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Avoiding structural collapses in refurbishment

A decision support system

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RESEARCH REPORT 463

Avoiding structural collapses in refurbishment

A decision support system

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This report is based on the research project 'Avoiding Structural Collapse in Refurbishment: Decision Support System' funded by The Health and Safety Executive. It documents the development of a Decision Support System to prevent structural collapses on refurbishment projects. The aim of the project, which commenced in April 2003, was to investigate the management of refurbishment projects and to identify areas where decision support can help in avoiding structural collapses.

It builds on the recommendations made in an earlier HSE-funded research project (HSE Research Report 204, 2004) on 'Health and Safety in Refurbishment Involving Structural Instability and Partial Demolition', which focused on identifying the key factors responsible for the high rate of accidents and safety incidents in refurbishment projects.

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LIST OF ABBREVIATIONS

ACoP	Approved Code of Practice
BRE	British Research Establishment
CDM	Construction (Design) and Management) Regulations 1994
CIRIA	Construction Industry Research and Information Association
DBMS	Database Management System
DETR	Department for Environment, Transport and the Regions
DRA	Design Risk Assessment
DS	Decision Support
DSS	Decision Support System
H&S	Health and Safety
HS&W	Health, Safety and Welfare
HSE	Health and Safety Executive
MS	Method Statement
O&M	Operation and Maintenance
ODPM	Office of the Deputy Prime Minister
PM	Project Manager
PS	Planning Supervisor
RBDM	Risk-Based Decision Making
RPM	Refurbishment Process Model
SCOSS	Standing Committee on Structural Safety
SME	Small to Medium Enterprise
SMS	Safety Management System

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EXECUTIVE SUMMARY

This report is based on the research project ‘Avoiding Structural Collapse in Refurbishment: Decision Support System’ funded by The Health and Safety Executive. It documents the development of a Decision Support System to prevent structural collapses on refurbishment projects. The aim of the project, which commenced in April 2003, was to investigate the management of refurbishment projects and to identify areas where decision support can help in avoiding structural collapses.

It builds on the recommendations made in an earlier HSE-funded research project (HSE Research Report 204, 2004) on ‘Health and Safety in Refurbishment Involving Structural Instability and Partial Demolition’, which focused on identifying the key factors responsible for the high rate of accidents and safety incidents in refurbishment projects.

This project on ‘Avoiding Structural Collapse in Refurbishment: A Decision Support System’ reviewed current strategies adopted for avoiding structural collapse in refurbishment projects, established the end-user requirements for a decision support system in this area, developed a new refurbishment process model (see Chapter 3) for refurbishment projects and developed a decision support system (see Chapter 4) for context-specific guidance (see Appendix A3) at all stages of the refurbishment process. The main conclusions and recommendations that can be drawn from the research project include:

- Approaches to avoiding structural collapse on refurbishment projects are highly variable and depend, to a large extent, on the expertise and competence of the project team;
- There is need to improve the decision-making process in refurbishment projects by providing information on structural safety and integrity, and highlighting the key problem areas that need to be considered;

- Careful and detailed consideration must be given to any partial demolitions and structural alterations that may interfere with the structural stability of the building;
- Detailed structural appraisals, including a review of the ‘as-built’ drawings and appropriate site investigations, should be carried out by competent structural engineers;
- Refurbishment projects involving partial demolition activities and/or structural alterations require the appointment of competent and qualified professionals who can ensure the integrity of the structure right from the feasibility stage to the actual refurbishment execution stage;
- There is the need for a Refurbishment Process Model, which provides for a structured sequence of activities during the refurbishment project life-cycle and incorporates multiple feedback processes at the various stages;
- End-users require decision support that is relevant to their particular context but, which also gives them the flexibility to be kept informed of the responsibilities of the other team members;
- The use of a Decision Support System (DSS) to prevent structural collapse can enhance safety in refurbishment projects while also facilitating collaborative working;
- 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 to consider during the refurbishment process;
- There is scope for exploring the use of the DSS developed on a real project (as this was outside the scope of the current project) - this will enable its full benefits and limitations to be realised and documented widely for the benefits of practitioners involved in refurbishment projects;
- There are significant advantages to making the DSS web-based and further work can be undertaken in this area.

