedly used on several occasions with the same person (Robson, 2002).

3.3.8 Prototype Development

Avison and Fitzgerald (2002) define the IS development methodology as a collection of procedures, techniques and tools which will help the system developers in their effort to implement a new information system. A specific research method should apply different skills, assumptions and research practices (Myers, 1997) and refers to principles and procedures of logical thought process that are applicable to scientific investigation (Fellows and Liu, 2003). The word prototype has a number of contextual meanings associated with the words 'pattern', 'ideas', 'precursor' and 'exemplar'. Olfman, (1984) clarified that prototyping could be thought of as a process of building a prototype, or building upon a prototype or both. There can be a range of different applications of a prototyping process in the development of information systems but in all cases the implication is that there is more to come besides the prototype. A number of development methodologies are available, but the Information Systems Development life Cycle (SDLC) and the 'Waterfall model' (see Figure 3.3) has been the general approach and basis for development of many IS developments since 1970's (Vidgen et al, 2002).
Basili and Turner (1975) highlighted that capturing end-user requirements is one of the key aspects which needs to be incorporated into prototype developments. Alavi (1984) proposed a detailed assessment of the prototyping approach to information systems development.

### 3.4 Research Methods Adopted and Justification

The choice of research method influences the way in which the researcher collects and interprets data. According to Creswell (2002) the guiding principle for developing any research methodology is that it must completely address the research questions. Tan (2004) explains that research design is not required in non-causal studies which are purely descriptive, mathematical, involve legal principles or software development.

It was considered that a combined research approach would ensure that the focus on the findings is maintained throughout the research life cycle. Quantitative methods like field tests were not relevant, but other quantitative methods such as questionnaires (to refine and evaluate the developed process model and DSS prototype) and interviews were utilised as the
information was mainly to be obtained from personal experience and practices adopted by organisations. Among qualitative methods action research was found to be suitable for development of process model and development of prototype (see Section 3.4.4 and Section 3.4.5). The other qualitative method (case study) was also adopted to address the research objectives.

To meet the research objectives, firstly, a review of the existing literature on health and safety in construction/refurbishment and implementation of decision support systems within construction was undertaken to identify the areas for decision support in refurbishment projects. The literature review drew on the findings of previous research on health and safety in refurbishment involving demolition and structural instability along with current research on decision support systems in the construction industry. This produced findings that identified the potential for development of a convincing decision support system as a decision tool for avoiding structural collapse during the structural refurbishment of buildings.

Semi-structured interviews with industry practitioners and refurbishment/safety experts were undertaken to establish end-user requirements and to elicit general background knowledge. The knowledge gained was then used in the development of a refurbishment process model and the decision support system. Process modelling techniques, based on the Process Protocol, were used to develop the refurbishment process model, which outlines the various stages and the actors involved.

Figure 3.4 shows major research steps undertaken and how the research progressed from the initial stages.
The specific research methods used to achieve the research objectives are as follows:

### 3.4.1 Technology and Literature Review

A review of literature and existing studies is part of the ground-clearing and preparatory work in the initial stages of an empirical research (Hakim, 2000) as it amounts, on average, to between 20 to 25 percent of a thesis content.
(Naoum, 1998). Commonly, a review is associated with 'the literature', it is easy to assume that the only source is written information. However, industry practitioners and interaction with them at various levels has been a very useful and reliable source of information. The document analysis method as suggested by Tesch (1990) was adopted for the qualitative review of literature. The literature review in the early part of the research helped in defining the broad aim and objectives of this research, investigating various issues relating to complexities and the nature of problems during refurbishment, as well as how decision support systems can facilitate refurbishment projects. Some of the major tasks during the literature review included:

- A detailed literature review of refurbishment projects to assess health and safety issues during the planning and design stages of refurbishment projects;
- A literature review on the available decision support systems and potential applications of these tools during refurbishment.
- Review of documents, completed project reports and guidance notes from organisations such as the BRE, CIRIA, HSE, SCOSS and IDE.

The literature review helped in delimiting the research under investigation, in identifying the research approaches to avoid errors in planning and identifying new sources of information. It was established that effective communication and support for decision-making can help structural refurbishment projects to be safer and more successful. The sources were mainly journals, conference papers, research reports and the Internet.

3.4.2 Review of Decision-Making Process and Decision Support Systems in Refurbishment

This task involved reviewing the decision-making process. Established survey techniques such as semi-structured interviews, structured questionnaires and interviews with key professionals involved with
refurbishment projects (see Chapter 4) were used to study the decision making process and to identify the decision support required at various stages of the refurbishment project life cycle. The interviews served two main purposes: firstly to reinforce the findings of the literature search by gathering the views of the key professionals on refurbishment projects and secondly to obtain insight into:

- Identifying the knowledge gap and establishing the need for a decision support tool;
- Current strategies and health and safety practices during refurbishment projects;
- The decision making process and the abilities and difficulties associated with structural refurbishments as well as the identification of areas which need decision support;
- Key enablers for decision-making on refurbishment projects and end-user requirements for the decision support system.

3.4.3 Case Studies and Documents Investigation

Yin (2002) defines a case study as an empirical enquiry that investigates a contemporary phenomenon within real-life context. Different researchers have tried to distinguish between various types of case studies (see Stake, 1994; Hakim, 2000; Yin, 2002). The case studies in the context of this research fall under two categories (see Table 3.3)

**Descriptive case studies**: The first set of five case studies of refurbishment sites sought to identify management practices and problems associated with structural refurbishments;

**Historic case studies through document Investigation**: A second set of five historic case studies were considered where collapses had occurred during structural refurbishments.
Table 3.3 Case Studies Details

<table>
<thead>
<tr>
<th>Type of Case Studies</th>
<th>No. of Case Studies</th>
<th>Companies Contacted</th>
<th>No. of Semi-structured Interviews</th>
</tr>
</thead>
<tbody>
<tr>
<td>Descriptive Case Studies</td>
<td>5</td>
<td>5</td>
<td>10</td>
</tr>
<tr>
<td>Historic Case Studies</td>
<td>5</td>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>

3.4.3.1 Descriptive Case Studies

Descriptive case studies attempt to present a complete description of a phenomenon (i.e. the study of various causes for structural collapse, involvement of project participants during decision making) within the context of structural refurbishments. A multiple-case study approach as suggested by Galliers (2002) was adopted. This was more appropriate as the research involved the investigation of causes of structural collapses, current practices for structural refurbishments and for capturing end user requirements for the decision support system. The details of the case studies are described in Chapter 4. The case studies involved semi-structured interviews with 10 senior staff from five companies to ensure that a comprehensive view was obtained. This involved people with different background and positions to avoid truncation of information and bias. The different interviewees included, project manager, structural engineer, H&S consultants, demolition contractors, planning supervisors, and inspectors from Health and Safety Executive. A short briefing about the project aim and scope of the project were given to the interviewees to avoid any misinterpretation and misunderstanding. Each interview lasted for about two hours and interviewees were specifically asked about:

- Health and safety problems on structural refurbishment;
- Key stages of decision making during refurbishment;
• Involvement of project participants and their role in decision making during various stages of the project;
• Areas for decision support during structural refurbishments;
• End-users' requirements for decision support system

3.4.3.2 Historic Case studies through Document Investigation

Existing records often provide insights into a scenario that cannot be observed or noted in another way. According to Lincoln and Guba (1985) information can be best found in document form. They define a document as 'any written or recorded material' not prepared for the purposes of the evaluation or at the request of the inquirer. This task was undertaken by limited case studies of selected refurbishment projects where collapses had occurred during structural refurbishments. Five case studies provided by the Health and Safety Executive, UK (HSE, UK) were undertaken including detailed review of relevant documents. The historic case studies and document investigation served two main purposes; first to gain an insight into the complexity and difficulties associated with structural refurbishments and second to understand the causes of structural collapses and what could have been done to avoid those collapses. The findings from the case studies are presented in Chapter 4.

3.4.4 Development of Refurbishment Process Model (RPM) and its Evaluation

The action research method was used to identify deficiencies in existing practices. The following tasks and activities related to the refurbishment process model were undertaken:

• Identify the role and involvement of various project participants during various stages of the project;
• Identification of the factors which influence and affect safety in a refurbishment project at each stage of the refurbishment lifecycle. This involved detailed discussions with a select group of senior industry personnel.

• Identification of major activities, sub-activities and role of each project participant during various stages of a refurbishment project life cycle.

• Evaluation of the refurbishment process model with industry practitioners and carrying out further refinements based on the feedback obtained.

The safety-integrated refurbishment process model, using rapid prototyping methods and Process Protocol as a template was developed. The developed refurbishment process model was then validated through interviews, presentations and evaluation workshops with experts and potential end-users. (see Table 3.4). This provided useful feedback via an evaluation questionnaire.

Table 3.4 Details of Participants at Workshops

<table>
<thead>
<tr>
<th></th>
<th>Workshop 1</th>
<th>Workshop 2</th>
<th>Workshop 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Process Model</td>
<td>7</td>
<td>11</td>
<td>31</td>
</tr>
<tr>
<td>DSS</td>
<td>27</td>
<td>7</td>
<td></td>
</tr>
</tbody>
</table>

The evaluations provided useful feedback (see Section 5.7) via a validation questionnaire (see Appendix C) to verify the functionality, acceptance and usefulness of the refurbishment process model. The model went through several iterations with appropriate refinements to improve it.

3.4.5 Development of A Prototype Decision Support System (DSS)

An important element of the research objective was the development of the prototype system (refer to Section 1.4.2). This involved the development of the prototype system based on the refurbishment process model. Interviews
with industry practitioners were conducted to establish the end-user requirements and identify the functional specifications. The development of the decision support system was driven by a collaborative action-research methodology to ensure that the needs and wishes of the end users were reflected and presented in the final product development. The process of prototyping is shown in Figure 3.5.

![Figure 3.5 Prototype Development Process](image)

The software was a bespoke development for a server-based software where the Graphical User Interface (GUI) was developed in Microsoft Visual Basic and the back-end database in MS Access. Chapter 6 presents the development, operation and evaluation of the DSS prototype.

### 3.4.6 Refinement and Evaluation of Prototype DSS

According to Preece et al (1994; 2002), evaluation is concerned with gathering data about the usability of a design or product by a specific group of people within a specified environment or work context. The developed systems need to be validated to identify the shortcomings and improvements. The next step is to evaluate the system for its appropriateness and further refinements. User comments and recommendations contribute to continued improvement until a reliable prototype is developed.
This is why it is essential to perform a thorough system evaluation to test the system design and functionality of the prototype using relevant end users (Miles et al, 2000). The main objective of the final system evaluation was to test the applicability of the decision support system in a 'real environment', evaluate its effectiveness, and identify the scope for further refinement. The developed prototype system was evaluated in two stages. The first stage involved the evaluation of the prototype system during the development stage at a workshop where decision support system was presented to construction professionals and a formative evaluation conducted (see Section 6.5). The feedback was collected by means of a questionnaire (see Appendix D) completed at the end of the software demonstration. The responses were noted and, where appropriate, the prototype DSS was modified in line with the critical feedback received. At the second stage, the DSS was presented to industry practitioners followed by a hands-on experience of using the software. The feedback was again obtained through an evaluation questionnaire. The prototype evaluation and evaluation result is described in detail in Chapter 6.

3.5 Summary

In this chapter basic concepts and principles relating to research philosophy and methodology were reviewed. The first part of this chapter presented general research methodologies, while the second part presented the research methods adopted in order to realise the aim and objectives of the research. The research adopted several approaches through five main sections: literature review; knowledge acquisition through case studies and document investigation; process model development; validation of the process model; prototype development and evaluation of the prototype system. The next chapter presents an overview of structural refurbishments, causes of structural collapses and a discussion of existing practices along with considerations for safer refurbishment.
4.1 Introduction

This chapter presents case studies undertaken as part of the study into structural refurbishments. Two types of case studies; descriptive case studies and historical cases were undertaken. These are analysed separately to explore and obtain deeper insight into the challenges and opportunities provided by structural refurbishments. The chapter presents details of the case studies, outlines the findings of the studies, and concludes with a discussion of the key considerations for structural refurbishments.

4.2 Case Studies

The second and third objectives of the research were to review the strategies adopted, identify areas that need support during structural refurbishments and establish end-user requirements for a decision support system. The case study method was selected because it enables an in-depth, empirical investigation of a contemporary phenomenon within its real-life context, especially when the boundaries between the phenomenon and the context are not clearly evident (Yin, 1994). In this research two types of case studies have been conducted:
1. **Group I**: Descriptive case studies were conducted using semi-structured interviews to identify the problems and strategies adopted on structural refurbishment projects and to establish end-user requirements for the DSS.

2. **Group II**: Historic case studies which had involved premature collapses were examined to identify the causes of collapses on refurbishment projects.

### 4.3 Descriptive Case studies (Group I)

Five case studies were undertaken to study the characteristics of structural refurbishment projects, the causes of structural collapses, learning situations, the roles of project participants, the involvement of key project participants in decision-making, and the end-user requirements for a decision support system. The approach adopted for case studies was the one proposed by Brookes and Backhouse (1998) and consisted of an initial contact with interviewees, semi-structured interviews, a review of the relevant documents, and discussions to clarify any unclear issues. The case study companies included demolition contractors, design consultants, consultants, contractors and enforcement agency, for example HSE.

**Composition of Case study Companies**

The five case study companies comprised:

- A design consultancy firm
- A demolition contacting firm
- An engineering consultancy firm
- A contracting firm
- A H&S enforcement organisation

The choice of these organisations was based on their background and the willingness of the individuals to make information available to enable the research project to obtain the required information. The interviewees
participating in the study were experienced construction professionals with between 4 and 35 years experience of managing construction/refurbishment projects. The details of the case study companies and the background information about the companies and interviewees are presented in Table 4.1.

Table 4.1 Background of the Case Study Companies

<table>
<thead>
<tr>
<th>Company</th>
<th>Position and Role of Interviewee</th>
<th>Area of Operation</th>
<th>Number of Employees</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Director</td>
<td>Demolition Contactors</td>
<td>140</td>
</tr>
<tr>
<td>B</td>
<td>Associate</td>
<td>Design consultants</td>
<td>300</td>
</tr>
<tr>
<td>C</td>
<td>Planning Supervisor / Senior Design Manager</td>
<td>Consultants</td>
<td>550</td>
</tr>
<tr>
<td>D</td>
<td>Project Manager / H&amp;S Advisor</td>
<td>Contractors</td>
<td>800</td>
</tr>
<tr>
<td>E</td>
<td>H&amp;S Principal Inspector / H&amp;S Inspector / H&amp;S Inspector</td>
<td>Enforcement Agency</td>
<td>1500</td>
</tr>
</tbody>
</table>

These companies/organisations are different in terms of their nature of business and role on construction/refurbishment projects. The varied backgrounds provided the opportunity for exploring the variations in their understanding of problems during structural refurbishments and identifying their roles at various stages of a project. This helped to prevent bias and ensure that various perspectives were obtained from the case studies. The analysis of the case studies was geared towards achieving the research objectives to investigate the potential for improving structural safety through a structured refurbishment process model and a decision support system. Semi-structured interviews were used based on the template shown in Appendix B. The interviewees were questioned under five main sections:
1. Health and safety problems on refurbishment projects;
2. Key stages of decision-making during refurbishments;
3. Roles and responsibilities of key project participants during refurbishments;
4. Key areas that need decision support; and
5. End-users' requirement for a decision support system.

4.4 Findings from the Descriptive Case Studies

The case studies represent the collective views of these construction professionals and their experience with refurbishment works. The findings from all case study companies are combined and presented under the following subheadings:

4.4.1 Health and Safety Problems on Refurbishment Projects

This explored the most significant problems pertaining to health and safety on the refurbishment sites. The interviewees pointed out that H&S plans and method statements are difficult to produce on refurbishment projects, due to the number of unknown factors and unexpected findings. For example, asbestos and lead are sometimes only found during the actual refurbishment works. Some of the problems affecting health and safety on a refurbishment project identified by these professionals were:

- Inadequate information about the structure and unplanned discoveries;
- Risks from the existing building materials and contaminations;
- Absence of a health and safety plan during the bidding stage;
- The workforce's competence, pre-qualification and selection criteria; and
- Communication of project-related health and safety information.
All the interviewees pointed out that refurbishment projects are more difficult to manage. There was consensus between the findings from the case studies and the findings from the literature review (Koehn and Tower, 1982; Egbu, 1996). Egbu (1995) states that the most difficult tasks in refurbishment, according to managers, are management of various risks, uncertainty about the structure, forecasting and planning. The interviewees revealed that there is incomplete information about the structure, which coincide with the identical findings by Daoud (1997).

4.4.2 Key Stages of Decision-Making during Refurbishment

Most of the interviewees could identify key stages during the refurbishment, but found it difficult to identify specific decision making opportunities. This stated, it was difficult because all the stages have the potential for some decisions to be made. They, however, admitted that there is a need to improve the management of information and decision-making ability during structural refurbishments. During interviews, it was revealed that refurbishment projects invariably have incomplete information due to missing design documents and drawings, thus making it difficult to make decisions with inadequate and incomplete information. The decision-making methods should enable the decision maker to make the decision that will be the most effective and appropriate. The key stages during decision-making begin right from the conception stage. Refurbishment design poses a number of specific problems as opposed to new design. The key decision making stages identified by the interviewees were as follows:

1. Conception of need
2. Feasibility stage
3. Preliminary design stage
4. Detailed design stage
5. Procurement stage
6. Actual refurbishment stage
7. Post-refurbishment stage
The average number of project participants in refurbishment projects is higher as there are more specialised sub-contractors required (Holm, 2000). Okoroh and Torrance (1996) in their study of refurbishment projects in the UK, pointed out that the most important cause for the noticeable increase in subcontracting may be the unpredictable nature of refurbishment works. As there are more participants involved in refurbishment projects, the need and opportunity for decision-making increases. Project managers pointed out that the ease of safety implementation/influence safety is inversely proportional to the cost of implementation of safety during a project's life cycle (see Figure 4.1).

![Figure 4.1 Safety Decision Making during Project Life Cycle](image)

Some key decision-making areas during refurbishment works, developed from the literature review and during interviews while undertaking case studies, are listed in Table 4.2.
Table 4.2 Activities, Sub-Activities and Potential Decisions-Making Areas During Refurbishment (Source: Anumba et al, 2006)

<table>
<thead>
<tr>
<th>Activity</th>
<th>Sub-activity</th>
<th>Potential Decision Making Areas</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maintenance</td>
<td>• Identify need for rehabilitation/maintenance</td>
<td>• Decision whether project involves any demolition/structural alteration/modification</td>
</tr>
<tr>
<td></td>
<td>• Formulation of user requirements.</td>
<td>• Decision on scope of refurbishment.</td>
</tr>
<tr>
<td></td>
<td>• Constant renewal and maintenance of construction elements.</td>
<td>• Choice of safest design option.</td>
</tr>
<tr>
<td></td>
<td>• Invite offers, tenders.</td>
<td>• Frequency of periodic maintenance of building and systems.</td>
</tr>
<tr>
<td></td>
<td>• Structural appraisal.</td>
<td>• Choice of best available technologies if parts of the building control system have to be replaced.</td>
</tr>
<tr>
<td></td>
<td>• Maintenance and renewal of building control systems.</td>
<td>• Selection of building materials.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Selection of procurement method.</td>
</tr>
<tr>
<td>De-construction, Demolition</td>
<td>• Elaboration of a deconstruction concept.</td>
<td>• Decision about rehabilitation/deconstruction or Demolition.</td>
</tr>
<tr>
<td></td>
<td>• Invite offers, tenders.</td>
<td>• Selection of demolition techniques.</td>
</tr>
<tr>
<td></td>
<td>• Execution of de-construction/demolition.</td>
<td>• Decision about recycling potential</td>
</tr>
<tr>
<td></td>
<td>• Separation of construction elements.</td>
<td>• Selection of de-construction methods.</td>
</tr>
<tr>
<td></td>
<td>• Evaluation of risks.</td>
<td>• Selection of contractor/sub-contractors.</td>
</tr>
<tr>
<td></td>
<td>• Scope of recycling.</td>
<td>• Scope of structural assessment and techniques.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Selection of procurement method.</td>
</tr>
<tr>
<td>Disposal/Recycling</td>
<td>• Disposal/Recycling.</td>
<td>• Decision about recycling potential of different construction materials.</td>
</tr>
<tr>
<td></td>
<td>• Separation of re-usable material.</td>
<td>• Decision regarding options available for disposal and recycling.</td>
</tr>
</tbody>
</table>

The stages identified above were utilised in developing the process model for refurbishment (see Chapter 5). The most common decision-making methods therefore work through a facilitating process involving various project participants and allowing each party to come up with the various available options.
4.4.3 Roles and Responsibilities of Key Project Participants During Refurbishment

During the case studies, it was revealed that the roles and responsibilities of project participants on a refurbishment project are different from new build projects and might be overlapping. Interviewees were asked to identify the role of project participants and responsibilities during various stages of a refurbishment project. The roles and responsibilities of key project participants are described in Table 4.3.