CHAPTER 1

INTRODUCTION AND BACKGROUND TO THE RESEARCH

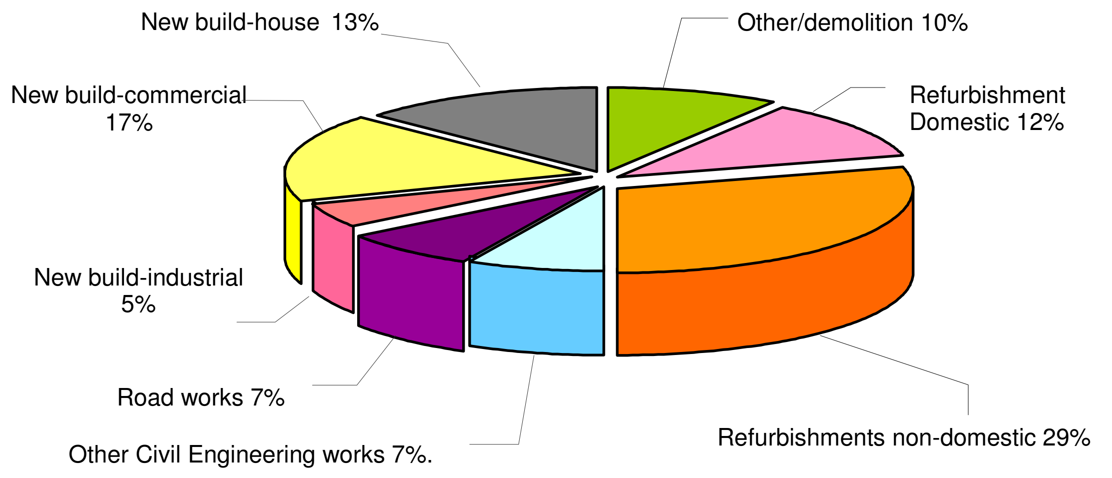
1.1 General Introduction

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 (Egbu, et al 1996). A European 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 the poor decisions made even before the work began (Croner, 1994). Among fatal accidents, the HSE in their study (HSE, 1988), had 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, within the context of this report, is defined as adaptation, extension, improvement and structural alteration of an existing building (Egbu,1996) to permit its re-use and meet functional criteria equivalent to those required for new buildings. Refurbishment work is less well-planned and more difficult to control than new-build (Egbu, 1996; Egbu,1999).

The renovation and refurbishment market is growing faster and rapidly expanding in comparison to the new construction market (Van Leeuwen et al., 2000). This growth in refurbishment work and its increasing importance, acknowledged by the 1995 Technology Foresight exercise (OST, 1995) exercise, is not matched by comparable empirical research on the subject. Furthermore, it is widely acknowledged that refurbishment projects are complex, risky and uncertain (Egbu, 1994; BRE 1990; Quah, 1992). Refurbishment projects are also dangerous, as demonstrated by the recent collapses in Hull, Bootle, Stoke and Tottenham.

In 1970, the UK repair and maintenance (R & M) sector accounted for £1109m (or 22.46%) of total construction output. By 1990, the figure had risen to £18,743m (or 42.88%). Unfortunately, no official statistics exist on the current proportion of refurbishment work but since 1990 the R & M sector (including refurbishment) has accounted for more than 40% of the total UK construction output and accounts for about 43% of the total number of fatal accidents in building and civil engineering industry in UK (see Figure 1.1). The most recent HSE statistics also 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.



Source : Revitalising Health and safety in Construction HSE Document 2002

Figure 1.1 Construction worker fatalities by site activities

Consequently, this project sought to investigate how these projects should be managed to prevent accidents, especially those due to structural collapses. A basic requirement for any building structure is that it does not collapse, causing death, injury or economic loss. However, overloading during the life-span of a building can seriously undermine the structural integrity of the building. Similarly, additional loads during refurbishment, change of use, additions and alterations to the structure can aggravate an under-designed building and contribute to its eventual collapse. The incidents of collapse of scaffolding and incidents of unintended collapse or partial collapse of any building (HSE Guidance note F2508RA) are reported under RIDDOR (Reporting of Injuries, Diseases and Dangerous Occurrences Regulations, 1995). Unfortunately there are no statistics available on 'building collapses during refurbishments', and the only one available (see Table 1.1) is from the dangerous occurrences data (HSE, 2005).

Table 1.1 Occurrences of structural collapses during construction in UK

Incidents \ Year	2000/01	2001/02	2002/03	2003/04	2004/05p
Complete or partial collapse of scaffold over 5.0 m high	63	94	64	65	73
Collapse or partial collapse of any building or structure under construction involving over 5.0 tonnes of materials or any floor or wall of a building used as a place of work	148	186	221	215	154

Table DO1 Dangerous occurrences 2000//01 - 2004/05p as reported to HSE
Source :http://www.hse.gov.uk/statistics/tables/tabledo.htm

The results of the previous 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. Anumba et al (2004), also emphasise the importance of improving the communication and exchange of information between the project team members during various stages of the refurbishment project lifecycle. Some of the other findings from the research project include the following:

- There is a shortage of decision support tools in the refurbishment and demolition sectors. Most of the existing decision support systems are geared towards the needs of new-build construction or aspects of the project delivery process other than safety (John et al, 1999; Anumba & Scott, 2001);
- There is need for much greater care in the management of health and safety in refurbishment projects;
- The development and use of graphics-based method statements that clearly illustrate how complex refurbishment and/or partial demolition projects should be carried out will enhance safety on such projects;
- There is considerable scope for improved communication of safety information between project team members as well as across the different stages in the refurbishment project lifecycle.

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 refurbishment projects. This is the focus of the current project, the aim and objectives of which are presented in the next section.

1.2 Research Aim and Objectives

The aim of this project was to investigate the management of refurbishment projects and identify the areas for decision support which can help in avoiding structural collapses. The specific objectives of the project are:

1. To review current strategies adopted for avoiding structural collapse in refurbishment projects, drawing on the findings of the previous HSE report (Anumba et al, 2004);

2. To establish end-user requirements for the development of a decision support system and to develop a functional specification;
3. To develop a new process model for refurbishment projects, which enables safety considerations to be taken into account from the earliest stages in the planning, design and execution of refurbishment projects;
4. To develop a decision support system for avoiding structural collapse on refurbishment projects using an appropriate system development environment;
5. To evaluate the resulting prototype system with industry practitioners and then to refine the system based on the feedback received.

1.3 Research Methodology

A combination of research methods were utilised to achieve the above objectives. First a review of the existing literature on health and safety in construction/refurbishment and on the implementation of decision support systems within the construction industry was undertaken. The literature review drew on the findings from the previous HSE-funded project on health and safety in refurbishment involving demolition and structural instability. Semi-structured interviews were conducted with industry practitioners and experts to establish end-user requirements and for general knowledge elicitation. The knowledge gained was used in the development of the refurbishment process model and the decision support system.

The development of the refurbishment process model, although not in the original project brief, was included in the work programme as it was considered essential for the development and implementation of 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 project participants involved in refurbishment projects.

The prototype DSS, based on the safety-integrated refurbishment process model, was developed using rapid prototyping methods. Preliminary evaluation of the resulting DSS involved presentations to 27 experts and potential end-users, followed by hands-on use of the system by 7 experts, who provided useful feedback via an evaluation questionnaire.

1.4 Structure of the Report

The first chapter provides an overview of the research project, introduces the subject matter, and the aim and objectives of the research. The second chapter reviews the relevant literature on issues related to decision making in refurbishment projects, while the third chapter presents the development of the Safety-Integrated Refurbishment Process Model. The fourth chapter describes the development of the prototype Decision Support System for avoiding structural collapse in refurbishment projects. Chapter Five summarises the research project, presents the conclusions drawn from the research and outlines recommendations for future work.