Table 4.3 Roles and Responsibilities of Project Participants at Various Stages

<table>
<thead>
<tr>
<th>Project Participant's Role</th>
<th>Whether involved in Decision-Making</th>
<th>Involvement Stage</th>
<th>Responsibility</th>
</tr>
</thead>
<tbody>
<tr>
<td>Client</td>
<td>Yes</td>
<td>FS, PRS</td>
<td>• Appointment of Planning supervisor/CDM co-ordinator;</td>
</tr>
<tr>
<td>Architect</td>
<td>Yes</td>
<td>FS, DS</td>
<td>• Prepare conceptual design and detailed Design;</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Design Risk assessment;</td>
</tr>
<tr>
<td>Planning Supervisor</td>
<td>Yes</td>
<td>FS, DS</td>
<td>• Prepare Pre-tender H&amp;S Plan;</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Develop temporary structure design;</td>
</tr>
<tr>
<td>Structural Engineer</td>
<td>Yes</td>
<td>FS, DS, ES</td>
<td>• Conduct Structural appraisal;</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Communication of risks arising out of any changes/surprises during structural investigation;</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Design Risk assessment;</td>
</tr>
<tr>
<td>Project Manager</td>
<td>Yes</td>
<td>PS, ES, PRS</td>
<td>• Manage project safely;</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Compliance with legislation;</td>
</tr>
<tr>
<td>Contractor</td>
<td>Yes</td>
<td>PS, ES, PRS</td>
<td>• Prepare, develop and implement H&amp;S Plan;</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Appoint competent and experienced contractors;</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Prepare Safety method statements;</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Workforce supervision;</td>
</tr>
<tr>
<td>Demolition Contractor</td>
<td>Yes</td>
<td>FS, DS, ES, PRS</td>
<td>• Selection of suitable technique and equipment for demolition;</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Communication of H&amp;S risks during demolition;</td>
</tr>
</tbody>
</table>

FS Feasibility Stage; DS Design Stage; PS Procurement stage; ES execution stage; PRS Post refurbishment stage.
The specific roles of different project participants in a refurbishment project are discussed below.

**Client**

The client should allow adequate time for the completion of all the preliminary structural investigations and assessments and involve themselves in the avoidance of conflicts and complexities arising from any simultaneous activities. The basic demands and requirements during a refurbishment project remain similar to new construction, even though different clients act in different ways. Clients can be classified into the following three categories:

- Property developers, who develop and refurbish old properties and are more focussed on the return on their investment but usually have a team of consultants and professionals;
- Regular clients of the construction industry who want to add to their existing capacity from a purely commercial point of view. Such clients can exert considerable influence over the parties involved in the construction process.
- Occasional one-off clients, who do not know enough to manage projects, but tend to manage the jobs themselves to keep the project costs low. They may engage the services of specialists depending on the scope and complexity of the project.

Health and safety inspectors stated that contractors are unaware of the actual scope of the work and whether it involves any removal of, or alteration to, the structural members.

**Planning Supervisor/ CDM Co-ordinator**

The role of the Planning Supervisor is mainly concentrated on the design and planning phase of a refurbishment project. The Planning Supervisor is responsible for preparing the health and safety plan for the project. The new CDM Regulations (2007) have changed the role to be that of CDM co-
ordinators who are required to advise clients on the competence of the designer and the contractor, and manage the H&S information flow as well.

**Project Manager**
The role of the Project Manager in a refurbishment project focuses on establishing the right conditions for the effective management and control of the different participants and their work. The project manager is specifically required to oversee the planning of any demolition jobs, the construction implications of design choices and the refurbishment process. The project manager disclosed that there are times when a pre-tender health and safety plan is not available at the time of tendering and hence it is only up to the contractors bidding for the work to estimate the risk and extent of the risk.

**Structural Engineer**
The Structural Engineer has to develop the structural design of the refurbishment project and he/she is required to carry out the preliminary structural surveys. Discussions need to be held with the appointed contractor and subcontractors early in the refurbishment project so that they are fully aware of the structural considerations and the scope of structural alterations during the refurbishment works.

**Contractor**
The contractor is required to select competent sub-contractors and a temporary works co-ordinator. The contractor has to inform the workers and, if necessary, provide training on health and safety prior to the start of the works. Demolition is a specialist activity required to be performed by a specialist demolition contractor. However, the demolition contractors revealed that on many smaller jobs demolition activities are undertaken by the main contractor and they are not always consulted at the feasibility stage. It is important, whoever undertakes the demolition should deploy a skilled workforce to undertake specific demolition activities.
4.4.4 Key Areas that Need Decision Support

This explores the potential of IT tools for decision support to reduce structural collapses. Most of the interviewees agreed that there are grey areas where IT tools could be of great importance and can assist in decision making. However, they were not able to highlight any specific areas. They were then apprised with the decision support tools and how such a tool could be used for context-specific information for the various participants during structural refurbishments. The safety factors, no matter how they are derived, are of little help in preventing collapses resulting from them as most of the times it is the management aspect and safety strategies. One of the designers stated "..before commencing detail design work for any refurbishment works sections of the works that are to be modified should be carefully examined and, assessed for strength and consequences on other components, for example, raising the height of wall, removal of chimney stack can lead to an increased loading", yet works are taken up without carrying out detailed investigation and appraisal of structure. The key areas that need decision support during refurbishments have been identified as:

- Structural appraisal and Investigation;
- Roles and responsibilities of the project participants;
- Identification of tasks and sequence of tasks;
- Health and safety management on site; and
- Communication and information flow.

4.4.5 End-User Requirements for Decision Support

The term 'end-users' was taken to mean those participants in refurbishment projects who would use a potential decision support system. One of the main requirements for the development of a decision support system (DSS) is to establish the end-users’ requirements. This was considered vital as they are the key stakeholders involved on a refurbishment project and can benefit most from the proposed DSS. The interviewees were not sure about how a
decision support system would work but pointed out that the system must address their particular needs and requirements for accessing information for decision making and reflect the fact that there are more project participants involved on a refurbishment project (as pointed out by interviewees in Section 4.4.2). The clients, architects and structural engineers (designers), planning supervisor (project co-ordinator in the new CDM Regulations), the project manager, the demolition contractors and the general contractors were identified as potential end-users of the DSS (see Figure 4.2).

![Decision Support System](image)

**Figure 4.2 End-Users of the Decision Support System**

Interviews with industry practitioners and people from academia were conducted to identify the end-user requirements and develop functional specifications for the system. The potential end users provided a theoretical framework for the systematic investigation into the end-users' requirements and various design development issues in the proposed DSS. The requirements and roles of the end users who require decision support and further guidance can be summarised as follows:

**The Client**
The Client plays the most crucial role in the whole refurbishment process, especially in pre-qualification and the selection of members of the project team (architect, structural engineer, planning supervisor, contractor/sub-contractors) and making decisions about the cost, quality and time-frame. The client has direct responsibility for ensuring the appointment of competent
persons and the production of a health and safety plan for the project. The requirements of clients as end-users of the DSS include the following:

- A reminder of their general responsibilities as the client;
- The duties of the clients under the CDM regulations;
- Guidance on H&S issues that commonly occur on refurbishment projects;
- Guidance on statutory duties imposed on the clients by regulations; and
- Hints on good H&S management practices on refurbishment projects.

The Contractor
The role of the contractor in the management of a refurbishment project covers all the different stages of the process. The contractor has to inform the workers and, if necessary, provide training on health and safety prior to the start of the works. It was pointed out by the interviewees that on many smaller jobs demolition activities are undertaken by the main contractor. The contractor's requirements with respect to the DSS are:

- A reminder of the duties and responsibilities of a contractor with regard to health and safety on a refurbishment project;
- Support in monitoring health and safety aspects during refurbishment activities;
- Information on key issues that might impact decision making during structural instability and demolition sequence;
- Guidance on H&S issues that commonly occur on refurbishment projects.

The Planning Supervisor/CDM Co-ordinator
The principal duty of the Planning Supervisor or CDM co-ordinator in the new CDM Regulation, 2007 is to co-ordinate the health and safety aspects of the project design and planning by preparing the Health and Safety Plan and to ensure that the principles of prevention and protection are adequately applied. The requirements of the planning supervisor/ CDM co-ordinator with regard to support from the DSS include:
Chapter 4 Case Studies in Refurbishment

- Identification of the relevant health and safety regulations and the legal responsibilities of all the project partners;
- A reminder of the roles and responsibilities of the planning supervisor/CDM co-ordinators at different stages of the project;
- Safety guidance in the design of temporary works;
- Identification of the risks involved during demolition and refurbishment;
- Reminder of key safety issues from the preliminary structural surveys; and
- Support in the preparation of the pre-tender Health and Safety Plan.

The Project Manager

There can be a nominated project manager specifically appointed for the job or the client himself/herself, designer, principal contractor or main contractor can act as project manager. However, in all situations, whoever is managing the project as project manager, should not only be aware of his/her duties and responsibilities but should be able to exercise control over day-to-day activities during refurbishment works. The requirements of the Project Manager as an end-user of the DSS include:

- A reminder of the duties and responsibilities of a Project Manager on a refurbishment project;
- Support in facilitating the co-ordination of safety information and communication;
- Guidance on health and safety requirements under the CDM regulations;
- Assistance with risk identification and assessment; and
- Guidance on H&S issues that commonly occur on refurbishment projects.

The Architect/Designer

The role of the Architect/Designer in a refurbishment project involves the design of the refurbishment works. Special attention needs to be paid to any alterations involving load-bearing members. The Architect is also specifically required to evaluate the safety and construction implications of his/her design choices. The architect/designer’s requirements with regard to the DSS include:
• A reminder of the duties and responsibilities of the Architect/Designer with regard to health and safety;
• Assistance with the evaluation of the safety implications of design options and changes;
• Guidance on health and safety issues that commonly occur on refurbishment projects; and
• Guidance on health and safety requirements under the CDM regulations.

The Structural Engineer
The Structural Engineer has to develop the structural design of the refurbishment project and he/she is required to carry out the preliminary structural surveys. These should be assessed and rectified in order to avoid any collapses during the refurbishment works. The requirements of the Structural Engineer with regard to support from the DSS include:

• A reminder of the duties and responsibilities of the structural engineer at different stages of the refurbishment project;
• Guidance on health and safety requirements under the CDM regulations;
• Assistance with risk identification and assessment;
• Guidance on the structural assessments and investigations; and
• Guidance on H&S issues that commonly occur on refurbishment projects.

4.5 Historic Case Studies (Group II)

Five Historic case studies, which had resulted in premature collapses during demolition and/or collapses during structural alterations/removal of building elements, were reviewed to explore and obtain a deeper insight into the areas investigated in this research. The Health and Safety Executive (HSE), UK provided documented case studies of premature collapses during demolition and/or collapses during structural refurbishments involving the
alteration/removal of building elements. Five case studies involving collapses are presented below to highlight the causes of collapses along with findings and recommendations to avoid structural collapses.

4.5.1 Case Study # 1
This case study is about a three-storey terraced building which resulted in the complete collapse of the walls and floors of the building. The building was nearly 150 years old and catastrophic collapse during refurbishment resulted in injuries to many site workers.

Causes of Failure: The failure was due to a combination of the following factors:

- The building was poorly constructed with an inadequate 115 mm thick, load-bearing outer wall;
- The lateral stability of the building was reduced due to the lack of a cross wall at ground level;
- The gable wall had bulged outwards. The extent of the distortion was assessed, but it was understood to have been sufficient for the department of environment to have recommended that it could be taken down and reconstructed;
- There was seemingly no great urgency or priority placed on taking down the gable wall as the owner intended to carry it out after the completion of the other strengthening works;
- Although no main structural element was removed or dismantled, yet, the removal of the floorboards reduced the tortional stability of the old structure;
- There were no drawings available and the contractor was handling the job without conducting any structural appraisal and without any structural engineer to advise on structural safety.
Findings and Recommendations: Lateral ties and lateral support at all levels of the structure, e.g. floorboards need to be checked to:

- Ensure the structure is engineered for lateral stability in all directions. The lateral stability can be achieved by connecting the structural element to a robust member to provide adequate support along with adequately propping and bracing the structure;
- Undertake a detailed examination of the verticality of the walls and careful removal of the walls which have bulged in either direction;
- Realise that it is not uncommon for external and internal walls to suffer deformation due to oblique or lateral loads and absence of sufficient lateral restraint within the structure. Because of these factors, an overloaded section of the wall started to fail through buckling. The external walls needed to be secured to the floor and opposite external walls should have been secured to each other with restraint ties.

4.5.2 Case Study # 2

This case study is about the collapse of masonry wall of a semi-detached building during rebuilding activity on a refurbishment project causing fatal injuries to a person.

Causes of Failure: The collapse of the masonry wall was due to the following circumstances:

- The old masonry wall was constructed without significant ground works;
- The ground had been excavated below the base of the structural wall without ensuring the stability to the adjacent wall;
- There was no check done to ensure condition of the wall and stability.
Findings and Recommendations: The findings and recommendations are as follows:

- Any activity involving significant change to the structure of a building should be planned to take account of the stability of both the load-bearing elements and the whole structure. It should continue for the whole operation to ensure continued stability;
- One of the methods to ensure stability of such walls could be adequate temporary shoring which should be structurally sound;
- It is also advisable that, if foundations need to be exposed to ascertain their load carrying capacity and the only solution, it should be done in short lengths and should be filled up immediately after the excavation.

4.5.3 Case Study # 3

This case study is about the collapse of concrete floor of a semi-detached old building, which occurred during partial demolition prior to refurbishment of the building causing serious head injuries to workers.

Causes of Failure: The floor collapse was due to the following circumstances:

- Failure to understand the nature of the structure where the underside of the floor was not an integral part of the floor. This emphasised that a structural survey should have been conducted prior to taking on any structural modification/alterations by a competent person;
- Absence of temporary supports to support the floor before demolition;
- Absence of a detailed method of working;
- Lack of written method statements and effective communication to those carrying out the works;
Chapter 4 Case Studies in Refurbishment

Findings and Recommendations: The findings and recommendations are as follows:

- Inadequate supervision to ensure that work was carried out in a safe manner during each activity.

- Even though several areas were supported by vertical adjustable props, the lateral ties were found to be missing;

- Failure to understand the structure emphasised that a structural survey should have been conducted to ascertain the way the floor was spanning prior to the removal of any structural member;

- There is a need for the props to be tied together using load bearing couplers in order to provide additional lateral stability to the vertical props.

4.5.4 Case Study # 4

This case pertains to collapse of a three storey semi-detached office building which occurred on 1 August, 1995, in Ashford, Middlesex, UK, killing four construction workers. The building, initially built as a single storey structure in 1969/70, was further extended upwards in 1970 and was being refurbished again when the collapse occurred.

Causes of Failure: The investigations revealed serious defects in the original construction of the vertical extension of the building and raised some wider issues concerning safety of low rise buildings when being adapted for any change of use. Some of the major causes which resulted in collapse of the building are summarised below:

- When the building was extended to three storeys, the lightweight concrete blocks forming the bottom course of the parapet wall were left in position and used to support the load-bearing columns at first floor level;
Chapter 4 Case Studies in Refurbishment

- The collapse was caused by the failure of one or more of these lightweight concrete blocks at first floor level, leading to the sudden and catastrophic collapse of two thirds of the building. The extent of the collapse was further aggravated because of a lack of structural continuity (ties) between key structural elements;

- Structural investigations of the brick columns at first floor level showed no externally visible signs of the lightweight concrete blocks in the columns. They had been effectively hidden by the facing brickwork, internal plaster and the inclusion of in-fill brickwork. These defects at the base of the columns at first floor level could not have been contemplated and therefore could not be detected during the assessment of the structure and how it was constructed;

- The defects discovered in the brick columns in the building reflect either gross incompetence or total irresponsibility on the part of those engaged in the original construction work and its management.

Findings and Recommendations: The HSE report (Ashford Building Collapse - HSE investigating report, 1999) made the following recommendations:

- The project team and their advisers when renovating, refurbishing, extending or demolishing a building, particularly if it was built before the 5th amendment in Building Regulations took effect, should address the possibility that it may not be robust, and that damage to a key structural element could lead to a disproportionate collapse. Whenever this is the case, the risk assessment should include an evaluation of the risks of such a collapse. For instance, if heavy plant is to be used near to key structural elements it may be necessary to provide barriers to prevent contact with the building;

- Planned systems would be needed with crane operations and appropriate propping of the building would be needed before making any structural alterations.
4.5.5 Case Study # 5

This case study is about a semi-structured terraced building which resulted in collapse of walls and floors of the building. The building was nearly 80 year old and collapse during refurbishment resulted in injuries to site workers during the removal of a front bay window.

Causes of Failure: The failure was due to a combination of the following factors:
- The lateral stability of the building was reduced due to the lack of a cross wall at ground level;
- There were no drawings available and there was no structural appraisal done to assess the structural safety and stability
- Failure to ascertain the load-carrying capacity of the existing lintel unit;
- Absence of temporary supports to support the wall ends before removal of the window frame;
- The masonry wall was constructed with shallow foundations.
- The failure to identify the load paths of the wall without ensuring stability and loads coming onto it.

Findings and Recommendations: The findings and recommendations are as follows:

- One of the methods to ensure stability of front walls with bay windows could be to support it adequately with temporary supports.
- Any activity involving structural change with the front bay windows should be planned with identifying load bearing walls and loads coming onto them both from the load bearing elements and the whole structure;
- The external walls could be secured to the internal floors to achieve a degree of lateral restraint.
4.6 Findings From the Historic Case Studies

The accident investigation reports and case studies provided by HSE highlighted a number of health and safety failures that caused collapses (with or without fatalities), because appropriate measures were not taken into consideration. Some of the findings from the study of the accident investigation reports and historic case studies, which had resulted in collapses during structural refurbishment are discussed below:

4.6.1 Absence of Structural Assessment During Refurbishment

Refurbishment works offer good opportunities to upgrade old or install new structural members as an effective means of improving structural safety provided the structure is capable of taking the additional loads. For any alteration, rehabilitation or repair works to existing structures or facilities, the original design documents and all available construction and operation records must be carefully reviewed to obtain a thorough appreciation of the original design principles and structural integrity of the existing works.

One of the designers stated "..before commencing detail design work for any refurbishment works sections of the works that are to be modified should be carefully examined and, assessed for strength and consequences on other components, for example, raising the height of wall, removal of chimney stack can lead to an increased loading". Despite this, refurbishment projects are often started without the benefit of condition surveys to determine the 'as built' information as pointed out in case study # 4. The HSE Investigation Report (1999), HSE Research Report 204 (2004), and SCOSS Reports (1994, 2001, 2005), pointed out that a sound structural appraisal should aim at providing information on the following aspects of the building:

- Review of relevant available documentation about original building design, the quality of the original construction and investigation of existing conditions;
• Ascertain the condition of substructure, where old buildings may not have been built to adequate standards. Foundations should be exposed at selective points to find out their condition and identify any damages using trial pits as required by Building Control;

• Assessment of the dimensions of the load-bearing masonry elements, to identify solid and cavity construction parts separately and to note the presence of any chases for services;

• The condition of adjacent structures (if any) and their stability should be established. In particular, it is important to explore any previous or planned underpinning and its effects on adjacent structures;

• Structural stability design should include pre-strengthening and pre-weakening design, for both the permanent structure and temporary works. Similarly, collapse/break-out design, should include stability of the retained part of the existing structure;

• Location of the existing pre-cast concrete floor and/or roof units and an assessment of the effectiveness of any lateral ties within the floor and roof construction;

• Location of any existing lintel units and assessment of the effectiveness of any longitudinal tying that may have been introduced between consecutive units;

• Detailed design risk assessment to control the risks;

• Planning of demolition sequences and demolition method statements;

• Supervision while undertaking demolition activities;

• Assessment of structural stability mechanism through a detailed structural survey and understanding the structure as it is now;

• Need for any temporary support system, auxiliary structures and false work including facade retention systems to support unstable elements;

• Identify clearly the load paths for each structural change;

• Method statements to include stability statements and design requirements prepared for each stage.
4.6.2 Insufficient Knowledge and Inadequate Information

Lack of structural engineering knowledge has produced more cases of collapse during refurbishment than any other single source. In the past, many failures have been the result of inadequate technical expertise, insufficient knowledge of structures for example, strength of latticed columns have contributed to many collapses. Until about two centuries ago all structures were designed and built with the best available knowledge and experience, involving sometimes fatal accidents. The designs and construction method were then modified until a satisfactory solution evolved, i.e. until the structure proved economical and its chances of falling down or becoming unsafe were remote. This method of design and construction was then repeated for many structures, perhaps with minor alterations, and it was passed on from generation to generation. As technical knowledge improved, errors became by far the major cause of known structural collapses. An error in this context is a gross management error or mistake, not a minor calculation or construction error. These errors are made by individuals, designers, builders or authorities responsible for checking a design or supervising a construction/demolition or refurbishment.

In almost all case studies undertaken (see Section 4.5) not one but a number of errors have contributed to collapse, and usually more than one person had some responsibility. Similarly insufficient knowledge about instability caused by removal of ties and structural information (see case study # 1, Section 4.5.1 and case study # 4, Section 4.5.4) led to the collapse of the walls and complete building respectively. The design of any refurbishment works should address the safety related requirements. For example, if the refurbishment work requires substantial modifications, or if the basic design assumptions have changed significantly since the original design, the complete structure should be reanalysed. The collapses in refurbishment largely attribute to allowable stress design, which does not provide sufficient safety in cases of stress reversal, for example, where wind load tension overcomes dead load compression.
4.6.3 Inadequate Temporary Supports and Bracings

The greatest problem with regard to structural instability during refurbishments has been due to the lack of competent structural engineering in the design of temporary structures and/or in the erection procedure of supports and bracing. Some of the worst collapses have occurred as a result of inadequate temporary supports. In most cases, lateral bracing to prevent buckling was either absent or not sufficient. Another error that occurs in reinforced concrete construction is the premature removal of temporary supports before the concrete has become sufficiently strong to carry construction loads. There are many structural or building elements which are, by themselves, unstable or incapable of resisting moderate wind loads until the structure or building has been completed. Cutting the upper chord bracing of a roof truss and redistribution of loads has led to sudden premature collapse of the roofs (see case study # 2 and case study # 3). Elements subject to wind collapse including free-standing masonry walls, wooden frames and trusses are inadequately connected. There have been many collapses of this type in UK. Elements subject to instability include plate girders, long-span joists and walls that function as beams in the completed structure. All such elements must be braced or guyed temporarily. Some designer's believe that excessive bracing increases the stiffness of the structure, but Haydl and Nikiel (2000) argue that this is not always true as resisting lateral force or vertical bracing require an understanding of the loads acting on the structure and their load path through the structure.

4.6.4 Controlling Demolition and Unplanned Collapses

Demolition activities are mainly carried out on projects where structural alterations are being made to the existing structure and can be considered as the most dangerous operations to be performed on site due to the high level of risk to the structure and workers as pointed out in case study # 3. The British Standard 6187 (BS: 6187, 2000) 'Code of Practice for Demolition' provides a very useful reference for the identification and classification of
demolition methods and techniques. Although major civil engineering structures are usually inspected carefully and regularly, this is not generally true for buildings. Change of use and structural alterations can cause overloading of load bearing elements and there may be higher probability of the collapse being disproportionate, as highlighted in case study # 3 and case study, # 4. If caused by a local accident, a local explosion or vehicular impact (HSE investigation report, 1999). Thoughtless alterations can drastically change the structural capacity, for example, cutting of reinforcing steel or re-roofing without maintaining the required lateral support to the roof structure case study # 3. There have been many collapses of walls and other parts of buildings into adjacent excavations as it is difficult to know what the existing foundations are like and ascertain their load carrying capacity after any alteration or change in use especially in case of old buildings.

4.6.5 Lack of Safety Supervision and Control

The structural refurbishments are considered one area which are not only complex by the very nature but the hazards involved in activities such as, structural investigation, erection of false work, erection of temporary supports, removal of key structural members, partial demolition, cutting of concrete with handheld equipment, and toe-nailing wood rafters for wind anchorage etc (CIRIA, 1994). Most of the manufacturing processes including construction require strict control and supervision to prevent accidents and serious defects. Hinze and Gambatese (2003) highlighted the value of line supervision and its direct link to site safety. By taking up safety supervisions and strict inspections site personnel can become acquainted with the nature and types of hazards on refurbishment site.

4.6.6 Structural Deterioration and Fatigue

Catastrophic structural collapse resulting from these phenomena can be reduced considerably by inspection and maintenance. Inspection includes looking for dangerous cracks, rot, corrosion and other material changes.
Although bridges are usually inspected carefully, this is not generally true for buildings. Sometimes a change of use and alteration can cause overloads; for example, as shown in case study #1, case study #3 and case study #4. Sometimes thoughtless alterations can drastically change the structural capacity, for example, cutting of reinforcing steel, removal of lintels, re-roofing without maintaining the required lateral support to the gable ends are some of the most common causes for structural collapses.

4.6.7 Lack of Expertise and Safety Training

It is widely accepted that in the construction industry training plays an important role in site and worker safety. Training in refurbishment typically begins with worker orientation and safety inductions. The accident occurred and discussed in case study #2 and case study #5 could have been easily avoided if the site personnel were trained in tackling structural refurbishments have gradually reduced over the years through improved knowledge and workmanship. There is considerable effort aimed at basing safety criteria directly on risk and the consequences of failure and realisation that errors are the major cause of structural collapse. Inadequate wind anchorage particularly to wind suction on roofs of buildings, to wall and roof panels is another area for errors.

4.6.8 Lack Of Communication and Team Co-ordination

Lack of positive communication between the structural engineer and the builder or architect is a potential source of trouble as evident in case studies #2, and case study #3. Good communication and inspection could have prevented some mistakes and errors from occurring in almost all the cases where collapses had occurred. Inadequate communication can be in the form of unclear specifications or contract arrangements. drawings that do not give sufficient detail, or inadequate understanding of drawings and specifications.
Communication is essential in coping with such contingencies as errors in design drawings, alterations in the construction method, and changes required by the owner or architect. Inspection by the structural engineer and communication of all relevant facts and risks involved would have informed contractor whether the walls and floor could have taken additional load or not (see case study # 4 in historic case study). Almost all the case studies point out that information about the structure, communication of risk and effective team coordination could have provided the opportunity for pursuing safer refurbishment without any dangers of collapses. However, from all the case studies it was found that team co-ordination lacked not only information flow within the team members but also the collective decision making and ability to contemplate risks, which was supported the view and findings by Kontogiannis and Kossiavelou (1999) in their study about problems with identification of hazards and chances of errors.

### 4.7 Analysis of Key Findings from Literature Review and Case Studies

The literature review in Chapter two identified the characteristics of structural refurbishments and highlighted various problems associated with structural refurbishments (see Table 4.4).

<table>
<thead>
<tr>
<th>Area</th>
<th>Identified Problems</th>
</tr>
</thead>
</table>
| Structural appraisal| • Absence of competent Structural Engineer  
                         • Absence of complete structural appraisal  
                         • Problems with identifying and calculating load paths  
                         • Quality of original construction |
| Structural collapse | • Risk of non deliberate collapse of building elements and temporary structures  
                         • Managing structural instability |

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The identification of these problem areas were then utilised to identify the key decision making areas, which is discussed in Chapter 4 (see Section 4.4.2). The major causes of occurrences of structural collapse during structural refurbishment identified after descriptive case studies (involving interviews with industry experts) and historical case studies (where collapses had occurred) are tabulated next:
Chapter 4 Case Studies in Refurbishment

Figure 4.3 Major Causes for Structural Collapses During Refurbishments

The above figure does not present an exhaustive list but failure to address the above mentioned problems can raise safety risks on a refurbishment project, which may lead to structural collapse. Research findings suggest that the most important aspect during structural refurbishment is to know the structure, what it was designed for and for what type of loading. It is vital to know what is holding the structure together. The existing structural elements (e.g. roof, beams, columns, floor and walls) should be checked thoroughly for any alterations/modifications, damage and any dilapidation. Lack of context-specific information, and communication of risk during various stages of
refurbishment were found to be common findings from the literature review presented in Chapter 2 and case studies presented in Chapter 4. Different stages of activities, sub-activities and tasks were developed from historic case studies and descriptive case studies. Similarly case studies also helped in identifying roles/responsibilities and involvement of various project participants on a refurbishment project. These findings formed the basis that a refurbishment process model (see Chapter 5) was necessary, not only to provide clarity on the key stages and involvement of key professionals in refurbishment projects but also to act as a framework based on which the decision support system could be developed to avoid collapses during structural refurbishments. The end-user requirements were captured by conducting interviews during case studies and were utilised to develop the functional requirements. The findings from the historical case studies and descriptive case studies as identified (see Appendix E for tasks in back-end database of DSS) during development of process model contributed in developing the decision support system, which is discussed in Chapter 6.

4.8 Summary

The refurbishment industry faces lot of challenges when taking up structural refurbishment. The structural refurbishment needs to address the constraints of the structural safety and efficient decision making. Often the decision on refurbishment are taken too early in the process without having enough information (e.g., whether the structure is structurally adequate for any modifications/alterations) and without following a structured process to tackle structural refurbishments. The case studies highlighted the need to have a information based process model to improve information flow within the project team. The unavailability of any standard process model for the refurbishment prompted the research to develop a Safety-Integrated Refurbishment Process Model (RPM). The next chapter discusses the rationale for developing a refurbishment process model.
5.1 Introduction

This chapter describes the development of a generic process model for refurbishment, which enables the early consideration of safety issues. It starts with a brief overview of process modelling and then describes the rationale for a refurbishment process model. The details of the development and evaluation of the process model are then presented.

5.2 Processes and Process Modelling

Prior to presenting the development of the refurbishment process model, it is pertinent first to explore what is meant by the term 'Process' and 'Process modelling'.

5.2.1 Defining Process

Process can be defined as set of activities that can be divided into smaller parts, which can then be executed sequentially or in parallel. Processes have been the subject of studies in many areas such as new product development, business process re-engineering, operations management, and construction management. The rationale for the process comes from the framework of
scientific management while accomplishing a task as defined by Taylor (1913). Due to the diversity with respect to the term 'Process', it has been difficult to come up with a commonly agreed definition as different definitions of processes are found in literature (Lindsay et al, 2003). A typical definition of a process is:

'A set of partially ordered steps intended to reach a goal'
(Humphrey, 1992).

Harrington (1991) defined a process as:

'Any activity or group of activities that takes an input adds value to it and provides an output'.

According to Davenport (1995) the concept of task is the transformation of inputs into outputs (see Figure 5.1) and defined a process as:

'A simple structured set of activities designed to produce a specific output'

![Figure 5.1 Transformation of Input into Output](image)

Koskela (2000) suggested that defining the task was the most important element necessary to make all pre-requisites ready to ensure that the most efficient method was followed. The process can be further broken up into smaller, more manageable, sub-processes (Slack et al, 2001) which simplifies the management as same set of managerial principles can be applied at different levels (Koskela, 2000). Tzortzopoulos (2004) showed that
Chapter 5 Development of Refurbishment Process Model

hierarchical order of process can be further decomposed into activities, sub-activities and tasks as shown in Figure 5.2.

![Figure 5.2 Process Level (Adapted from Tzortzopoulos, 2004)](image)

5.2.2 Process Modelling

Process modelling, or mapping has been recognised as an important managerial tool (Clark and Fujimoto, 1991; Winch and Carr, 2001). Modelling gives a snapshot of what is perceived at a point in time, while process models are used to represent the internal elements for example the activities, sub-activities, their dependencies, the data flow, the roles and actors involved, and the perceived goals (Lindsay et al, 2003). Smith and Morrow (1999) point out that developing models is useful for both learning about an actual process and finding ways for improvements and control. The creation of predictive models improves managerial decision-making and helps in optimising process predictability. According to DTI (1997), process maps are visual documents that should:

- be able to clearly identify individual and collective activities;
- allow for process improvement;
- act as a clear and concise visual aid;
- provide a generic model that can be customised for specific projects; and
- should be able to demonstrate cross-functionality.

There are mainly two types of process maps (Winch and Carr, 2001), i.e., true maps representing what actually happens ('as-is' model) and protocols representing what ought to happen (to-be models):

1. 'As-is' models try to depict the process, focusing on the process as a whole (for example, Prasad et al, 1998; Yazdani and Holmes, 1999), while others describe parts of the process (Mazijoglou and Scrivener, 1998).
2. 'To-be' models provide protocols and tools to support improved product development. These models are supposed to be used as templates representing a generic model, as well as the flow of information (Prasad, et al, 1998).

Process models can present different levels of detail of the process being modelled. Two different levels found in the literature are: detailed level and high level (which is also termed as generic). The most commonly used modelling technique to describe the process at a detailed level has been the integrated definition language (IDEFO) for function modelling. It depicts processes with inputs, outputs, control and mechanism and can reveal increasing levels of detail. It has been argued that the IDEFO approach tends to be over-detailed for use by non-specialists and does not allow identification of non-value-adding activities (Kartam et al, 1997; Kagioglou et al, 1998; Winch and Carr, 2001).

The details of levels are excessive and restrict the applicability as a generic reference (Kahru, 1999). On the other hand, generic (High level) maps provide an overview of the whole process, describing the main stages and / or activities (Austin et al, 1999). Table 5.1 presents a comparison of the different process modelling methods.
Table 5.1 Comparison of Process Modelling Methods  (Source: Anumba et al, 1998)

<table>
<thead>
<tr>
<th>Methods</th>
<th>IDEF/SADT</th>
<th>IDEF3</th>
<th>DFD</th>
<th>Role Activity Diagram (RAD)</th>
<th>Unified Modelling Language (UML)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modelling Approach</td>
<td>Static Activities</td>
<td>Static Activities</td>
<td>Data Flow Diagrams</td>
<td>Emphasis on Roles</td>
<td>Object Oriented</td>
</tr>
<tr>
<td>Applicability</td>
<td>Functional Modelling</td>
<td>Functional Modelling</td>
<td>Data Flows</td>
<td>Software Process Modelling</td>
<td>Object-Oriented Analysis</td>
</tr>
<tr>
<td>Link to Data Model</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Understandability</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>fair</td>
<td>Yes/No</td>
</tr>
<tr>
<td>Dynamics Aspect</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Flexibility</td>
<td>Fair</td>
<td>Fair</td>
<td>Fair</td>
<td>Fair</td>
<td>Yes</td>
</tr>
<tr>
<td>Layering</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Ease of Use</td>
<td>Yes</td>
<td>Yes/No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes/No</td>
</tr>
<tr>
<td>Software Availability</td>
<td>Yes</td>
<td>Yes</td>
<td>yes</td>
<td>Yes</td>
<td>yes</td>
</tr>
</tbody>
</table>

It should be noted that only the most commonly used process modelling methods have been included for comparison in the above summary.

5.3 Modelling of the Construction Process

This section provides a selected overview of previous modelling efforts in the construction industry. Several process models have been developed by researchers in the domain of construction. Some of the models developed to describe the construction process are discussed below:

5.3.1 Wheeler’s model

Wheeler (1978) developed a comprehensive model for managing the building construction process. The project life cycle is considered from the organisation of the building team to the occupancy of the building and project...
life cycle is divided into nine sequential phases. Each phase was then divided into sub-phases called steps, which were further divided into activities. Wheeler's model has been a significant development as it defined the entire project life cycle as a set of activities. One of the shortcomings of this model is that does not represent the interrelationships among activities.

5.3.2 Project Initiation Model

Cumberpatch's project initiation model (1983) depicts a generic model of the project generation process within a typical organisation. The model traces the flow of 'ideas' into projects, and represents the possible steps required for the generation of a project proposal. The project is limited to the project initiation process and represents the decision making process involved in developing a project proposal. The project does not represents flow of information.

5.3.3 Project Definition Model

In the project definition model, Salapatas (1983) models the project definition process in flow chart form, beginning with 'Establish Objectives & Schedules' and ending with 'Execute Project Plan'. The model provides an overview of the major decision made in developing the project plan. The model does not attempt top define the activities, participants,

5.3.4 Walker's Model of the Construction Process

Walker (1985) developed an input-process-output model of the project delivery process. The construction process here is seen as a parallel function to the owner's process and each process is assumed to transform inputs into outputs. The model is a hierarchical model of the construction process which is modelled as three sequential systems consisting of conception, inception and realisation. This model offers two major contributions. First, the construction process is seen as a transformation process from inputs to
outputs. Secondly, the processes involved are divided into tasks which may be interpreted as a representation of information.

5.3.5 Sanvido’s Construction Process Model

Sanvido (1984) created a conceptual model of the construction process. The model is a generic, time-independent representation of project site operations. The model depicts planning, resource acquisition and output coordination as three major functions in the construction process and identifies major influences of each function. The planning and resource acquisition are governed by influences on planning and influences on supply of resources. The output coordination function exerts influences on participants and environment. The model emphasised on management and control aspects of construction process. One of the shortcomings of this model is that actual process and information flow are not identified. Sanvido developed another Project Management Model in 1986 with three major functions in project management; the project function, the engineering function, and the construction functions. The model divides the entire construction process into three major functions and each function is further detailed as a set of activities in the checklists. This step was an important extension to the previous model. However the model needs to be expanded to represent the tasks as well as the interdependencies and overlap in functions among project participants.

5.3.6 RIBA’s Plan of Work

One of the most popular and widely acknowledged plan of work in practice to demonstrate different stages of a construction project has been set out by the Royal Institute of British Architects (RIBA) ‘Plan of Work’ (also referred to as the RIBA stages of work). RIBA’s plan of work divided the construction projects into three stages: Pre-Design; Design; and Construction, which are further subdivided into eleven activities as shown in Figure 5.3:
5.3.7 Integrated Building Process Model (IBPM)

Integrated Building Process model (IBPM) was developed using IDEF0 modelling methodology. The Integrated DEFinition (IDEF) methodology is a suite or family of methods that supports a paradigm capable of addressing the modelling needs of an enterprise and its process (Hanrahan, 2006). The Integrated Computer Aided Manufacturing (ICAM) Definition Method (IDEF) is a set of structured analysis technique to provide engineering methods for designing complex systems (Wallace et al., 1987). The discussion here is succinct and ICAM publications (ICAM 1978; 1981) can be referred to for more discussion on IDEF0 methodology. The functional model, IDEF0, produces a structured representation of the functions of the system. IDEF1 which is also referred as information model is used to represent the structure of the information needed to support the functions of a system. The IDEF2 represents the time varying interaction of the system and shows the different states and the events which cause the transition from one state to the next (Wallace et al., 1987). Five entity types: Activity, input, output, control and mechanism are used in the IDEF0 modelling methodology (see Figure 5.4).
Lot of academic work (see, Karhu, 1999; Austin, et al, 1999) has been done in several areas and fourteen IDEF methods exist in various stages which intend to provide the capability to describe additional views (see Table 5.2).

Table 5.2 Various IDEF Methods Developed
(Source: Hanrahan, 2006)

<table>
<thead>
<tr>
<th>IDEF</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>IDEF0</td>
<td>Function Modelling</td>
</tr>
<tr>
<td>IDEF1</td>
<td>Information Modelling</td>
</tr>
<tr>
<td>IDEF1X</td>
<td>Data Modelling</td>
</tr>
<tr>
<td>IDEF2</td>
<td>Simulation Model Design</td>
</tr>
<tr>
<td>IDEF3</td>
<td>Process Description Capture</td>
</tr>
<tr>
<td>IDEF4</td>
<td>Object-Oriented Design</td>
</tr>
<tr>
<td>IDEF5</td>
<td>Ontology Description Capture</td>
</tr>
<tr>
<td>IDEF6</td>
<td>Design Rationale Capture</td>
</tr>
<tr>
<td>IDEF8</td>
<td>User Interface Modelling</td>
</tr>
<tr>
<td>IDEF9</td>
<td>Scenario-Driven IS Design</td>
</tr>
<tr>
<td>IDEF10</td>
<td>Implementation Architecture Modelling</td>
</tr>
<tr>
<td>IDEF11</td>
<td>Information Artifact Modelling</td>
</tr>
<tr>
<td>IDEF12</td>
<td>Organization Modelling</td>
</tr>
<tr>
<td>IDEF13</td>
<td>Three Schema Mapping Design</td>
</tr>
<tr>
<td>IDEF14</td>
<td>Network Design</td>
</tr>
</tbody>
</table>
5.3.8 Process Protocol

Many governmental and institutional reports, such as Latham (1994) and Egan (1998), identified poor co-ordination and communication, informal and unstructured learning processes, adversarial contractual relationships as key inhibitors to the construction industry's performance. Latham (1994) recommended taking a holistic process view of construction to help eliminate these inhibitors to improve construction. The British Airports Authority (BAA) and London Underground (LU) started to map their own design and construction processes. Their approaches highlighted a common process structure, which contributed to the development of the Generic Design and Construction Process Protocol (GDCPP) or Process Protocol (Kagioglou et al, 1999). Process Protocol is a framework of common definitions, documents and procedures developed to help project participants work together seamlessly. The Process Protocol has four broad stages: Pre-Project, Pre-Construction, Construction and Post-Construction; and ten phases. The construction process has been mapped into eight sub-processes (Activity Zones); Development, Project, Resource, Design, Production, Facilities, Health & Safety, Statutory and Legal, and Process Management. The process protocol, however, has been developed mainly for new construction.

5.3.9 Other Process Maps

The construction industry has developed other process models to map various other domains of construction, e.g., MoPo model (Cooper, 1998) which covers the whole construction life-cycle and the prototype tool for construction process modelling and management. Some other process models developed by Anumba and Evbuomwan (1996) and Kaneta et al (1999) introduced concurrent engineering (CE) features and Kamara et al (2000) developed a model for processing client requirements in construction. Some other attempts have been in modelling the different stages of the construction process. For example Austin et al (1996) presented a data flow model for planning and managing the building design process. The
Information Reference Model for AEC (IRMA) monitored construction information by studying the reference mechanisms of integrated project aspect models (Luiten et al, 1993). The ICON (Information/Integration for CONstruction) project studied the feasibility of using an object-oriented database to develop an information framework for integrating design and construction information (Aouad et al, 1994). Song and Chua (2003) developed the COSEE Model to integrate product, and process consistencies in project schedules. While all these attempts have been focussed on new construction, there has not been any attempt to describe and model refurbishment processes. The next section outlines the rationale for the development of a safety-integrated process model for refurbishment.

5.4 Rationale for Refurbishment Process Model

The modern construction sector requires a skilled work force capable of delivering improved quality, increased productivity and better value for money, which can only be obtained through improved project processes. The complexity of construction projects and the fragmentation of the construction process has led to the development of a generic project process, the Process Protocol (Kagioglou et al, 1998, 2000). The recent research focus on construction as a manufacturing process (Egan 1998) has resulted in a wider understanding of the need for integrated process efficiency in the UK construction industry.

It has been shown that more than 80% of commonly associated problems in the construction industry are process-related (Kagioglou et al, 1998), and not product-related. Previous initiatives have primarily concentrated on process efficiency, rather than process effectiveness as related to the wider business environment. However, given the nature, uncertainty and overlapping of activities with refurbishment projects, it is necessary to build-in checks to ensure not only efficiency but also continued effectiveness. Effective health
and safety management systems, such as the training of individuals and providing improved and more sophisticated information on which the decisions can be based, would enhance the process to a large extent. Holm (2000), while defining the characteristics, highlighted that refurbishment is undertaken in an existing building in comparison to a new building which starts with a clear site. This results in a different sequence of work and activities (See Bennet, 1983; Daoud, 1997).