CHAPTER 2

KEY ISSUES IN STRUCTURAL REFURBISHMENT

2.1 Introduction

The construction industry is continually faced with difficult decisions. It is a simple fact that the hazards during refurbishment are of great concern, more complex, difficult to observe and evaluate (Egbu, 1994; Egbu,1996; Egbu,1999) than the hazards on new build. 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. The heterogeneous nature of each refurbishment project and the lack of projects of sufficient size and scope have prevented the refurbishment industry from standardisation. It is therefore, difficult to mechanise, plan and efficiently organise refurbishment work due to the small, labour intensive, adhoc and dynamic nature of the refurbishment works involving structural alterations/modifications.

2.2 Key Problems in Structural Refurbishments

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. Some of the key problems, during structural refurbishment which have been identified after literature review and discussions with industry experts are:

- Unavailability of reliable information such as age of the structure, basis of design, any alterations/modifications/damage that have occurred prior to refurbishment;
- Quality of materials used and quality of original construction;
- Presence of weak/deteriorating materials and structural elements;
- Presence of asbestos and its safe removal;
- Managing structural instability;
- Managing health and safety;
- Risk of non deliberate (premature) collapses of any portion of the building;
- Managing partial demolitions and deliberate structural collapse;
- Identification of load paths.

The above list is not exhaustive but failure to address even one of the above mentioned problems can raise health and safety problems on a refurbishment project, which may lead to structural collapse.

2.3 Causes of Structural Collapses

Structural collapses can occur for a variety of reasons. They can result from a major structural fault but, any seemingly minor faults can contribute to a chain of events that inevitably may lead to a collapse, which can be classified under three categories:

1. **Localised collapse**: This relates to collapses that are confined to a small part of the building, without any induced damage occurring on other parts;

2. **Progressive collapse**: Progressive collapse occurs when a key member, or members of a structure fails. The isolated failure of this key member or section then initiates a sequence of events, causing failure of the entire structure.

3. The prevention or delay of progressive collapse in large buildings is an important area to strengthen in our current infrastructure. All buildings are susceptible to progressive collapse to varying degrees (Taylor, 1975; Ellingwood and Leyendecker, 1978). It is generally agreed that the key feature distinguishing progressive collapse from localized collapse is that the resulting damage is disproportionate to the local damage (Ellingwood, 2005) caused by the initiating event. Continuous, highly redundant structures with ductility tend to absorb local damage well. Research findings suggest the need for more redundancy (multiple approaches to structural support) while designing structures (Levy and Salvadori, 2002).

4. **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). The load bearing elements such as walls, floors and roofs are either not strong enough or adequately strengthened to resist the loads and overstressing causing disproportionate collapse.

Some of the major causes of occurrences of collapses during structural refurbishment as identified after literature review, case studies made available by HSE, discussions with HSE inspectors, industry practitioners and demolition contractors are listed below:

- Failure to determine structural integrity;
- Inappropriate weakening of structures;
- Accumulation of smaller weaknesses in structures;
- Activity induced (e.g. poor weakening);
- Load induced failures (e.g. debris, climatic);
- Spontaneous failures of structures (deterioration and sunlight);
- Remote activity (e.g. vibration) during partial demolition/removal of any structural element and/or structure;

- Lack of or inadequate method statements for the erection and safe removal of structural elements;
- Lack of appropriate temporary support;
- Early removal of formwork/temporary supports;
- Misunderstanding of load paths;
- Differential settlement (e.g. liquefaction of soil) of the foundation.

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. Buildings must be strong enough to deal with three main types of loads, known as static, dynamic, and hidden 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 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).

The hidden loads, which may not be sudden, may 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.