There are often small amounts of work scattered all over the building, and process of carrying out refurbishment work becomes more important than the quantity of work (Okoroh, 1992). In the dynamic, safety-critical situations presented by refurbishment sites, processes shift the emphasis from well-structured and well-defined sequential activities to simultaneous activities. Managers rely on information to gauge the urgency and importance of the current situation and to decide upon the appropriate level of safety management. The first condition for the success of a refurbishment project is that the whole project progresses systematically.

The project has to be organised such that all necessary tasks and activities are executed in the right order and at the right time. The construction Industry has developed various process models to map various domains of construction to enable better understanding of the real-world, but same can not be said about refurbishment. It was evident from a previous study (Anumba et al, 2004) and the case studies presented in Chapter 4 that a refurbishment process model was necessary, not only to provide clarity on the key stages and involvement of key professionals in refurbishment projects (a novel and useful contribution on its own), but also to act as a framework based on which the Decision Support System could be developed. Furthermore, the development of a process model will allow the creation of a safe system of work to ensure that the tasks are taken up in the right sequence and allow a project to be carried out with minimum risk to everyone involved.
5.5 Development of the Refurbishment Process Model

The development of the refurbishment process model was undertaken to identify the activities during various stages of the refurbishment process so that guidance could be provided to project respondents at all stages. Tasks and activities related to refurbishment were identified and a safety-integrated refurbishment process model was developed using the Process Protocol and the RIBA plan of work (2000) as reference points.

The approach adopted involved discussions with both refurbishment and process modelling experts, developing a draft version of the process model and going back to the experts to check its accuracy. This was repeated until the experts were satisfied with the model. It was proposed that refurbishment work in the new refurbishment process model should begin by identifying the need and scope of the refurbishment and continue to the post-refurbishment phase. It was necessary to build-in checks to ensure that simultaneous and concurrent activities make the process efficient and effective. The opportunities for such checks are provided by the hard gates and soft gates which punctuate the project process.

The flow of information and the resulting interdependencies among the project participants was considered an integral component for developing the process model. The detailed activities are presented in two levels at each phase. The first three phases of the Process Protocol correspond to the pre-project phase of the feasibility stage. The next three phases fall within the pre-refurbishment phase which comprises two main stages: the design stage and the procurement stage. The next two phases fall within the refurbishment phase which consists of the demolition stage and the execution stage. The ninth phase matches the post-refurbishment stage of a refurbishment project. The involvement of various project participants at each stage of the refurbishment lifecycle was also established. The process model comprises four phases and six stages as shown in Figure 5.5.
Figure 5.6 illustrates the proposed refurbishment process model from the hierarchical point of view (see Figure 5.8). First four process levels (phase, stage, main activity and sub-activity) have been considered for refurbishment process model, while fifth level (tasks) has been covered while developing decision support system in Chapter 6, (see checklist of tasks in Appendix E).
Figure 5.7 shows the basic structure of the process model comprising project phase, process stage, major activity in a particular stage and sub-activities.

![Diagram of Process Model](image)

**Figure 5.7 Different Components of the Process Model**

The proposed refurbishment process model, is presented as representing the refurbishment management activity zone of the Process Protocol. The refurbishment process model and corresponding work stages of the RIBA Plan of Work and Generic Construction Phases are also shown (see Figure 5.8). Subsequent figures (Figure 5.9 to Figure 5.14) provide the details to illustrate the various stages, activities and sub-activities at each phase of the developed refurbishment process model. The project participants involved at each stage are shown in ovals below each activity. Figure 5.8 illustrates the proposed refurbishment process model, which is presented as representing the refurbishment management activity zone of the Process Protocol.
Figure 5.8 Refurbishment Process Model
Pre-Project Phase

The pre-project phase relates to the strategic considerations of any potential refurbishment project and comprises feasibility stage in the proposed process model. Though it is assumed that the knowledge possessed by speculative building developer and consultants could assist clients in these early stages of the project. The problems associated with the structural refurbishment at this stage could be substantially eliminated by taking up additional activities along with the conventional briefing at this stage. The feasibility stage would therefore have following three main activities:

- Refurbishment plan and Identify scope of refurbishment
- Structural assessments and Investigation
- Identify extent of demolition

These three main activities in turn, have been further divided into a set of second level sub-activities (see Figure 5.9). The first activity *refurbishment plan and identify scope of refurbishment* has five sub-activities; *structural assessments and Investigation* has four sub-activities; and *identify extent of demolition* has four sub-activities. The main project participants at this stage are client, architect and structural engineer for first two main activities and it is proposed that demolition contractor should also get involved for the third activity.
Figure 5.9 Pre-Project Phase – Feasibility Stage
(First and Second Level Activities During Feasibility Stage)
Pre-Refurbishment Phase

After completing feasibility studies and approvals obtained from the concerned authorities, project progresses through to the pre-refurbishment phase where the defined need for refurbishment is developed into appropriate design. This is one of the most important phases as decisions taken at this stage affect health and safety and in controlling the associated risks with structural refurbishments. Pre refurbishment phase has two main stages:

- Design stage
- Procurement stage

The design stage has been further divided into three main activities and twelve second level sub-activities (see Figure 5.10). The main project participants at this stage are client, project manager, structural engineer, and planning supervisor.

Similarly the procurement stage is further divided into three main activities and eleven second level sub-activities (see Figure 5.11). The main project participants at this stage are client, architect, structural engineer and planning supervisor.
Figure 5.10 Pre-Refurbishment Phase – Design Stage
(First and Second Level Activities During Design Stage)
Chapter 5  Development of Refurbishment Process Model

Figure 5.11 Pre-Refurbishment Phase – Procurement Stage
(First and Second Level Activities During Procurement Stage)
Refurbishment Phase

The refurbishment phase is mainly concerned with the actual on-site activities. The actual benefits of briefing, communication, structural assessments can be realised here fully. Other issues such as health and safety on site along with site activities, hazard identification, risk assessments, communication and information flow and coordination tend to take the centre stage at this stage. The 'hard gate' should not prevent taking up simultaneous activities wherever concurrency is possible and should be accommodated. Additionally this also signifies that approvals are obtained or granted before taking up activities at this stage.

The refurbishment phase has two stages:

- Partial demolition and structural alteration stage; and
- Actual execution stage

Partial demolition and structural alteration stage has demolition as the main activity and further five sub-activities (see Figure 5.12). The main project participants involved at this stage are project manager, designers, structural engineer, demolition contractor, temporary structures coordinator.

The actual execution stage has two main activities (1) actual refurbishment (on site activities) and (2) project commissioning and handover of the facility, which have further five sub-activities each (see Figure 5.13). The main project participants involved at this stage are project manager, contractor, designer, structural engineer, planning supervisor.
Figure 5.12 Refurbishment Phase – Partial Demolition/Structural Alteration Stage
(First Level and Second Level Activities During Refurbishment Phase)
Figure 5.13 Refurbishment Phase – Actual Refurbishment and Handover Stage
(First Level and Second Level Activities During Refurbishment Phase)
Post-Refurbishment Phase

The process model continues into post-refurbishment phase after completion of the refurbishment phase. The main aim is to monitor the maintenance aspect of the refurbished facility from a health and safety point of view. The post-refurbishment review needs to be completed and recorded for the purpose of any further changes and associated work especially with the findings of structural survey and investigations.

The post-refurbishment phase has post-refurbishment stage as the main stage. This stage incorporates preparation of maintenance plan and post-refurbishment review as the main activity and further four sub-activities (see Figure 5.14). The main project participants involved at this stage are project manager, client, architect, contractor, planning supervisor.
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Figure 5.14 Post Refurbishment Phase – Post Refurbishment Stage
(First Level and Second Level Activities During Post-Refurbishment Phase)
The refurbishment process model has been based on the Process Protocol to provide a framework for carrying out structural refurbishment safely. Some of the potential advantages of adopting the Process Protocol as an industry standard are:

- It recognises the interdependency of activities throughout the whole project life-cycle;
- It enables co-ordination of the participants and activities during refurbishment and identifies the main project participants responsible;
- It encourages the establishment of a multi-functional team and provides basis to work together seamlessly on refurbishment project;
- It is activity based model focusing on safety requirements right from the conception stage;
- It provides basis for team environment to communicate risk information for timely decision making.

The above advantages were the main drivers for developing refurbishment process model (RPM) based on the Process Protocol. Once the basic framework was developed, process model was presented at workshops. The main aim was to get it validated within the construction industry to check its relevance, practicality, and use. The next section outlines the validation process for the process model.

5.6 Validation of the Refurbishment Process Model

5.6.1 Introduction

This section describes the validation of the refurbishment process model. The validation and refinement of the RPM was iterative and hence required feedback from industrial practitioners and continuous review of the model.
objectives, approaches adopted and the results of the validation are presented in detail:

5.6.2 Objectives of the Validation

The aim of the validation was to explore the extent to which the Refurbishment Process Model adequately represented the refurbishment process. The specific objectives of the validation were to:

1. Assess the effectiveness, functionality and coverage of the refurbishment process model;
2. Identify any activities or sub-activities which have not been covered in the process model;
3. Explore the applicability and usability of the refurbishment process model as a reference model for improving safety on refurbishment projects.

5.6.3 The Approach Adopted

The approach adopted for validating the refurbishment process model involved exposing it to a wider set of industry practitioners for review and critiques. The model was presented during a 'Workshop on Structural Refurbishment' at the Institution of Civil Engineers in London. Later, two more evaluation workshops were held in Loughborough and Glasgow to validate the process model. These workshops were designed to elicit feedback from academics, researchers and industry practitioners on the appropriateness of the refurbishment process model. The workshops started with presentations on the main problems associated with structural refurbishments and on the developed refurbishment process model. A validation questionnaire (see Appendix C) was then handed out to the participants to complete. The details of the responses received on validation questionnaire are presented in section 5.7.
Table 5.3 summarises the number of participants at each of the validation workshops.

<table>
<thead>
<tr>
<th>Workshop</th>
<th>Workshop 1</th>
<th>Workshop 2</th>
<th>Workshop 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of Participants</td>
<td>7</td>
<td>11</td>
<td>31</td>
</tr>
</tbody>
</table>

Workshop # 1
The model was presented during a half-day seminar on 'Structural Refurbishment' at the Institution of Civil Engineers in London on 2 March, 2004. The model was presented and copies of the model were distributed to the audience, which included demolition contractors, general contractors, planning supervisors and designers. The research team received feedback from a subset of the delegates (7) regarding the activities and sub-activities at various stages of the process.

Workshop # 2
The second validation workshop was held at Loughborough University during a workshop in April, 2005. A presentation was made about the problems in refurbishment projects and how these can be addressed by a refurbishment process model. Copies of the refurbishment process model along with the evaluation questionnaire were then distributed to the participants, which comprised 4 academics and 7 researchers. The eleven delegates provided feedback on the various components of the RPM.

Workshop # 3
The third validation workshop was held at Glasgow Caledonian University (GCU) under the auspices of the Centre for the Built Environment (CBE), Scotland in September 2005. The workshop started with presentations on the problems in refurbishment and how refurbishment could be made safer by
Chapter 5 Development of Refurbishment Process Model

adopting a safety-integrated process model. The workshop was attended by thirty-one participants, which included architects, structural engineers, contractors, planning supervisors and H&S advisors representing different sections of the construction industry. Participants were then given detailed notes on the process model and invited to complete a questionnaire (see Appendix C). The break up of participants depending on their role is presented in Figure 5.15.

Figure 5.15 Classification of Participants by Role at Validation Workshop

5.6.4 Questionnaire Design

A questionnaire (see Appendix C) was designed to validate the process model for refurbishment projects. The questionnaire comprised two sections. Section A covered the background information about the participants, while Section B consisted of four sub-sections relating to the refurbishment process model and six open ended questions. There were eleven questions in Section B sub-section as follows:

Section 1 - Effectiveness of RPM;
Section 2 - Functionality of RPM,
Section 3 - Coverage and Scope of RPM,
Section 4 - Ease of use/user friendliness and
The participants were requested to provide their answers to the questions using a rating on a 5 point Likert scale with 1 (representing the poor) to 5 (representing excellent/very effective). The set of open-ended questions provided an opportunity for the participants to identify the most useful sections of the process model and to put forward their suggestions for improvements (see Table 5.5 and Section 5.7.3)

5.7 Analysis of the Validation Results
5.7.1 Overview of Results

This section summarises the responses from the validation exercise. The responses were analysed under four categories (see Appendix C - validation questionnaire for RPM) to understand the effectiveness, functionality, scope and usability of the process model in refurbishment projects. All participants felt that process model is relevant to organisations and individuals involved in refurbishment projects. Table 5.3 presents the average rating and equivalent percentages from the validation questionnaire.

Table 5.4 Summary of Responses to Validation Questionnaire

<table>
<thead>
<tr>
<th>KEY FEATURES</th>
<th>Workshop 2</th>
<th>Workshop 3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Average Rating (Out of 5)</td>
<td>Equivalent %age</td>
</tr>
<tr>
<td>EFFECTIVENESS</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>How effective can the RPM be for the refurbishment process?</td>
<td>2.9</td>
</tr>
<tr>
<td>2</td>
<td>How effective can the RPM be in decision-making relating to refurbishment?</td>
<td>3.1</td>
</tr>
<tr>
<td>3</td>
<td>How effective can the RPM be in reducing structural collapses in refurbishment projects?</td>
<td>3.4</td>
</tr>
</tbody>
</table>
FUNCTIONALITY

<table>
<thead>
<tr>
<th></th>
<th>To what extent does the RPM represent an improvement over your current refurbishment process?</th>
<th>3.0</th>
<th>60</th>
<th>2.7</th>
<th>64</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>To what extent do you think the RPM would facilitate planning for safety in refurbishment?</td>
<td>3.2</td>
<td>64</td>
<td>3.45</td>
<td>69</td>
</tr>
<tr>
<td>6</td>
<td>To what extent is the RPM suitable for the refurbishment process?</td>
<td>3.4</td>
<td>68</td>
<td>3.0</td>
<td>60</td>
</tr>
</tbody>
</table>

COVERAGE AND SCOPE OF THE RPM

<table>
<thead>
<tr>
<th></th>
<th>In your views, to what extent does the RPM cover all the key stages of a refurbishment project?</th>
<th>3.6</th>
<th>70</th>
<th>3.6</th>
<th>72</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>How well covered are the activities addressed in the RPM model?</td>
<td>3.6</td>
<td>72</td>
<td>3.35</td>
<td>67</td>
</tr>
<tr>
<td>9</td>
<td>How well are the key problem areas addressed in the RPM?</td>
<td>3.4</td>
<td>68</td>
<td>3.6</td>
<td>70</td>
</tr>
</tbody>
</table>

EASE OF USE AND USER FRIENDLINESS

<table>
<thead>
<tr>
<th></th>
<th>How user friendly is the format of the RPM?</th>
<th>4.0</th>
<th>80</th>
<th>3.86</th>
<th>77</th>
</tr>
</thead>
<tbody>
<tr>
<td>11</td>
<td>How easy is it to use the RPM?</td>
<td>3.8</td>
<td>76</td>
<td>3.8</td>
<td>76</td>
</tr>
</tbody>
</table>

Effectiveness

Seventy four percent (74%) of the respondents (see Figure 5.16) felt that the deployment of a refurbishment process model could be very effective or quite effective for the refurbishment projects and 26% felt that RPM could be effective.

![Figure 5.16 Effectiveness of the RPM](image-url)
Fifty eight percent (58%) of the respondents (see Figure 5.17) felt that RPM can be very effective or quite effective for the decision-making in refurbishment. Twenty six percent felt it can be effective, whereas only 3% felt it would not positively affect decision-making.

![Figure 5.17 Effective of RPM in Decision Making](image)

Sixty eight percent (68%) respondents (see Figure 5.18) felt that RPM can be very effective or quite effective in reducing the collapses in refurbishment projects, while 29% felt it could be effective and 13% felt it could be somewhat effective.

![Figure 5.18 Effectiveness of RPM in Reducing Structural Collapse](image)

**Functionality**

Sixty four percent of the respondent felt that RPM presents improvement from some extent to great extent over their current practices, while 23% of the
respondents felt that it presents minor improvement and only 3% of respondents felt that RPM does not represent any improvement over their current practices of refurbishment (see Figure 5.19).

![Figure 5.19 Extent to which RPM Represents Improvement](image)

Fifty two percent (52%) of the respondents (see Figure 5.20) felt that RPM would be quite effective or effective to great extent in facilitating planning for safety in refurbishment, while 48% of the respondents felt that the use of RPM would facilitate planning for safety effectively or to some extent in refurbishment.

![Figure 5.20 Extent To Which RPM Facilitates Planning For Safety](image)

All the respondents felt that RPM is suitable (see Figure 5.21) for actual breakdown of refurbishment process, with 84% respondents classifying RPM as being quite effective or effective.
Coverage and Scope of RPM

On coverage of all the key stages (see Figure 5.22) during refurbishment, 10% of the respondents felt that the key stages are covered to a great extent. Eighty four percent of respondents felt that the key stages have been covered quite effectively or effectively, whilst only 3% of respondents responded negatively to this.

All the respondents felt that refurbishment activities are covered in the RPM. Seventy seven percent (70%) of the respondents felt that these have been covered extremely well, very well or quite well in the RPM while 23% were of the view that coverage of main activities is to some extent only (see Figure 5.23).
All the respondents felt that the key problem areas are covered extremely well or quite well in the RPM. See Figure 5.24 for the detailed break down of the responses.

User Friendliness

Seventy five percent (75%) of the respondents felt that the format of the RPM is very easy or quite easy to understand. Nineteen percent of the respondents felt it was neither easy nor difficult, while 6% felt it was easy. See Figure 5.25 for the detailed break down of the responses.
Almost all the respondents felt that it is easy to use RPM (See Figure 5.26 for the detailed break down of the responses). Seventy four percent (74%) of the respondents felt that the format of the RPM is very easy or quite easy to use. Another 10% of the respondents felt it is somewhat easy, whilst 16% felt that it is neither difficult nor easy to use.

Overall, the validation results were very positive. Participants in the validation workshops felt that process model does present a structured model suitable for refurbishment works. The fact that most of the people involved with validation exercise understood the RPM and appreciated its usefulness was a
very useful feedback. Suggestions and comments as pointed out in Section 5.7.2 (See Table 5.4) could provide the basis for the further work. From the results of validation, it is evident that the objectives set out in Section 5.6.2 have been achieved.

5.7.3 Comments from the Validators

The comments from the participants during the validation workshops are listed below:

- The best aspect of RPM is the identification of the activities and breakdown of the actual process;
- The good aspect of the RPM is that it shows continuity between activities;
- The RPM is a very useful tool to track the sequences of work in meeting best practices during structural refurbishments;
- The RPM presents a logical sequence of activities and raises awareness about the involvement of project participants;
- The RPM is quite useful as it puts a logical order in identifying potential problems and formulating guidelines to avoid structural collapse, especially conforming to iterative nature of CDM and design issues which run parallel;
- Stage headings are all embracing, and if considered properly should enable designer to take account of all relevant issues;
- The list of enlisted stages and main activities as a checklist enables to check that each major activity has been completed or thought about. The use of hard gates and soft gates creates a sense of urgency and provides enough flexibility to perform tasks within that particular stage;
- It is a competent attempt at addressing the issues to improve evaluation of the decision making process associated with structural refurbishment;
• A very useful system for more wide ranging projects as opposed to only structural refurbishments and handy for administrative purpose also. It should be extended to, working at height; provision of dates for proposed completion of an activity would provide a convenient and quick access to important contract information;

• It is a very useful tool and it would be a waste not to use the structured process on refurbishment projects;

• The thoroughness of the process provides a structured process associated with refurbishment, but should include planning and building control issues.

5.7.4 Feedback from the Validators

Feedback and suggestions for improvement of RPM included the following:

• Clients and designers need to address potentials of hazards from waste re-cycling and occupational health right from the feasibility stage and safety implications these might have on structural refurbishment projects;

• A health and safety policy to avoid any structural collapse should be prepared during the feasibility stage;

• Respondents/Interviewees suggested to give more emphasis to the contractors' team than to the client team.

The feedback received from the participants during the validation workshops and action taken to refine the process model are tabulated in Table 5.4.
Table 5.5 Validators Feedback on RPM

<table>
<thead>
<tr>
<th>Feedback/Suggestions for Improvement</th>
<th>Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>One of the participant at workshop suggested there is need to include an activity (Architects/Designer to produce drawings) to make available 'As Built Drawings' required by planning supervisor at Feasibility stage which are not always available and may not be accurate.</td>
<td>The task was recognised as an important task and added to DSS Database.</td>
</tr>
<tr>
<td>One of the participant at the workshop suggested to add 'Pre-refurbishment H&amp;S Plan' instead of just H&amp;S plan or Pre-Tender H&amp;S Plan.</td>
<td>Added as main activity in RPM.</td>
</tr>
<tr>
<td>It was suggested that demolition contractors/consultants should be involved right from the beginning at the feasibility stage.</td>
<td>The suggestion was well appreciated and incorporated accordingly.</td>
</tr>
<tr>
<td>It was suggested that the identification of hazardous substances (e.g. asbestos) cannot be left out from the structural investigations and should be an integral part of the structural appraisal.</td>
<td>This was also added and incorporated.</td>
</tr>
<tr>
<td>Roles of project participants for sub-activities should be mapped out, especially in scenarios where there is one key participant and/or when one of the key participants has taken up the role of another key player.</td>
<td>Recommendations for future work (see Section 7.5)</td>
</tr>
<tr>
<td>Temporary works should be identified as a sub-activity during 'Demolition Activities' and 'Actual Refurbishment'.</td>
<td>Added as task in DSS database</td>
</tr>
<tr>
<td>Need to address the flexibility/overlapping of activities within RPM when applying and using it with different situations and project stages.</td>
<td>Soft gates introduced to provide that flexibility</td>
</tr>
<tr>
<td>The sequence of some stages e.g., conceptual design and detailed design need some modification.</td>
<td>Sub-activities (e.g., investigate structural rigidity, preparation of a waste management plan) were added.</td>
</tr>
</tbody>
</table>
5.7.5 Benefits of the RPM

The benefits that the refurbishment process model offers can be summarised as follows:

- RPM represents one of the first attempts to formalise the refurbishment process and provides greater clarity on the key stages, activities, sub-activities and participants in a refurbishment project;
- RPM adds to the Process Protocol by modelling the 'Refurbishment Management Activity Zone';
- RPM provides for safety considerations to be taken into account from the early stages of a refurbishment project;
- RPM offers support to project participants at both strategic level and operational levels;
- RPM helps users to identify the key decision-making stages and encourages a structured approach to tackling refurbishment projects and enhancing safety;
- RPM serves as a useful framework for the development of a DSS to improve safety on refurbishment projects.

5.7.6 Limitations of the Validation Process

The main limitations of the validation were identified as:

- The validation was based on a paper review of the process model, as it was beyond the scope and timeframe of the research project to use it in a real life project;
- The participants during the third validation workshop represented a wide spectrum of industry practitioners rather than specialised contractors;
More targeted feedback from contractors involved in different types of refurbishment projects (i.e. type of building) would probably have elicited additional perspectives on structural refurbishments.

5.8 Summary

The review of process modelling in construction highlighted the absence of a information based process model for refurbishment sector. The developed Safety-Integrated Refurbishment Process Model, provides structured sequence of activities during the project life-cycle and incorporates multiple feedback process for all the project participants involved at various stages of the actual process. The process model was validated at three workshops. Overall the validation was considered a success as most of the participants appreciated the usefulness of the RPM and provided very useful feedback, which informed the further refinement of the process model. The chapter provided an efficient framework for the decision support system by developing a safety-integrated refurbishment process model. The next chapter describes the Decision Support System, which is based on the process model.
6.1 Introduction

This chapter describes the development of the DSS to avoid structural collapses on refurbishment projects. It starts with an outline of the objectives of the system development, which is followed by a detailed description of the system development process including database design, user interface design, and code development. The evaluation of the system is also presented and the results analysed.

6.2 Objectives of the System Development

The primary objective of the system development was to demonstrate how the decision support system can offer proactive support to the key parties involved in refurbishment projects. From the end-user requirements captured, the HSE inspectors involved with refurbishment projects were of the opinion that the system should be able to prompt the end-users with the information and about their roles and responsibilities at different stages of the project. The decision support system does this by providing guidance in a structured manner so as to facilitate making the right decisions at the right time. It was also important to ensure that the DSS was aligned with the new refurbishment process model, and that it contained enough information to
help refurbishment project team members avoid structural collapses in their projects.

6.3 Decision Support System Development

6.3.1 System Architecture

The system architecture of a software system is the design of the entire software system. The architecture of the prototype decision Support System (DSS) or avoiding structural collapse in refurbishment projects is shown in Figure 6.1.

![System Architecture of the DSS](image)

Figure 6.1 System Architecture of the DSS
6.3.2 Components of the DSS

The principal components of the architecture are discussed below:

**Graphical User Interface (GUI):** The GUI acts as the medium through which the end-user interacts with the DSS. It provides user-friendly mechanisms for user input as well as the display of the system's outputs.

**Database Module:** This module contains all the information relevant to the system and handles all the queries. The checklist of questions that are relevant at various stages of the refurbishment process is stored in the database.

**External Information Link:** This module in the system architecture provides the user with a link to external information available elsewhere (e.g. on the Internet).

**Project-Context Information:** This module contains project-context-information about a particular refurbishment project. The system uses this as the context for user’s input at a particular stage. The evaluation score thus provides the project participant decision-making at each stage of the refurbishment process. The project-specific information is saved automatically in the database.

**Decision Analysis:** This module performs the reasoning function within the DSS and processes the user’s inputs and performs the safety evaluation at a particular stage. This module also makes recommendations on what action(s) the user should take. This information needs to be ‘saved’ and ‘updated’ if the user wishes to return to it at a later date.

The refurbishment process model provides the context for the interaction and enables the system to tailor the guidance provided to the end-user based on the specific stage of the refurbishment process. The end-user interacts with
the system via the graphical user-interface, which provides access to the back-end database and external information.

The flow of end-user interaction with the system is illustrated in Figure 6.2.

![Diagram of Interaction Flow for the DSS]

**Figure 6.2 Interaction Flow for the DSS**

A set of general and role-specific guidance is provided for all project participants. The guidance provided varies in accordance with the stages in the refurbishment process model, as both the requirements and personnel involved also change. Where appropriate, links are provided to help files or websites that contain additional information. Further details of the DSS are provided in the subsequent sections of this chapter.

### 6.3.3 User-Interface and Development of Program Codes

The user interface (i.e. Human-computer Interface) provides communication between user the system. The design of user-interface is a very important aspect of the software development because this affects the user-friendliness of the system. In Visual Basic the user interface is developed first followed by programme codes. This user interfaces developed in Visual Basic were
shown to potential end-users for feedback before the associated programme codes were fully developed. This helped in progressing with the prototype, saving time and effort in the rewriting of programme codes and redesign of the database as selection of the suitable development environment has an impact on the speed and cost of development.

6.3.4 Database Design

The DSS comprises a Database created in Microsoft Access. The database contains the information about the identity and authentication of the users and project information. It helps to ensure that the user with correct user name and password and authorization can access the stipulated sections of the DSS. The database stores all the details pertaining to the DSS and details of the information items are contained in the relevant tables where each table stores only the relevant information. The data stored in tables are linked by relations to create a relational database. This ensured that a non-primary key data is stored in only one table in the database and eliminated the requirement for data updates. Program codes extract information from the relevant tables and update tables. The details of the tables are as follows:

1. Checklist table comprises details of checklists in the database.
2. Functional table comprises details of functions in database.
3. History table comprises details and stores record of inputs by end users.
4. Project history table maintains the history of project records
5. Project Info table stores and maintains the project information entered by end users.
6. Project scores table contains the evaluation scores and reflects evaluation scores on the main screen.
7. UserTable has the list of end-users as identified earlier
8. ZoneStatusTable has details of completion status of a particular zone

Figure 6.3 illustrates the back-end database for the DSS.
Figure 6.3 The Back-end Database

Figure 6.4 depicts the relationships between the various tables in the database.
Figure 6.5 provides details of one of the backend database phase table while Figure 6.6 illustrates the back-end database zone table in relation to other tables.

Figure 6.5 Back-end Database Phase Table

Figure 6.6 Back-end Database Zone Table
Figure 6.7 shows the backend functional table featuring the various end-users of the system.

![Figure 6.7 Back-end Database Functional Table](image)

Figure 6.8 shows the user table with user names and passwords to log-on to the system which can easily be changed if required.

![Figure 6.8 Back-end Database User Table with username and password](image)
6.4 System Operation

Since prospective users of the DSS include engineers, managers and site based staff, practicality and ease of use are of paramount importance. Hence, commonly used Windows-based software was selected as the platform for the prototype development. The prototype system has been developed using Visual Basic (VB) which enables the development of programs that can be used as a front-end application to a database.

The operational objectives of the system were to:

- Provide structured information at various stages of the refurbishment project life-cycle;
- Enable the project participants to undertake safety evaluation to know if they have done what they are supposed to have done at a particular stage;
- Enable project participants to make rational and justified decisions by providing context-specific information before taking on next activity;
- Enables the user to access additional domain specific information available at various internet portals;
- Provide a project management tool by providing a stage specific evaluation score to monitor and compare the safety evaluation at a later stage.

6.4.1 System Requirements

The prototype system has been designed to run on a personal computer as an installable software running windows, 2003 and latest version. It requires Microsoft Word, 2003 and Microsoft Access 2003. Visual Basic 6.0 is required to make any changes to the user-interface and MS Access to work with database for adding more relevant questions in the checklist suitable to a particular stage and activity.
The Decision Support System is composed of two main parts: a knowledge base and a decision-making sub-system. The iterative nature of the process in the system insists that certain safety conditions are fulfilled before the user (and the refurbishment project) moves to the next stage. A graphical user-interface (GUI) has been developed to facilitate end-user login and to incorporate the other forms designed to accept the users' input. It interacts with the database and information source which are interconnected. The user-interface design was very important as the system needed to be easy to use. The resulting DSS can be easily navigated, with user friendly screens and dialogue boxes that guide the user through the system. Figure 6.9 illustrates the start screen of the decision support system.

![Decision Support System Start Screen](image)

**Figure 6.9 Decision Support System Start Screen**

The following section describes the operation of the DSS with the relevant screen shots. After logging into a particular category the end-user is prompted to look at the various stages of the refurbishment project and, depending on what activities he/she is involved in, can have access to the guidance needed (based on the data stored in the back-end database). The end-user, after going through the checklists, can have an interim safety evaluation to know if
he has done what is required of him for his role and involvement at that particular stage before proceeding to the next phase/stage of the refurbishment project. Figure 6.10 illustrates the welcome screen, providing initial guidance to the end-user about the system and how the DSS works.

![DSS Welcome Screen](image)

Figure 6.10 DSS Welcome Screen

6.4.2 Logging In

The user logs into the system using a pre-assigned username and password and has to specify his/her role on the project. The user is also required to enter the details of the project. These are essential requirements and must be filled in correctly, so that the appropriate guidance is provided by the system. are essential. Figure 6.11 illustrates login dataflow diagram.
Figure 6.11 Login Dataflow Diagram

When the DSS is started, the login screen is displayed (see Figure 6.12).

Figure 6.12 The log in screen
On completion of his/her session, the user can log-out. Where appropriate (e.g. when a user has more than one role; for example if a contractor is project manager as well), he/she can log-in again using different username, password under different category.

![Invalid Password](image1.png)

**Figure 6.13 Invalid Password**

The user then is required to enter the project details (See Figure 6.14) into the login box and Project ID needs to be unique as the system will not allow the user to use the same project ID (see Figure 6.15 and 6.16).

![Creating a New Project](image2.png)

**Figure 6.14 Creating a New Project**
According to the text provided, the user is required to go through the top level evaluation by either opting 'Yes' or 'No' and evaluate his score. Answering 'Yes' to all the top level questions prompts the user to either exit out of the system or start afresh. In the event of answering 'No' to even one of the questions, the system asks the user to do a detailed evaluation and
takes him/her to the first activity, for example 'Feasibility Plan and Identify Scope of Refurbishment' for a detailed evaluation. The user is required to 'click' the next button to go through the next relevant stage. The colour of the flag lights beside the stages reveals the score after the evaluation.

Figure 6.17 Initial DSS Screen

If the user is not sure and has any doubts about the system and needs to know how to start with the system, the screen has a button 'How do I start' on the top right hand corner (see Figure 6.18). The user can click on this button to have access to the required information, and after reading the screen, the user can click 'OK' to start with the system.
The OSS supports various project participants in decision making to avoid structural collapse during structural refurbishment of buildings.

**HOW DO I START**

All users must complete the top level evaluation by selecting either 'Yes' or 'No' and press the 'Evaluate' button to calculate their score. If the user has successfully done the top level evaluation, he can either click on 'Exit' to get out of the system or opt for 'Back to start' to start after log-in you need to undertake the top level evaluation, which is comprised of six top level questions. You can either 'Evaluate' or 'Exit' from the system. After a successful evaluation you can either opt for 'Back to start' or 'Exit' from the system. With an unsuccessful evaluation, you will have to undergo for the detailed evaluation.

At the detailed evaluation stage you have to answer two sets of questions. With the first set you are required to rate the questions between 1 and 5 depending on the extent to which you have addressed a particular question. The second set of questions require a 'yes' or 'no' answer. The rating questions turned if you have not answered the question to the required level. If you are not sure about a question or need additional information, you can 'click' on the question itself and related web links will be made available, if appropriate. Clicking on the 'Evaluate' button results in an evaluation score being computed.

The traffic lights allows user to navigate through the relevant stage and only after successfully answering the question to the desired satisfactory level lets you go the next relevant stage, which will otherwise remain inactive.

**Figure 6.18 How to start with DSS**

Next screen shot (Figure 6.19) illustrates the checklist screen for the 'Architect' during the 'Feasibility Plan and Scope of Refurbishment' stage. The checklist screen allows the user to check on his/her roles and responsibilities and specifies the information needed for this particular activity during that particular stage of the refurbishment process.

The questions are in two categories: the first set has ratings from 1 to 5 (1 representing 'haven't done anything', 2 representing 'thinking of doing it', 3 representing 'in the process', 4 representing 'advanced stage' and 5 representing have 'completed the task') and the user is required to specify the degree of confidence he/she has that a particular requirement has been satisfied. Unless a pre-determined threshold (set based on previous literature and case studies) for each question has been achieved, the user is not allowed to proceed any further. Guidance is provided on what needs to be done to achieve the required confidence and, hence, safety level.
The second set of questions has to be answered by selecting the ‘Yes’ or ‘No’ button. This applies in situations where something has either been done or not.

Figure 6.19 Checklist Screen for the Feasibility Plan Stage

Again, the right answer must be provided before the user can proceed. Clicking on the ‘Evaluate’ button at the bottom of the screen makes the system evaluate the safety confidence level of the end-user for that particular stage of the process. The user is then required to click on the ‘Update’ button at the bottom to save the evaluation and click on the ‘Exit’ button to go back to the initial DSS screen and move to the next activity at that stage.

Next screen shot (Figure 6.20) illustrates the checklist screen for the ‘Architect’ during the ‘Feasibility Plan and Scope of Refurbishment’ stage.
There is also scope for end-users to request more information on aspects of the checklist. For example, when the user (e.g. client) is undergoing the evaluation and not clear about a question which asks him about his role and responsibilities not he is not sure what his duties and responsibilities really are, the system can generate an alert box by clicking on the question itself that will give further details. Figure 6.21 shows the ‘More information alert box’ for one of the questions on the checklist screen during the ‘Feasibility plan and identify scope of refurbishment’ stage.

Figure 6.20 The Checklist Screen for the Demolition Stage

Figure 6.21 More Information Alert Box
Figure 6.22 shows the external link to other resources and information on the Internet or elsewhere and illustrates one of the key features of the system.

6.4.4 Report Generation and Dissemination of Information

This section describes how the information generated is to be disseminated. After the detailed evaluation is completed, the system generates an 'evaluation report' in Microsoft Word (see Figure 6.23). The system allows the user to download/print or save this report for future references and keeping a track record of evaluation by a particular project participant at a particular stage on a particular date. In addition this information can be made available to the project manager for any future actions and decisions regarding safety of the structure and site.
Chapter 6 Development of Decision Support System

The next diagram (Figure 6.24) depicts the DSS flow diagram.
Figure 6.24 DSS Flow Diagram
6.5 Testing and Evaluation of the Decision Support System

6.5.1 Introduction

This section describes the objectives, procedures and results of the testing and evaluation of the prototype DSS. The acceptance test was first conducted on the prototype software, followed by evaluation of the DSS prototype by industry practitioners as described in Section 6.6.3. Although there is some overlap between software testing and software evaluation in literature, it is essential to distinguish between the testing and evaluation of software. Hence, for the purpose of this research, testing is regarded as an examination of the functionality to ensure that the software is free from error. While evaluation is regarded as the subsequent process to obtain feedback from the potential end-users on whether the software has addressed its design requirements and for further refinement of the system. Thorough testing requires considerable effort because of the problems associated with getting suitable evaluators and the practicality of carrying out the evaluation. In the light of this, an evaluation of the DSS was undertaken using industry practitioners and researchers. The objectives of the testing and evaluation were as follows:

6.5.2 Objectives of the Testing

Software testing and the systematic thorough evaluation of decision support systems is a critical aspect of software development in order to determine whether the results it produces are correct (Glass, 1979). Omission of this step may lead to reliance on a system with outputs of uncertain quality, although, according to Roper (1994), software testing tends to refer to testing of program codes only. Hetzel (1993) defines testing as any activity aimed at ‘evaluating’ the capability of a program or system. However, the testing aspect will be covered inevitably as various aspects of the software are assessed in software evaluation (Vlahavas et al, 1999).
The main objective of the testing was to ensure that the prototype will work as intended. The requirement details of the DSS prototype that were subjected to testing are depicted in Table 6.1

### Table 6.1 Test Results from the Requirement Test

<table>
<thead>
<tr>
<th>Input</th>
<th>Output</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Logging into the system using user name, password and category</td>
<td>Login successful</td>
<td>✓</td>
</tr>
<tr>
<td>Creating New project</td>
<td>Created successfully</td>
<td>✓</td>
</tr>
<tr>
<td>Log out from system</td>
<td>Log out successful</td>
<td>✓</td>
</tr>
<tr>
<td>Access to Welcome screen defining scope of DSS</td>
<td>Next screen appears</td>
<td>✓</td>
</tr>
<tr>
<td>Click to access system information</td>
<td>Next screen appears successfully</td>
<td>✓</td>
</tr>
<tr>
<td>Click to start DSS application</td>
<td>The main screen displayed</td>
<td>✓</td>
</tr>
<tr>
<td>Click to perform top level evaluation</td>
<td>Top level evaluation performed</td>
<td>✓</td>
</tr>
<tr>
<td>Click to help menu ‘How do I start’</td>
<td>Help screen appears</td>
<td>✓</td>
</tr>
<tr>
<td>Click to get more information about the question</td>
<td>The window appears providing clarity about the question</td>
<td>✓</td>
</tr>
<tr>
<td>Click to access additional information through hyperlinks</td>
<td>Links to additional information available on web</td>
<td>✓</td>
</tr>
<tr>
<td>Click to do detailed evaluation score</td>
<td>Calculates the evaluation result</td>
<td>✓</td>
</tr>
<tr>
<td>Click to save the score</td>
<td>Saves the evaluated score</td>
<td>✓</td>
</tr>
<tr>
<td>Click to update the score</td>
<td>System updates the score for future reference</td>
<td>✓</td>
</tr>
<tr>
<td>Report generation</td>
<td>System generates an evaluation report</td>
<td>✓</td>
</tr>
</tbody>
</table>

### 6.5.3 Objectives of the Evaluation

The evaluation can be distinguished into ‘formative’ or ‘summative’ depending on the stage at which it occurs. According to Scriven (1991), formative evaluation is usually done with a small group of people to ‘test run’ various aspects during the development or improvement of a program with the intent to improve, whereas summative evaluation of a program (the ability to do what it was designed to do) is conducted after completion of the program for
the benefit of an external audience or decision-makers. It is only by carrying out an evaluation that the strengths and weaknesses of the system can be truly assessed (Miles et al, 2000). Paec (2001) suggested four typical basis for evaluation as:

- To identify the features in the system that can be improved;
- To provide accurate estimation of how well a system meets the goals of domain task;
- To allow for comparative judgement of one system against another; and
- To discover tradeoffs between various features.

Given the current research context, the first two of the aforementioned objectives are considered very relevant while the last two are not considered particularly relevant. Thus in order to evaluate the usefulness and the impact of the prototype, the following evaluation objectives were identified:

- To assess the functionality of the system;
- To obtain user feedback for further refinement of the system;
- To assess the effectiveness and coverage of the system; and
- To explore the applicability and usability issues related to the prototype deployment.

6.5.4 The Adopted Evaluation Approach

it is important that engineering researchers subject their research to thorough evaluation procedures as recommended by Miles et al. (2000). System evaluation was undertaken by conducting workshops, where the DSS was presented to industry experts involved in refurbishment projects. The responses of the participants were noted and, where appropriate, the DSS was modified in line with the feedback received. The evaluation and refinement of the DSS was iterative and hence required feed-back from
industry practitioners and continuous update of the system. In order to assess the decision support system two workshops were conducted at the end of system development. Both of these were held in Glasgow - the first involved 27 participants, who watched a presentation of the system and then completed an evaluation questionnaire, while the second was a follow-on which involved 7 participants who had hands-on experience of using the system (see Table 6.2).

<table>
<thead>
<tr>
<th>Workshop</th>
<th>Workshop 1</th>
<th>Workshop 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>No of Participants</td>
<td>27</td>
<td>7</td>
</tr>
</tbody>
</table>

**First workshop**

The first workshop was held in Glasgow and organized by Glasgow Caledonian University and The Centre for the Built Environment (CBE). The workshop was well attended by 27 participants which included architects, structural engineers, contractors, planning supervisors and H&S advisors (see Figure 6.25). The participants represented large and small organisations.

![Graph showing diversity of participants during DSS evaluation workshop](image)

**Figure 6.25** Classification of Participants by Role at Workshops
The workshop started with the presentations on problems with refurbishment and how refurbishments could be made safer by adopting a safety-integrated refurbishment process model. This was followed by a demonstration of the DSS after which the participants completed a questionnaire. The results are presented in Section 6.7

**Second workshop**

A follow-on workshop was held at Glasgow Caledonian University so as to afford participants from the first workshop, the opportunity of a hands-on practical workshop. The workshop was attended by seven respondents including architects, structural engineers, contractors and planning supervisors. Each evaluator was given sufficient attention and adequate time to go through the entire evaluation of the system.

**6.5.5 Evaluation Questionnaire Design**

A questionnaire (see Appendix D) was designed to evaluate the prototype against the end-users' requirements for developing a DSS to avoid structural collapses on refurbishment projects. The questionnaire comprised two sections. Section A covered the background information about the participants. Section B comprised 5 open ended questions and 13 questions grouped under four sub-sections:

Section 1 - Effectiveness of DSS,
Section 2 - Functionality of DSS,
Section 3 - Coverage and scope of DSS,
Section 4 - Ease of use and
five open ended questions about the DSS.

The participants were requested to provide their answers to the questions using a rating on a 5 point Likert scale with 1 representing the lowest and 5 the highest rating. The open ended questions provided an opportunity for the
participants to identify the most useful sections of the process model and to put forward their suggestions for improvements.

6.6 Analysis of the Evaluation Results

6.6.1 Overview

Table 6.3 provides the average ratings with respect to the specific questions in the evaluation questionnaire.

Table 6.3 Ratings of Key Features of the Prototype DSS
(Obtained from Evaluation Questionnaire)

<table>
<thead>
<tr>
<th>EVALUATION QUESTIONS</th>
<th>Workshop 1</th>
<th>Workshop 2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Average Rating (Out of 5)</td>
<td>Equivalent %age</td>
</tr>
<tr>
<td>EFFECTIVENESS</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 How effective might the DSS be in decision making relating to refurbishment?</td>
<td>3.2</td>
<td>64</td>
</tr>
<tr>
<td>2 How effective/well does the DSS fit into your current work practice?</td>
<td>2.8</td>
<td>56</td>
</tr>
<tr>
<td>3 Do you think the DSS can be effective in reducing structural collapse in refurbishment projects?</td>
<td>3.2</td>
<td>64</td>
</tr>
<tr>
<td>FUNCTIONALITY</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4 How suitable is the DSS for existing refurbishment process?</td>
<td>2.9</td>
<td>58</td>
</tr>
<tr>
<td>5 How appropriate are the questions/issues addressed in the DSS?</td>
<td>3.0</td>
<td>60</td>
</tr>
<tr>
<td>6 To what extent does the DSS represent an improvement over your current refurbishment process?</td>
<td>2.6</td>
<td>52</td>
</tr>
<tr>
<td>COVERAGE AND SCOPE OF THE DSS</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7 How well does the DSS cover the duties of the key players and key stages of a refurbishment project?</td>
<td>3.3</td>
<td>66</td>
</tr>
<tr>
<td>8 How well are the activities addressed in the DSS?</td>
<td>3.3</td>
<td>66</td>
</tr>
<tr>
<td>9 How well are the key problem areas addressed in the DSS?</td>
<td>3.4</td>
<td>68</td>
</tr>
</tbody>
</table>
It is evident from the high average rating score that most of the participants found that DSS to be effective and easy to use. Another notable finding has been that perception about the DSS improved significantly after the hands on use of the DSS. The responses were analysed under four categories to understand the effectiveness, functionality, scope of DSS and its usability in refurbishment projects.

### Effectiveness

Thirty six (36%) percent of the respondents (see Figure 6.26) felt deployment of a refurbishment process model could be quite effective or very effective for the refurbishment projects, whilst 40% felt that DSS could still be effective. Only four percent of the respondents gave negative feedback.

<table>
<thead>
<tr>
<th></th>
<th>Effectiveness of DSS in Decision Making</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Effective</td>
</tr>
<tr>
<td>12%</td>
<td>20%</td>
</tr>
</tbody>
</table>

Figure 6.26 Effectiveness of DSS in Decision Making
Majority of respondents (87%) felt that DSS could effectively fit into their system of work (see Figure 6.27). Twenty nine percent (29%) of the respondents felt that DSS can fit in quite effectively or very effectively into their current work practices. Another 58% felt it could be effectively or somewhat effectively fit into their current system of work. Only 13% responded negatively.

![Figure 6.27 How effectively DSS fits into current work practice](image)

All the respondents agreed that the DSS can be effective to varying degrees at reducing the structural collapses in refurbishment projects (see Figure 6.28). While 75% of the respondents felt that DSS can be quite effective or effective in reducing the collapses in refurbishment projects, 25% felt it could be somewhat effective.

![Figure 6.28 How effective can the DSS be reducing structural collapse](image)
Functionality

Sixty eight percent (68%) of the respondents (see Figure 6.29) felt that DSS is suitable for their current practices of refurbishment, while 32% of the respondents felt that DSS does provide some improvement over their current practice.

![Figure 6.29 Suitability of DSS for existing refurbishment practice](image)

Twenty three (23%) percent of the respondents (see Figure 6.30) felt that issues and questions in DSS are covered to a great extent or quite an extent. Another 72% percent of respondents felt the issues and questions in DSS covered effectively or effective to some extent, while only 5% responded negatively.

![Figure 6.30 Appropriateness of Issues and Questions in DSS](image)
About suitability of DSS over existing practices, forty six (46%) of the respondents felt that DSS can be greatly effective or effective. Another 31% of the respondents felt it could be effective to some extent, while 23% respondents responded negatively (see Figure 6.31).

Figure 6.31 Suitability of DSS over Existing Practice

Coverage and scope of the DSS

On the coverage of duties of key players during structural refurbishment, thirty eight percent of the respondents felt that it is covered extremely well or very well. Another 43% of the respondents felt that DSS covers the issue quite well, while 19% felt it does to some extent (see Figure 6.32).

Figure 6.32 Coverage of Duties of Key Players in DSS
All the respondents felt DSS will facilitate in planning for safety (see Figure 6.33). Forty seven (47%) of the respondents felt deployment of DSS will facilitate to great extent in planning for safety. Twenty nine percent respondents felt that it could facilitate to quite an extent, while 24% felt that use of DSS will definitely facilitate to some extent in planning for safety.

![Figure 6.33](image)

Figure 6.33 How Well Does DSS Facilitate in Planning for Safety

All the respondents felt that key problem areas are covered in the DSS (see Figure 6.34 for the detailed break up of the responses). Forty eight percent (48%) respondents felt that key problem areas have been covered extremely well or very well in the DSS. Thirty three percent (33%) of the respondents felt these have been covered quite well, while 19% felt that these areas are covered to some extent.

![Figure 6.34](image)

Figure 6.34 Addressing Key Problem Areas in DSS
Usability

Sixty percent (60%) of the respondents (see Figure 6.35) felt that format of the DSS is quite easy to understand, while 40% felt that it was not neither easy nor difficult.

![Figure 6.35 Format of DSS](image)

Thirty three percent of the respondents felt (see Figure 6.36) that the user-interface of DSS is consistent and quite easy to understand, while 67% were not sure about it.

![Figure 6.36 Ease in Use of DSS](image)

Forty percent (40%) of the respondents (see Figure 6.37) felt that it was quite easy or consistent to navigate through various parts of the DSS, while 60% felt that it was neither easy nor difficult to navigate.
Forty percent (40%) of the respondents (see Figure 6.38) felt that prompt and help facilities in DSS are very useful or quite useful, while 60% percent of the respondents were not sure about it.

6.6.2 Discussion

Although the respondents at the first workshop were generally satisfied with the DSS demonstration, they felt that it would be good to have hands on experience of the software. It was in response to this that the second hands-on workshop was held. The evaluation of the DSS can be considered successful which was manifested by the positive responses obtained from the evaluators. As evident from Table 6.3 the ratings and equivalent percentages
improved considerably after the first workshop and after the respondents could work independently with the DSS software. From the results of the evaluation, it is evident that the objectives set out in Section 6.5.3 have been achieved.

6.6.3 Comments by Evaluators

Some of the comments by the evaluators include:

- External link and help function to other sources prompts user to excellent information;
- The use of traffic lights (green, amber, red, magenta, black) clarifies involvement of an individual, maintains evaluation record to create a sense of urgency and prompting action;
- It is a simple compact tool with gateway facility whereby question turning red with low rating during evaluations give indication of the seriousness of a particular issue;
- The list of enlisted stages and main activities as a checklist enables to check that each major activity has been completed or thought about;
- It is a competent attempt at addressing the issue to improve evaluation of decision making process associated with structural refurbishment and a good guide for staff training for structural refurbishment works;
- Very useful system for more wide ranging projects as opposed to only structural refurbishments and handy for admin purpose also and should be extended to, working at height, dates should be added for proposed completion of an activity as it would provide a convenient and quick access to important contract information;
- It is a very useful tool and would be a waste to restrict its use only on ‘Refurbishment’ projects as it could be further developed to prompt on all types of projects;
• The system should be a web-based as it goes far beyond structural collapse issues to enable people who might benefit even if not associated with refurbishment;

• Following CDM regulations some of the participants felt it should adhere to roles described in CDM like principal contractor and CDM co-ordinator in place of planning supervisors who have more powers in New CDM Regulations 2007.

6.6.4 Feedback by Evaluators

The fact that most of the evaluators understood the DSS and appreciated its usefulness provided the real credibility to the DSS. The participants described the prototype as, ‘an excellent decision aid tool’. They appreciated the function in the DSS which allows to add relevant information and documents easily into the system. The interface design, and easy format proved that the DSS had successfully addressed the end-user requirement of providing context-specific information to aid in decision making without significant additional workload.
Table 6.4 Summary of Evaluator’s feedback

<table>
<thead>
<tr>
<th>Feedback from Evaluators / Suggestions for Improvement</th>
<th>Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>One participant questioned whether all the evaluators need to go through the detailed evaluation every time one undertakes the evaluation.</td>
<td>Top level evaluation introduced. Only those who do not qualify at top level evaluation need to go through the detailed evaluation.</td>
</tr>
<tr>
<td>Three evaluators suggested if there is possibility to see all the tasks by all the end-users irrespective of the role to understand about what is being expected by others and what is being/has been done by other project participants?</td>
<td>List of tasks was amended to include complete list of tasks during a particular sub-activity. However only those relevant to a particular end-user will be active, while others remain inactive.</td>
</tr>
<tr>
<td>One evaluator questioned about the clarity and additional information about a particular task?</td>
<td>Task details introduced by ‘clicking’ on the task itself, with additional information available.</td>
</tr>
<tr>
<td>Another evaluator questioned about how would an end-user know about his involvement at relevant stages and his result from his previous evaluation.</td>
<td>Six Traffic lights introduced to keep the end-user aware of the level achieved and completion of task.</td>
</tr>
<tr>
<td>An industry expert had concerns about the utility of such system for project management.</td>
<td>Further development required.</td>
</tr>
<tr>
<td>An expert wanted to explore if evaluation report could be generated that can be viewed and printed for audit purpose?</td>
<td>Option to print evaluation report introduced.</td>
</tr>
<tr>
<td>One participant wanted to know how much time would the developers want the people on site could devote to such system?</td>
<td>The task was introduced in the evaluation task and responses were sought by the evaluators during the workshop on average 20-25 minutes.</td>
</tr>
</tbody>
</table>
An industry expert suggested if it the system could have external link to access available information on other portals.

One evaluator highlighted the trust issue on responses by the system users.

Provide sufficient and user-friendly guidance on how to use the system. Another evaluator wanted to know if one can have access to the ‘Help function’ to access the guidance and working of the system not just at the beginning but throughout the evaluation.

Another evaluator expressed concerns about problems encountered with regular update of database and to keep it context-specific.

Another user wanted to know how would system respond if the user has multiple roles and/or if the end user wants to change the role?

One evaluator pointed out difficulty in accessing and using such system

| Suggestion taken on board and Incorporated in the user interface. |
| Rating scale provide details what is meant by opting 1, 2 and subsequent options. |
| ‘How Do I Start’ button introduced on the main screen. The user can 'click' on the button to access information about the DSS any time during the evaluation. |
| Recommended in further development of the system as web-based for better accessibility. |
| The user can log out and log in as different end-user. |
| The system developed as Installable programme was then uploaded as executable file. Suggestion included in further recommendations. |
6.6.5 Strengths of Evaluation Approach

The evaluation approach adopted to evaluate the system proved to be appropriate. This was revealed by the positive feedback received from the evaluators. Although there were limitations, further evaluation and improvement of the system would facilitate the use of the prototype for practical purpose. The strengths of the adopted system evaluation can be summarised as follows:

- The evaluation questionnaire covered all major aspects of the system that needed to be evaluated and was useful for obtaining the required feedback from the evaluators;
- The evaluation workshops provided a platform for the participants to engage in discussion;
- The evaluation provided an insight into how the system could be improved;
- Ninety two percent (92%) of the participants in first workshop came from the industrial background and thus provided a thorough assessment on the practicality of the prototype.

6.6.6 Limitations of the Evaluation Approach

The comments regarding the limitation of the prototype system evaluation were not too many. The main limitations of the evaluation approach are outlined below:

- The evaluation did not involve the deployment of the DSS on a real life refurbishment project, as there was neither time nor a suitable project available;
• The DSS was evaluated at two workshops attended by a wide spectrum of industry practitioners. Though most of the participants had been involved in refurbishment projects, only a few were representative of small contracting firms involved in structural refurbishment projects.

6.7 Summary

This chapter has described the development and evaluation of the Decision Support System (DSS) for avoiding structural collapses on refurbishment projects. Details of the system operation were presented by the inclusion of the numerous screen shots from the software. The system was evaluated during workshops with a cross-section of practitioners from the industry.

The decision support by providing guidance and certainty in the structured manner would definitely help making right decisions at right times. DSS will provide support to project participants during various stages of refurbishment with information, options, safety control measures and will improve end-users’ decision making capabilities where further guidance is required during structural refurbishments. The next chapter presents the conclusions drawn from the research and the recommendations for further research.
7.1 Introduction

This chapter concludes the research that sought to develop a decision support system to avoid structural collapse during structural refurbishments. It summarises the research undertaken, followed by the key conclusions drawn from the research. The subsequent section presents the limitations of the research and makes recommendations for further research.

7.2 Summary

The aim of the research was to develop a methodology for developing a Safety-Integrated Refurbishment Process Model and establish its viability as the basis for a Decision Support System (DSS) to avoid structural collapses in refurbishment projects and exploit the benefits of technology. The rationale for undertaking the research was the need to address the issue of decision support during structural refurbishments. The aim was achieved following the successful development and positive evaluation of the DSS. The methodology developed comprises refurbishment process model and decision support system. Various research methodologies were used to achieve the objectives of the research, including an extensive literature review; case studies, interviews, workshops and evaluation of the RPM and
the DSS software. The aim was achieved through following six specific objectives of the research:

- To review current practices adopted for managing health and safety on refurbishment projects with a view to adopting best practice and identifying opportunities for improvement;
- To identify the different stages of involvement of key functionaries under given circumstances and situations and their effect on decision-making during refurbishment;
- To identify areas that need support for effective health and safety management on refurbishment projects and to establish end-users' requirements;
- To develop a safety-integrated process model for structural refurbishment to ensure that safety considerations are taken into account from the earliest stages in the planning and design of refurbishment works;
- To develop a Decision Support System (DSS) to avoid structural collapses during structural refurbishments by identifying functional specifications through appropriate system development;
- To evaluate the resulting prototype system with industry practitioners and then to refine the system based on the feedback received.

The specific tasks undertaken during this research, with respect to research objectives are summarised below:

**Objective 1 : To review current practices adopted for managing health and safety on refurbishment projects with a view to adopting best practice and identifying opportunities for improvement.**

This objective was set in order to identify the gaps in existing knowledge with a view to identifying best practice and problem areas. The literature review and case studies demonstrated that the main causes of structural collapses
during structural refurbishments are: unplanned demolition; lack of detailed structural appraisal, unavailability of ‘as built’ drawings; incompetent or inexperienced project teams and absence of decision support tools to undertake the works safely. It was also found that some previous studies on health and safety in refurbishment have tried to look at some of these problems specifically with demolition and structural instability; design aspect during refurbishment; indoor and environment quality of the facility.

**Objective 2 : To identify the different stages of involvement of key functionaries under given circumstances and situations and their effect on decision-making during refurbishment.**

Detailed literature review on the practices and process of refurbishment revealed that there are several problems during different stages of structural refurbishments. These are: unavailability of complete information; poorly defined scope of work; the additional risks involved with refurbishment including findings, structural collapse; simultaneous activities and overlapping process. Detailed discussions with industry practitioners to understand the way in which key decisions are taken during structural refurbishments were held. The major factors which influence decision-making were identified as lack of information and information flow. The complexity of refurbishment projects and the fact that in many instances clients, contractors and subcontractors often take up refurbishment jobs without involving specialists and competent personnel further add to the problems. The involvement and appointment of a demolition consultant and/or contractor at the feasibility stage of the project would not only make demolition safer but would provide access to expert advice right from the feasibility stage to post-refurbishment stage. There is need to overcome information-specific barriers for decision-making. The key decision-making areas during structural refurbishment and the key enablers for effective decision-making have been established and documented in this study. Further review of existing literature helped in identifying major issues during the planning and design stages of the refurbishment projects.
Chapter 7 Conclusions and Recommendations

Objective 3: To identify areas that need support for effective health and safety management on refurbishment projects and to establish end-user requirements.

This task was undertaken through a limited set of case studies of selected refurbishment projects where collapses had actually occurred. The aim was to establish the end-users' requirements and to identify the areas where decision support is required, prior to refurbishment. This involved case studies and interviews with contractors, demolition contractors, structural engineers, project managers, planning supervisors and health and safety practitioners, who were identified as the end-users of the decision support system and would benefit most from such a system. The end-user requirements for the development of the DSS were as follows:

- The DSS must facilitate the project participants about their role and their responsibilities;
- The DSS should be able to highlight the major tasks to be undertaken by a particular project participant at a particular stage of the refurbishment;
- The DSS should be able to provide required guidance on H&S problems commonly occurring on refurbishment projects;
- The system should be capable of legal requirements and statutory duties imposed on various project participants by the regulations;
- The DSS should be able to provide context-specific information to aid in decision making without significant additional workload.

Objective 4: To develop a safety-integrated process model for structural refurbishment to ensure that safety considerations are taken into account from the earliest stages in the planning and design of refurbishment works.

The literature review suggested the need for the development of a process model for the refurbishment projects. The research undertaken in achieving...
this objective highlighted the need for early involvement of project participants and need for a refurbishment process model that incorporated safety considerations right from the feasibility stage. This led to the identification of the requirements of such a model and appropriate modelling techniques to represent it. In order to achieve the afore-mentioned objective it was envisaged that any such model should be realistic, genuine and should account for the dynamics of collaborative working among multi-disciplinary teams involved during refurbishment projects. The other task undertaken was to identify major activities, sub-activities and the role of each project participant during the various stages of a refurbishment project’s life-cycle and the evaluation of this process model by industry practitioners. The overall evaluation of the model was a success as most of the evaluators appreciated the usefulness of the RPM and provided very useful feedback, which were incorporated to refine the model.

**Objective 5**: To develop an **Decision Support System (DSS)** to avoid structural collapses during structural refurbishments by identifying functional specifications through appropriate system development.

The research project focussed on the development of a Decision Support System, the appropriate use of which is expected to improve decision-making during refurbishment projects and enable the reduction of structural collapses. This involved a review of current industry practices and an assessment of the available decision support tools. In addressing this objective, insights were gained into the available decision support tools for construction and refurbishment works. Other activities as part of this task included the development of the functional requirements of the system, and capturing end-user requirements by conducting semi-structured interviews with industry practitioners. This enabled the development of functional specifications, that formed the basis for the decision support system. The methodology was encapsulated into a prototype application using Visual Basic 6.0 and Microsoft Access.
Objective 6: To evaluate the resulting prototype system with industry practitioners and then to refine the system based on the feedback received.

The overall aim of the research comprised development of a refurbishment process model and a decision support system. The testing of the decision support system in an experimental environment with industry practitioners allowed its appropriateness and usefulness during structural refurbishment. This involved a demonstration of the system, hands-on trials and the completion of an evaluation questionnaire. Based on the findings of the evaluation, the prototype was further refined. The prototype was demonstrated to 27 participants during a workshop for evaluation of the system, followed by another hands-on workshop comprising 7 participants to assess the extent to which it had met the end-user requirements identified from the case studies. Many of the evaluators were of the opinion that the DSS would improve end-users' decision making capabilities and/or in the areas where further guidance is required during structural refurbishments. They also suggested that a Web-based DSS, having more links to additional information from various internet portal would be beneficial.

7.3 Conclusions

The development of the Refurbishment Process Model and the Decision Support System provided insight into the management of health and safety in refurbishment works. The heterogeneous nature of each refurbishment project, lack of research initiative in refurbishment projects and project characteristics have prevented the refurbishment industry from standardisation, which supported the findings by Gibb (2001). Thus, making it difficult to plan and organise safe demolition, alterations and/or modifications of the load bearing members. Some of the main conclusions that can be drawn from the research include:
Refurbishment projects invariably suffer from incomplete information due to missing design documents, 'as-built' drawings and construction records. Detailed structural appraisals, including production of 'as-existing' drawings and appropriate site investigations, should be carried out by competent structural engineers. It was established that right people with adequate experience and knowledge are often available but the right decision which will then trigger the right responses are not taken at the right times; either because the decision maker could not get complete and correct information or the correct information was not available/made available to decision maker;

There is a need to improve the decision-making process in refurbishment projects by providing information on structural safety and integrity as they have inherent risks. This can be achieved by adopting risk-based decision making by which decisions can be made regarding safety, stability and maintenance during structural refurbishments. The RBDM process will ensure that all available information and uncertainties are considered while making the decision to ensure that optimal decisions are made which are consistent with the safety perceptions of all the project participants. With increased group involvement there may be many benefits, such as collaborative working, better understanding of the safety requirements, increased ability to effectively support safety-related activities, and ability to optimise process, procedures and resources during refurbishments;

Refurbishment projects involving partial demolition activities and/or structural alterations require not only experienced and trained, but professionals competent in contemplating risks involved with structural refurbishments. Careful and detailed consideration must be given to any partial demolitions and structural alterations that may interfere with the structural stability of the building;

There is a need to improve the communication and information-flow process during refurbishment projects. Even on a small refurbishment projects project participants, sub-contractors seem to take more risks.
Sub-contractors believe their role is just restricted to a particular job and do not really need to involve/interact with other trade contractors. They do not seem to appreciate the need to inform and kept informed of the responsibilities of other team members. Although most of the time people are used to making decisions on issues which they are familiar with and know the basic information within their own expertise and experience, but many a times they are not so sure what is expected and required from the other project participants;

- There is absence of an information based process model for refurbishment sector. There is a need to improve the investigation, planning, communication, and information flow during the entire refurbishment process. The developed Safety-Integrated Refurbishment Process Model, provides structured sequence of activities during the project life-cycle and incorporates multiple feedback process for all the project participants involved at various stages of the actual process;

- The project participants require decision support that is not only relevant to their particular context but, which also gives them the flexibility to be kept informed of the responsibilities of other team members. The use of decision aid tools can inform the decision-maker prior to each and every stage of the project about the specific requirements;

- The use of a DSS can assist the project participants during the decision-making process by identifying the roles and responsibilities of the various participants, and providing context-specific guidance on issues requiring consideration. The design of DSS prompts collaborative working and thus facilitates in safety during structural refurbishment. Yet, approaches to avoiding collapse on structural refurbishment projects are highly variable and depend, to a large extent, on the available information, expertise and competence of the project team.
7.4 Limitations of the Research

All research studies have their limitations and this research is no exception, as a number of issues have been identified to improve the methodology developed. The limitations of this research include:

- The difficulty of conducting live case studies on structural collapses during refurbishment/construction. The confidentiality and ongoing legal proceedings on some of the recent incidents hampered the conducting of an independent case study. The case study approach relied on semi-structured interviews and thus bias may affect the findings;

- The evaluation of the RPM was based on a paper review of the process model, as it was beyond the scope and timeframe of the project to use it in a real-life project. More targeted feedback could have been elicited from designers and contractors involved in different types of refurbishment projects;

- During evaluation of the DSS it became evident, that people had different perception of the rating scale. This made it hard to make an assessment of whether there was more risk at a particular stage or whether it was simply a matter of difference in perceptions.

- The prototype application which was developed using Microsoft’s Visual Basic can only run on the Microsoft’s Windows platform and the prototype did not provide dynamic, real-time database management system. The system requires regular updates to the database by an authorised person to keep it context-specific;

- It is recognised that more time is required to fully evaluate the prototype application while obtaining constructive suggestions for improvements through individual experience in using it over a longer period of time. This will enable further improvements to the user interface and enhance the richness of the questions in the database. However, this was not possible due to the time constraints inherent in a PhD study.
7.5 Recommendations for Further Work

Despite the generally positive feedback from the respondents in the evaluation of the refurbishment process model (RPM) and decision support system (DSS) and subsequent refinement undertaken, there is still scope for improvement and further research, as follows:

1. There is scope for further development of the process model. Future research on exploring the use of the RPM on a real project will provide more evidence on the validity of the developed process model. This will not only assess the appropriateness of the process model, but further refinement for its use. Some of the additional features that would make the process model more robust and acceptable include:

   - Identification of the project participants responsible for each sub-activity rather than their involvement in general at each stage;
   - Identification of the deliverables and expected outcomes with each sub-activity;
   - Development of the RPM as an authentic plan of work for refurbishment.

2. The DSS can be further improved and further work that can be undertaken in this area include:

   - Exploring the use of the DSS on a real project (as this was outside the scope of the current study); to provide more evidence for the validity of the developed DSS and assess the degree of effectiveness and efficiency achieved by its use, compared to current practices. This will enable its full benefits and limitations to be realised;
   - Making the DSS web-based as the DSS environment is fast changing with the advent of internet. While the traditional server based system have
software installed on individual workstation, web based DSS are available to any person who has access to internet. The additional benefits include accessibility, cross platform flexibility, effective administration and efficient, information and knowledge distribution. Klercker and Klercker (1998) suggested that with growing number of internet users, World Wide Web provides the most significant advantage and best opportunity for greater dissemination of DSS;

- Creating additional web links to information available on various portals. This can be handy for smaller contractors who can have all relevant information available at one place.

3. Another area where future work can be taken up is to study the communication of safety information with the individual’s requirements. While the DSS can flag up issues that need to be considered, there is little guidance on the most appropriate mechanisms for conveying safety information to site workers especially those site operatives whose first language may not be English.

7.6 Concluding Remarks

The process of structural refurbishment is associated with several problems where current strategies and practices fall short of dealing with all of them. The current approaches do not address the problems associated with structural refurbishment completely. The management of refurbishment projects remains generally under-researched and there is need for more work, particularly with regard to collapse/accident causality and other health and safety issues which might have impact on overall safety. This research has made a fundamental contribution by developing a refurbishment process model for better understanding of the refurbishment process. This study has made a contribution by developing a prototype DSS and demonstrated the potential of decision support for facilitating the safe structural refurbishment
by drawing on an integrated knowledge base to provide context-specific information throughout all stages of refurbishment project. The proposed recommendations deriving from both the literature and the main findings emphasise that utilisation of a structured refurbishment process model and implementation of decision support system will provide useful insights and outputs during decision-making which the project participants can utilise to ensure the avoidance of unplanned structural collapses.
References


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40. BS: 6187 (2000), British Standard Institute - Code of Practice for Demolition, UK.


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¹ The Standing Committee on Structural Safety is an independent body supported by the Institutions of Civil and Structural Engineers and the Health & Safety Executive to maintain a continuing review of building and civil engineering matters affecting the safety of structures.


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References

Construction Engineering and Management, Vol.130, No. 2, April, pp 249-257.


References


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35. Ling, Y. Y., Ong, S. Y. and Teo, A. I. (2004), Predicting Safety Levels of Construction Project Sites, Proceedings of the CIB World Congress: Building


55. Sherif, K., and Vinze, A., (2003), Barriers to Adoption of Software Reuse - A Qualitative Study, Information and Management, Vol. 41, pp 159-175.


APPENDIX A

Publications from the Research
Publication List


APPENDIX B

Template for Semi-Structured Interviews for Case Studies
Template for Semi-Structured Interviews

1. Health and safety problems on refurbishment projects
   - What is your experience on managing a refurbishment project and how does the experience helps in addressing the various issues related to refurbishment?
   - What are the most common problems on a refurbishment project?
   - What is the most challenging aspect in structural refurbishment?

2. Key stages of decision-making during refurbishments
   - What are the key decision-making stages during structural refurbishment?
   - Do you think all the site personnel are experienced enough to take independent/joint decisions wherever necessary?
   - How do you communicate the information and do you think you always have sufficient information to take timely decisions?
   - How do you think the decision making could be improved?

3. Roles and responsibilities of key project participants during refurbishments
   - What are the key decision-making stages during structural refurbishment?
   - Have you ever tried to map out the dependencies in terms of responsibilities?
   - How often your personnel who have undertaken training (e.g. health and safety, demolition, asbestos removal, structural appraisal) share their knowledge and help in mentoring the inexperienced staff?
   - Do you think there are any joint responsibilities?

4. Key areas that need decision support
   - What are the typical decisions which are required to be made during structural refurbishments?
   - Are there any particular activities which require decision support?
   - Do you think any support in decision making will actually affect safety during demolition?

5. End-users’ requirement for a decision support system
   - Do you use computers/specialised software for additional information or managing activities?
   - Do you have access to internet / intranet on construction site?
   - Are you able to contemplate how a decision support system can be utilised for refurbishment project?
   - Are you able to visualise what kind of support can be provided by a DSS?
APPENDIX C

Questionnaire for Validation of
Refurbishment Process Model (RPM)
Validation of the Refurbishment Process Model (RPM)

A. Background information
1. Type of organisation (e.g., client, design, contracting)
2. Role of the respondent (e.g., architect, contractor, designer)

B. Validation of Refurbishment Process Model (RPM)
(Please tick the box that best represents your assessment of the question)

1. EFFECTIVENESS
   - How effective can the RPM be for the refurbishment process?
   - How effective is the RPM in decision making relating to refurbishment?
   - How effective can the RPM be in reducing the structural collapse in refurbishment projects?

2. FUNCTIONALITY
   - To what extent does the RPM represent an improvement over your current refurbishment process?
   - To what extent do you think the RPM would facilitate planning for safety in refurbishment?
   - To what extent is the RPM suitable for the refurbishment process?

3. COVERAGE AND SCOPE OF THE RPM
   - In your views, to what extent does the RPM cover all the key stages of a refurbishment project?
   - How well are the activities addressed in the RPM model?
   - How well are the key problem areas addressed in the RPM?
4. USER FRIENDLINESS

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<td>5</td>
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</tbody>
</table>

How user friendly is the format of the RPM?

How easy is it to use the RPM?

5. Would you use or recommend the RPM? Yes / No
   If yes, at what stage and during what activities ________________________________

6. In your view, are there any activities that need to be added? Yes / No
   If yes, could you please suggest ____________________________________________

7. In your view, are there any stages to be added? Yes / No
   If yes, could you please suggest ____________________________________________

8. In your view, are there any sub-activities that need to be added or deleted? Yes / No
   If yes, could you please suggest ____________________________________________

9. What aspects of RPM did you particularly like?
   ____________________________________________________________

10. Please feel free to provide any further comments/suggestions regarding the RPM
    ____________________________________________________________
APPENDIX D

Evaluation Questionnaire for
Decision Support System (DSS)
Evaluation of the Decision Support System (DSS)

A. Organisational Details of the Respondent
1. Type of organisation (e.g., client, design, contracting)
2. Role of the respondent (e.g., architect, contractor, designer)
3. Have you been/still involved with refurbishment projects? (Yes/No)

B. Evaluation of Decision Support System (DSS)
(Please tick the box that best represents your assessment of the question)

1. EFFECTIVENESS

| How effective might the DSS be in decision making relating to refurbishment? | 1 | 2 | 3 | 4 | 5 |
| How effectively/well does the DSS fit into your current work practices? |   |   |   |   |   |
| Do you think the DSS can be effective in reducing structural collapse in refurbishment projects? |   |   |   |   |   |

2. FUNCTIONALITY

| How suitable is the DSS for existing refurbishment process? | 1 | 2 | 3 | 4 | 5 |
| How appropriate are the questions/issues addressed in the DSS? |   |   |   |   |   |
| To what extent does the DSS represent an improvement over your current refurbishment process? |   |   |   |   |   |

3. COVERAGE AND SCOPE OF THE DSS

| How well does the DSS cover the duties of the key players in a refurbishment project? | 1 | 2 | 3 | 4 | 5 |
| How well do you think the DSS will facilitate planning for safety in Refurbishment? |   |   |   |   |   |
| How well have the key problem areas with regard to safety been addressed in the DSS? |   |   |   |   |   |
4. EASE OF USE/USER FRIENDLINESS

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<tr>
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<th>2</th>
<th>3</th>
<th>4</th>
<th>5 very easy/very consistent/very useful</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>How easy is it to use the DSS?</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>2</td>
<td>How consistent is the user interface in the DSS?</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>3</td>
<td>How easy is it to navigate the various parts of the DSS?</td>
<td></td>
<td></td>
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<tr>
<td>4</td>
<td>How useful are the prompts/help facilities in the DSS?</td>
<td></td>
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</tr>
</tbody>
</table>

5. Which part(s) of the application of the DSS (e.g., the use of amber, green and red signals to flag up the criticality of issues, external links to other sources on health and safety issues) **impressed** you most and why

6. Which part(s) of the application of the DSS (e.g., the use of amber, green and red signals to flag up the criticality of issues, external links to other sources on health and safety issues) **fell short** of your expectations and why

7. Do any new issues/questions need to be added? Yes / No
   If yes, could you please suggest

8. Given the varied issues covered within the DSS, how much time are you able to devote to the DSS at any one time
   < 15 min □
   15 to 20 min □
   20 to 25 min □
   25 to 30 min □
   > 30 min □

9. Please feel free to provide any further comments/suggestions regarding the DSS

___________________________________________

___________________________________________
APPENDIX E

List of Questions from Database
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<td>No</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Has the Client's brief or requirements for the refurbishment project been met by the Designer's drawings and/or specifications?</td>
<td>Yes</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>The Client has duty to appoint a competent planning supervisor/CDM co-ordinator under CDM regulations. Please refer to HSE information sheet no 39 and 40 for more information.</td>
<td>Yes</td>
<td>4</td>
<td><a href="http://www.hse.gov.uk/pubs/cis40.pdf">http://www.hse.gov.uk/pubs/cis40.pdf</a></td>
</tr>
<tr>
<td>3</td>
<td></td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>The Client is supposed to appoint a competent planning supervisor/CDM co-ordinator. Please refer to Health and safety at work Inspectorate information document: CDM to understand the role of the planning supervisor/CDM co-ordinator.</td>
<td>No</td>
<td>1</td>
<td><a href="http://www.gov.im/lib/docs/digci/odmisno247.pdf">http://www.gov.im/lib/docs/digci/odmisno247.pdf</a></td>
</tr>
<tr>
<td>4</td>
<td></td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>The Designer could be the Architect, Engineer or any person who carries out this function in the process.</td>
<td>Yes</td>
<td>2</td>
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<tr>
<td>5</td>
<td></td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>The Clients have specific duties to carry out under CDM regulations. For more information please refer to HSE information sheet 39.</td>
<td>Yes</td>
<td>5</td>
<td><a href="http://www.hse.gov.uk/pubs/misc193.pdf">http://www.hse.gov.uk/pubs/misc193.pdf</a></td>
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<td>6</td>
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<td>No</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>The feasibility study should clearly identify the scope of refurbishment projects i.e., the extent of demolition, details of structural members and any alterations/modifications involved.</td>
<td>No</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td></td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>The purpose of the Construction Notification (Form 10) is to notify the HSE for projects covered under CDM Regulations in UK.</td>
<td>No</td>
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<td><a href="http://www.hse.gov.uk/forms/notification/f10.pdf">http://www.hse.gov.uk/forms/notification/f10.pdf</a></td>
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248
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<tbody>
<tr>
<td>9</td>
<td>How far has the Client progressed with the appointment of the Structural Engineer?</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>The Client does not have to necessarily appoint a Structural Engineer as such but it is required to have necessary professional advice especially if refurbishment requires any sort of Structural refurbishment.</td>
<td>Yes</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Has the Designer/Architect prepared the safety requirements and needs assessment report for the refurbished facility?</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>As with new build, refurbishment projects need to follow the current regulations. This is particularly relevant for structural aspects and end user requirements. Current design philosophy and structural capability of the structure should be carefully taken into account.</td>
<td>No</td>
<td>1</td>
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<tr>
<td>11</td>
<td>To what extent has the Architect identified, evaluated and reviewed potential refurbishment proposals with respect to Health and Safety?</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td></td>
<td>Yes</td>
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<tr>
<td>12</td>
<td>Is the existing structure a framed structure?</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>This is important to determine as load paths and failures (for example progressive collapse) occur differently on framed structure than in a load bearing structure.</td>
<td>No</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>To what extent has the Structural Engineer identified existing structural distress, deformation and deterioration in the building elements?</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>The condition of the structure needs to be assessed along with signs of any fatigue and dilapidation.</td>
<td>Yes</td>
<td>2</td>
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<tr>
<td>14</td>
<td>To what extent has the structure been investigated for stability, integrity, and distortion?</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>Comprehensive surveys do not reveal an accurate picture because many defects only become apparent when the</td>
<td>Yes</td>
<td>2</td>
<td></td>
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</tbody>
</table>

249
Building is opened up. It is only when the building is thoroughly investigated and sample checks carried out on, for example, opening up a in-situ joint, removal of few cladding panels, that defects can be discovered.

<table>
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<tr>
<td>15</td>
<td>Has the Structural Engineer examined the structure for any movement in foundations, structural frame and wall panels?</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>1</td>
<td>The Pre-Tender Health &amp; Safety Plan is prepared by the Planning Supervisor/CDM co-ordinator during the Design &amp; Planning Phase. It is prepared from information given by the Client and the Designers, and will allow the Principal Contractors to prepare the Health &amp; Safety Plan.</td>
<td>Yes</td>
<td>2</td>
<td></td>
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<tr>
<td>16</td>
<td>To what extent has the Client been able to furnish information relating to design, construction, maintenance and history of the use of the building?</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>1</td>
<td>The condition of foundations, roofs, walls and floors need to be assessed along with signs of fatigue and extent of deterioration and rot. Please refer to BRE Digest 177 (1975) for decay in buildings. Please refer to BRE Digest 299 (1985) for Dry rot and its control.</td>
<td>Yes</td>
<td>4</td>
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<tr>
<td>17</td>
<td>Has the Structural Engineer examined 'as built drawings', structural design and construction details of the existing structure?</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>1</td>
<td>No</td>
<td>1</td>
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<td>18</td>
<td>To what extent have the condition of the foundations, roofs, walls and floors been assessed?</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>1</td>
<td>No</td>
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<td>Has the Designer/Architect</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>2</td>
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<td>20</td>
<td>prepared drawings from site surveys in case no such drawings are available?</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
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<td></td>
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<td>No</td>
</tr>
<tr>
<td></td>
<td>Does any damaged or deteriorated structure have strength less than 85% of full strength?</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>2</td>
<td>The following aspects need to be ascertained to identify defects: defects in design, defects in construction, deterioration since construction or last modification, accidental deliberate damage change of ground/external environment, change of use or increased loading and change in pattern of use.</td>
<td>No</td>
<td>1</td>
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<tr>
<td>21</td>
<td>Are any of the floors, beams pulling away and/or appear to have a sag or cracks?</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>2</td>
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<tr>
<td>22</td>
<td>Has the Structural Engineer quantified the severity of any damage and geometric location of the damage?</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>2</td>
<td></td>
<td>Yes</td>
<td>2</td>
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<tr>
<td>23</td>
<td>Is there any record/prediction about the remaining service life of the damaged structure?</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>2</td>
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<td>Is there structural continuity between key structural elements?</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>2</td>
<td></td>
<td>No</td>
<td>1</td>
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<td>25</td>
<td>Has Structural Engineer assessed the structural stability and rigidity of the structural members?</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>2</td>
<td>Structural stability could be lost with foundation failure, impacts, while structural rigidity could be lost with fatigue, deterioration, high temperatures caused by fire etc.</td>
<td>No</td>
<td>1</td>
<td></td>
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<tr>
<td>26</td>
<td>Have the load paths been identified during the structural appraisal?</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>2</td>
<td></td>
<td>No</td>
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<td>cid</td>
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<td>27</td>
<td>Have all load bearing elements been assessed for load carrying capacity?</td>
<td>No No No No Yes 2</td>
<td>In a load-bearing capacity evaluation, the safety requirement for the ultimate limit state depends on the type of failure envisaged. The type of failure is assessed on the basis of the characteristics for the given material, component or structure. The following three types of failure may be investigated: Failure with warning and with load-bearing capacity reserve, which includes ductile failure, for which a capacity reserve in addition to the defined capacity is required, for example in the form of deformation tempering. Failure with warning but without load-bearing capacity reserve, which includes ductile failure without extra load-bearing capacity. Failure without warning, which includes brittle failure and stability failure.</td>
<td>No</td>
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<tr>
<td>28</td>
<td>To what extent have the load bearing elements been assessed for the presence of any cavities, chases or other sources of potential failure?</td>
<td>No No No No Yes 2</td>
<td></td>
<td>Yes</td>
<td>5</td>
<td></td>
<td></td>
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<tr>
<td>29</td>
<td>Have the vertical load bearing components been strengthened?</td>
<td>No No No Yes No 2</td>
<td></td>
<td>No</td>
<td>1</td>
<td></td>
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<tr>
<td>30</td>
<td>To what extent have the method statements been prepared for safe working?</td>
<td>No No No Yes No 3</td>
<td></td>
<td>Yes</td>
<td>2</td>
<td></td>
<td></td>
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<tr>
<td>31</td>
<td>Do the method statements identify</td>
<td>No No No Yes No 3</td>
<td></td>
<td>No</td>
<td>1</td>
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<tr>
<td>32</td>
<td>To what extent does the risk assessment include full risk assessment including risk of collapse?</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>3</td>
<td>It is important to identify the speculative risks (possibility of an accident or technical failure), particular risks (for example subsidence, vibrations, removal of support) and controllable and uncontrollable risks (for example negative connotations and risks those can be managed).</td>
<td>Yes</td>
<td>2</td>
<td><a href="http://www.hse.gov.uk/pubns/indg218.pdf">http://www.hse.gov.uk/pubns/indg218.pdf</a></td>
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</tr>
<tr>
<td>33</td>
<td>Does the risk assessments outline sequence, method of dismantling and demolition?</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>3</td>
<td>No</td>
<td>1</td>
<td><a href="http://www.hse.gov.uk/pubns/indg218.pdf">http://www.hse.gov.uk/pubns/indg218.pdf</a></td>
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<tr>
<td>34</td>
<td>To what extent the method statements include detailed design of temporary supporting structures?</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>3</td>
<td>Yes</td>
<td>4</td>
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<tr>
<td>35</td>
<td>Have the designers considered wind load conforming to BS 6399?</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>3</td>
<td>No</td>
<td>1</td>
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<tr>
<td>36</td>
<td>To what extent has the contractor conducted safety induction for all the workers and explained the method statements?</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>3</td>
<td>Yes</td>
<td>3</td>
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<tr>
<td>37</td>
<td>Has the Project Manager got the safety plan, method statements, risk assessments and refurbishment plan readily available before the work commences?</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>3</td>
<td>No</td>
<td>1</td>
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<tr>
<td>38</td>
<td>Has the Project Manager got the safety plan, method statements, risk assessments and refurbishment plan readily available before the work commences?</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>4</td>
<td>No</td>
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<tr>
<td>39</td>
<td>To what extent have the Designers/Architect undertaken an environment impact assessment?</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>4 The designers play a major role in managing hazards associated with refurbishment. Please refer to Construction Industry council CDM Designers' Technical guidance note T 20.005</td>
<td>Yes</td>
<td>3</td>
<td><a href="http://www.safetyindesign.org/REFURBISHMENT.pdf">http://www.safetyindesign.org/REFURBISHMENT.pdf</a></td>
</tr>
<tr>
<td>41</td>
<td>To what extent have all the project participants complied with (Design and Management) regulations 1994</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>4 The CDM regulations place duties on all those who can contribute to health and safety and improve overall management and co-ordination of health and safety. Please refer to following HSE website for more information on construction Design and Management Regulations.</td>
<td>Yes</td>
<td>2</td>
<td><a href="http://www.hse.gov.uk/pubns/conindex.htm">http://www.hse.gov.uk/pubns/conindex.htm</a></td>
</tr>
<tr>
<td>42</td>
<td>Is any of the project participants ICE Health and Safety Registered?</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>4 The Institution of Civil Engineers has established a health and safety register for those who wish to demonstrate a defined level of experience and competency in the application of health and safety and are likely to be involved in the projects, future maintenance, demolition or refurbishment. For more information please look at the following website.</td>
<td>No</td>
<td>1</td>
<td><a href="http://www.ice.org.uk/downloads/(1)%20Register%20Information.odf">http://www.ice.org.uk/downloads/(1)%20Register%20Information.odf</a></td>
</tr>
<tr>
<td>43</td>
<td>To what extent has the Designer prepared the design risk assessment?</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>4 A design risk assessment (DRA) is the act of determining potential risk in a design process, either in a concept design or a detailed design.</td>
<td>Yes</td>
<td>3</td>
<td></td>
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<tr>
<td>44</td>
<td>Has the Designer provided all the relevant and sufficient information to enable the Planning</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
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<tr>
<td>45</td>
<td>To what extent have all the Health and Safety issues been identified and enlisted before any proposed demolition?</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>10</td>
<td>Yes</td>
<td>4</td>
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<tr>
<td>46</td>
<td>Has the Planning Supervisor/CDM Co-ordinator prepared the pre-tender health and safety plan?</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>5</td>
<td>If the Planning Supervisor/CDM co-ordinator has not prepared a health and safety pre-tender plan and work is not being internally procured, then he should try to prepare one Health and Safety refurbishment plan.</td>
<td>No</td>
<td>1</td>
<td><a href="http://www.hse.gov.uk/pubns/cisl42.pdf">http://www.hse.gov.uk/pubns/cisl42.pdf</a></td>
<td></td>
</tr>
<tr>
<td>47</td>
<td>To what extent has the Designer detailed the potential problems during and after the structural alterations?</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>5</td>
<td>Yes</td>
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<tr>
<td>48</td>
<td>Has the Structural Engineer/Designer identified the elements which might be adversely affected during any additions and/or alterations?</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>5</td>
<td>No</td>
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<tr>
<td>49</td>
<td>To what extent has the Planning Supervisor/CDM Co-ordinator prepared Health and Safety control procedures?</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>5</td>
<td>Planning Supervisors (or CDM Co-ordinators as identified in the new CDM Regulations, 2007) examine project plans, risk assessments and method statements, give suggestions for enhancing project health &amp; safety, produce the necessary pre-tender (Stage 1) documents and deliver the completed Health &amp; Safety File at handing-over of the facility. Early consideration and designing risk out of projects</td>
<td>Yes</td>
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<tr>
<td>50</td>
<td>Has the Planning Supervisor/CDM Co-ordinator prepared a risk mitigation plan?</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>5</td>
<td>It is core to the CDM Regulations.</td>
<td>No</td>
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<tr>
<td>51</td>
<td>To what extent has the Client provided all the information to enable the Planning Supervisor/CDM co-ordinator prepare the Pre-tender Health &amp; Safety Plan?</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>5</td>
<td></td>
<td>Yes</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>52</td>
<td>Has the project manager prepared the sequence of refurbishment activities?</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>6</td>
<td>It is the responsibility of Project Manager prepare or approve the work sequences prepared by construction manager/ sub contractor.</td>
<td>No</td>
<td>1</td>
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<tr>
<td>55</td>
<td>To what extent has the Designer reviewed specifications relating to Health and Safety issues?</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>7</td>
<td></td>
<td>No</td>
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<tr>
<td>56</td>
<td>Has the Planning Supervisor/CDM Co-ordinator been involved in the review process of method statements?</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>7</td>
<td></td>
<td>Yes</td>
<td>5</td>
<td></td>
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<tr>
<td>57</td>
<td>To what extent has the Project Manager aligned Health and Safety plan with the procurement plan?</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>7</td>
<td></td>
<td>Yes</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>58</td>
<td>Has the Contractor ensured the structure is left in a stable condition at all stages of the project?</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>7</td>
<td>Structure under refurbishment can collapse due to other loadings, such as wind, storm, and vibrations due to traffic and movement of construction plants. This requires structure to be left secure with props.</td>
<td>No</td>
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<td>59</td>
<td>Has the Planning Supervisor/CDM Co-ordinator identified safe practices and procedures?</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
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<td>No</td>
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<tr>
<td>60</td>
<td>Has the Planning Supervisor/CDM co-ordinator determined safe site transport arrangements and identified access points, egress routes and rescue procedures and practices?</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>7</td>
<td>No</td>
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<tr>
<td>61</td>
<td>Has the Project Manager prepared any procurement strategy suitable for refurbishment?</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>8</td>
<td>No</td>
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<tr>
<td>62</td>
<td>Has the Contractor prepared an operation and maintenance plan?</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
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<td>No</td>
</tr>
<tr>
<td>63</td>
<td>Has the Project Manager finalised the sequence of works?</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
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</tr>
<tr>
<td>70</td>
<td>Has the Project Manager got safety plan, method statements, risk assessments and refurbishment plan readily available before the work commences?</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>9</td>
<td>No</td>
</tr>
<tr>
<td>72</td>
<td>Has the Project Manager identified Health and Safety criteria for the supply chain?</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>9</td>
<td>No</td>
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<tr>
<td>73</td>
<td>Have all the work</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
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<tr>
<td>74</td>
<td>To what extent have the Project Manager and/or Construction Manager reviewed method statements?</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>9</td>
<td>No</td>
<td>1</td>
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<tr>
<td>75</td>
<td>To what extent has the Contractor responded to any reviewed method statements?</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>9</td>
<td>Yes</td>
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</tr>
<tr>
<td>76</td>
<td>Has the Contractor/Demolition Contractor communicated all risks to site workers and operatives?</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>10</td>
<td>No</td>
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</tr>
<tr>
<td>77</td>
<td>Have the construction methods and sequences been communicated to each and everyone on site?</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>10</td>
<td>Construction methods in this context would include demolition, and dismantling elements of the project as part of the work.</td>
<td>No</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>78</td>
<td>Has the Project Manager delegated people to identify any risks and monitor demolition activities?</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>10</td>
<td>Designers play a major part in minimising the hazards associated with demolition. The avoidance of accidents depends on the quality and thoroughness of the Designers plan for the project</td>
<td>No</td>
<td>1</td>
<td><a href="http://www.safetyindesign.org/DEMOLITION.pdf">http://www.safetyindesign.org/DEMOLITION.pdf</a></td>
</tr>
<tr>
<td>79</td>
<td>Has the Contractor been informed to record all operations, risks associated and mitigation plans in the Health and Safety file?</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>10</td>
<td>No</td>
<td>1</td>
<td></td>
<td></td>
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<tr>
<td>80</td>
<td>To what extent are you sure that any adjacent structure will not be affected by the</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>10</td>
<td>No</td>
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<td>-------</td>
</tr>
<tr>
<td>81</td>
<td>Has the Client ensured that the report of the survey is available and s/he has informed the utility companies?</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>10</td>
<td></td>
<td>No</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>82</td>
<td>Does the Demolition Contractor understand methods of construction and stress patterns?</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>10</td>
<td></td>
<td>No</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>83</td>
<td>Has the Demolition Contractor knowledge of typical failures and collapse hazards from previous failures and experiences?</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>10</td>
<td></td>
<td>No</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>84</td>
<td>Have all the affected walls and floors been adequately supported, shored or braced before demolition?</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>10</td>
<td></td>
<td>No</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>85</td>
<td>Have the gable walls been braced and tied properly?</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>10</td>
<td></td>
<td>No</td>
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<td></td>
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<tr>
<td>86</td>
<td>To what extent has the Demolition Contractor ensured that manual demolition starts at the top and proceeds downwards?</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>10</td>
<td></td>
<td>Yes</td>
<td>2</td>
<td></td>
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<tr>
<td>87</td>
<td>Has the Project Manager ensured that inspections to detect hazards and unsafe conditions are carried out on a daily basis or other appropriate levels?</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>10</td>
<td></td>
<td>No</td>
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<tr>
<td>88</td>
<td>Is the structural steel being removed column</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>10</td>
<td></td>
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<tbody>
<tr>
<td>89</td>
<td>Is the opening cut into floor extending the full span of the floor between supports?</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>10</td>
<td>No</td>
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</tr>
<tr>
<td>90</td>
<td>Is the Project Manager managing and monitoring the construction work against the job specifications and method statements?</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>11</td>
<td>No</td>
<td>1</td>
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<tr>
<td>91</td>
<td>Has the Designer ensured compliance with statutory approvals?</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>11</td>
<td>No</td>
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<tr>
<td>92</td>
<td>Has the Project Manager made input to Health and Safety file?</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>11</td>
<td>No</td>
<td>1</td>
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<td></td>
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<tr>
<td>93</td>
<td>To what extent have the daily inspections to detect hazards and unsafe conditions been carried out?</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>11</td>
<td>Yes</td>
<td>5</td>
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<tr>
<td>94</td>
<td>Has the Project Manager prepared the snag list and handed this over to the contractor?</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>12</td>
<td>No</td>
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<tr>
<td>95</td>
<td>Has the Contractor finalised procedures and plans to hand-over the refurbished project/facility?</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>12</td>
<td>Yes</td>
<td>3</td>
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<tr>
<td>96</td>
<td>Has the final Health and Safety file been handed over to the Client?</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>12</td>
<td>Yes</td>
<td>4</td>
<td><a href="http://www.safetyindesign.org/HEALTH">http://www.safetyindesign.org/HEALTH</a> AND SAFETY FILE.pdf</td>
<td></td>
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</tr>
<tr>
<td>97</td>
<td>Has the Health and Safety File been handed over to the client at the end of a project. For more information please refer to following web site.</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>12</td>
<td>Yes</td>
<td>2</td>
<td><a href="http://www.hse.gov.uk/pubns/cis43.pdf">http://www.hse.gov.uk/pubns/cis43.pdf</a></td>
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<td>weight</td>
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<td></td>
</tr>
<tr>
<td>98</td>
<td>Safety plan handed over to the Client?</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>included in the health and safety plan for the construction phase which is required under the Construction (Design and Management) Regulations 1994. For more information please refer to HSE information sheet no. 43.</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>99</td>
<td>Have you conducted the end of project review to produce end-of-project review report?</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>4</td>
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<tr>
<td>100</td>
<td>Has the maintenance plan been prepared for efficient operation of the facility?</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>1</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>105</td>
<td>Has the Demolition Contractor prepared an asbestos removal report?</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>106</td>
<td>Has the Demolition Contractor prepared the final demolition report?</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>1</td>
<td></td>
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<tr>
<td>107</td>
<td>To what extent the Demolition Contractor communicated the residual risks to the planning supervisor/CDM co-ordinator for the health and Safety file?</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>109</td>
<td>Has the method statement and risk assessment been approved for any</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>1</td>
<td></td>
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</tr>
<tr>
<td>110</td>
<td>Has the method statement and risk assessment been carried out by competent person approved by the designated person on site?</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>10</td>
<td></td>
<td>No</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>111</td>
<td>If the work is being carried out next to a wall or partition, to what extent as the stability of opposite and adjacent walls been checked?</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>10</td>
<td></td>
<td>Yes</td>
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</tr>
</tbody>
</table>
APPENDIX F

Programme Code
This section does not contain the complete codes which may be accessed from the programme folder in the attached CD. However this presents the essential codes written for evaluation results.

Private Sub evaluateCmd_Click()
    rating11b.Visible = True
    ratingTx.Visible = True
    yesNo11b.Visible = True
    yesNoTx.Visible = True
    overall11b.Visible = True
    overallTx.Visible = True
    'evaluate the overall completion of the checklist
    Call cal
    ratingTx.Text = optionCompletedQ & " / " & optionTotalQ
    yesNoTx.Text = yesNoCompletedQ & " / " & yesNoTotalQ
    Dim NoOfOptionRedQ As Integer, OptQ() As String, OptQ1 As String
    NoOfOptionRedQ = 0
    For i = 0 To optionQuestionCount - 1
        If checklistLabel(i).ForeColor = vbRed Then
            NoOfOptionRedQ = NoOfOptionRedQ + 1
        End If
    Next i
    If NoOfOptionRedQ > 0 Then
        OptQ1 = "You have : " & NoOfOptionRedQ & " Red Questions from Rating selection. " & vbCrLf & vbCrLf
        ReDim OptQ(1 To NoOfOptionRedQ)
        NoOfOptionRedQ = 0
        For i = 0 To optionQuestionCount - 1
            If checklistLabel(i).ForeColor = vbRed Then
                NoOfOptionRedQ = NoOfOptionRedQ + 1
                OptQ(NoOfOptionRedQ) = checklistLabel(i).Caption
            End If
        Next i
        OptQ1 = OptQ1 & "Question " & NoOfOptionRedQ & " : " & OptQ(NoOfOptionRedQ) & vbCrLf & vbCrLf
    End If
    Else
        OptQ1 = "You have no Red Questions from Rating selection. " & vbCrLf & vbCrLf
    End If
    Dim NoOfBooiRedQ As Integer, BooIQ() As String
    NoOfBooiRedQ = 0
    For i = 0 To yesNoQuestionCount - 1
        If yesNoLabel(i).ForeColor = vbRed Then
            NoOfBooiRedQ = NoOfBooiRedQ + 1
            BooIQ(NoOfBooiRedQ) = yesNoLabel(i).Caption
        End If
    Next i
    If NoOfBooiRedQ > 0 Then
        OptQ1 = OptQ1 & vbCrLf & vbCrLf
        OptQ1 = OptQ1 & "You have : " & NoOfBooiRedQ & " Red Questions from Yes/No selection. " & vbCrLf & vbCrLf
        ReDim BoolQ(1 To NoOfBooiRedQ)
        NoOfBooiRedQ = 0
        For i = 0 To yesNoQuestionCount - 1
            If yesNoLabel(i).ForeColor = vbRed Then
                NoOfBooiRedQ = NoOfBooiRedQ + 1
                BoolQ(NoOfBooiRedQ) = yesNoLabel(i).Caption
            End If
        Next i
        OptQ1 = OptQ1 & "Question " & NoOfBooiRedQ & " : " & BoolQ(NoOfBooiRedQ) & vbCrLf & vbCrLf
    End If
    Else
        OptQ1 = OptQ1 & vbCrLf & vbCrLf
        OptQ1 = OptQ1 & "You have no Red Questions from Yes/No selection. " & vbCrLf & vbCrLf
    End If
    OptQ1 = OptQ1 & vbCrLf & vbCrLf
    If (overallCompleted > 0) Then

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Private Sub cal()
    optionCompletedQ = 0
    optionTotalQ = 0
    yesNoTotalQ = 0
    yesNoCompletedQ = 0
    overallTotal = 0
    overallCompleted = 0
    Dim i As Integer
    For i = 0 To optionQuestionCount - 1
        ' if related to the user
        If (optionArray(i, 3) = 1) Then
            ' total number of question
            optionTotalQ = optionTotalQ + 1
            Select Case optionArray(i, 2)
                Case 1
                    Select Case optionArray(i, 1)
                        Case 1
                            optionCompletedQ = optionCompletedQ + 0.2
                        Case 2
                            optionCompletedQ = optionCompletedQ + 0.4
                        Case 3
                            optionCompletedQ = optioncompletedQ + 0.6
                        Case 4
                            optionCompletedQ = optionCompletedQ + 0.8
                        Case 5
                            optionCompletedQ = optionCompletedQ + 1
                    End Select
                Case 2
                    Select Case optionArray(i, 1)
                        Case 1
                            optionCompletedQ = optioncompletedQ + 0
                        Case 2
                            optionCompletedQ = optionCompletedQ + 0.25
                        Case 3
                            optionCompletedQ = optionCompletedQ + 0.5
                        Case 4
                            optionCompletedQ = optionCompletedQ + 0.75
                        Case 5
                            optionCompletedQ = optionCompletedQ + 1
                    End Select
                Case 3
                    Select Case optionArray(i, 1)
                        Case 1
                            optionCompletedQ = optionCompletedQ + 0
                        Case 2
                            optionCompletedQ = optionCompletedQ + 0
                        Case 3
                            optionCompletedQ = optionCompletedQ + 0.33
                        Case 4
                            optionCompletedQ = optionCompletedQ + 0.66
                        Case 5
                            optionCompletedQ = optionCompletedQ + 1
                    End Select
                Case 4
                    Select Case optionArray(i, 1)
                        Case 1
                            optionCompletedQ = optionCompletedQ + 0
                        Case 2
                            optionCompletedQ = optionCompletedQ + 0
                        Case 3
                            optionCompletedQ = optionCompletedQ + 0.33
                        Case 4
                            optionCompletedQ = optionCompletedQ + 0.66
                        Case 5
                            optionCompletedQ = optionCompletedQ + 1
                    End Select
            End Select
        End If
    Next i
End Sub
Select Case optionArray(i, 1)
    Case 1
        optionCompletedQ = optionCompletedQ + 0
    Case 2
        optionCompletedQ = optionCompletedQ + 0
    Case 3
        optionCompletedQ = optionCompletedQ + 0
    Case 4
        optionCompletedQ = optionCompletedQ + 0.5
    Case 5
        optionCompletedQ = optionCompletedQ + 1
End Select
Case 5
Select Case optionArray(i, 1)
    Case 1
        optionCompletedQ = optionCompletedQ + 0
    Case 2
        optionCompletedQ = optionCompletedQ + 0
    Case 3
        optionCompletedQ = optionCompletedQ + 0
    Case 4
        optionCompletedQ = optionCompletedQ + 0
    Case 5
        optionCompletedQ = optionCompletedQ + 1
End Select
End Select
End If
Next i
Dim j As Integer
For j = 0 To yesNoQuestionCount - 1
    If (yesNoArray(j, 3) = 1) Then
        yesNoTotalQ = yesNoTotalQ + 1
    Select Case yesNoArray(j, 2)
        Case 0
            If (yesNoArray(j, 1) = 11 Or yesNoArray(j, 1) = 12) Then
                yesNoCompletedQ = yesNoCompletedQ + 1
            End If
        Case 1
            If (yesNoArray(j, 1) = 11) Then
                yesNoCompletedQ = yesNoCompletedQ + 1
            End If
        Case 2
            If (yesNoArray(j, 1) = 12) Then
                yesNoCompletedQ = yesNoCompletedQ + 1
            End If
        End Select
    End If
Next j
overallTotal = yesNoTotalQ + optionTotalQ
overallCompleted = yesNoCompletedQ + optionCompletedQ
End Sub
Guidance to Install/Run the Programme
Guidance to Run the DSS

The software has been developed with Visual basic at front-end and MS Access at back-end. The accompanying The DSS software CD is an installable software. The CD also contains an executable file to run the software programme. Please follow the following steps to install / run the software:

Insert the CD - it contains three files:

1. Installer,
2. InstallationDemo.wmv and
3. Setup_DSS. exe

There are two options to run the programme:

- Option 1 (To Install the DSS software) : Double click on Setup_ DSS.exe to install the programme on hard drive (For installation demo - double click on InstallationDemo.wmv file).

- Option 2 (To run the Executable DSS) : Double Click on installer and Double-click again on DSS.exe to run the executable DSS.

Login Details:

- Please enter the respective User Name, Password, Project Details and choose the End User Category from the drop down menu in the login screen;
• Please use the following table to enter **User Name** and **Password**.

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<thead>
<tr>
<th>Use Name</th>
<th>Password</th>
<th>End User</th>
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</tr>
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<td>arch</td>
<td>ARCHITECT</td>
</tr>
<tr>
<td>contr</td>
<td>contr</td>
<td>CONTRACTOR</td>
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<td>cdmc</td>
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<td>proj</td>
<td>proj</td>
<td>PROJECT MANAGER</td>
</tr>
</tbody>
</table>

**Note:**

• Please look at the research Report / Report appendices for detailed instructions.

• The files are read only files, but, the system is a knowledge based system where the end users can add questions in any checklist by adding the question in the appropriate table in back-end database.