2.4 Case studies

2.4.1 Introduction

One of the objectives of the research was to review the strategies adopted during structural refurbishments. This involved a review of the case studies presented in the previous report (Anumba et al, 2004) and additional cases reviewed during the course of this research. HSE provided the research team with several documented case studies which had resulted in premature collapses during demolition and/or collapses during structural alterations/removal of building elements. A subset of the case studies involving collapses are presented below to highlight the causes of collapses and the recommendations made to avoid structural collapses:

2.4.2 Case study 1 : Catastrophic collapse of a three storey building

Type of building **:** Terraced three storey building
Details of failure : Complete collapse of walls and floors of a 150 year old building during refurbishment, which resulted in minor injuries to 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 lack of 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 to take it down and reconstruct;

- There was seemingly no great urgency or priority placed on taking down the gable wall as the owner intended to carry it out after completion of the other strengthening works.
- Although no main structural element was removed or dismantled, removal of the floorboards reduced the tortional stability of the already weakened structure

Recommendations by HSE

- Check for lateral ties and lateral support at all levels of the structure, e.g. floorboards;
- Ensure the structure is engineered for lateral stability in all directions. The lateral stability can be achieved by :
  1. Connecting the structural element to a robust member to provide adequate support;
  2. Adequately propping and bracing the structure;
- Detailed examination of the verticality of the walls and careful removal of the walls which have bulged in either direction;

2.4.3 Case study 2 : Collapse of masonry wall

Type of building **:** Semi-detached barn

Details of failure **:** Collapse of masonry wall during rebuilding activity on a refurbishment project causing fatal injuries to a person.

Causes of failure **:** The collapse of the masonry walls 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 stability to the adjacent wall.

Recommendations by HSE

- 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; and 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 excavation is a necessity and the only solution, it should be done in short lengths and excavations are filled with the new floor immediately after the excavation.

2.4.4 Case study 3 : Collapse of a concrete floor

***Type of building* :** Semi-detached old building

***Details of failure*:** Part of concrete floor collapsed during demolition work prior to refurbishment of a building causing serious head injuries to one of the workers.

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

- Failure to understand that the underside of the floor was not an integral part of the floor. This revealed that a structural survey should have been conducted by a competent person;
- Absence of temporary supports to support the floor before demolition;
- Absence of detailed method of working;
- Lack of written method statements and effective communication to those carrying out the works;
- Inadequate supervision to ensure work was carried out in a safe manner during each activity.

Recommendations by HSE

- Even though several areas were supported by vertical adjustable props, the lateral ties were found to be missing.
- There is need for the props to be tied together using load bearing couplers in order to provide additional lateral stability to vertical props.

2.4.5 Case study 4 : Ashford building collapse

Type of building **:** Three storey semi-detached building

Details of failure **:** This collapse of a three-storey office building occurred on 1 August, 1995, in Ashford, Middlesex, 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 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;
- 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 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 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.

Recommendations by HSE

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 is required before making any structural alterations;

2.5 Avoiding Structural Collapse in Refurbishment – Key Considerations

2.5.1 Overview

It is very important to know the structure being refurbished, what it is 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, walls etc.) should be checked thoroughly for any alterations/modifications, damage and any dilapidation. 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. Major findings from the study of the accident investigation reports, case studies and literature review which need to be carefully considered during structural refurbishment are listed below:

- Assessing the structural stability mechanism through a detailed structural survey and understanding the structure as it is now;
- Designing an adequate temporary support system, auxiliary structures and false work including facade retention systems. 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;
- 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;
- Appointment of 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;
- Identify clearly the load paths for each structural change;
- Lack of risk assessment at design stage, neglecting CDM requirements;
- Method statements to include stability statements and design requirements prepared for each stage.

2.5.2 Evaluation of the existing structure

For any structural 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 the structural integrity of the existing building. This entails that any building being refurbished must go through a detailed initial inspection as they may have been exposed to the risk of abnormal loading and instability (SCOSS, 2003). The provision of measures for their safety, therefore, 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).

The structural appraisal of any such building, therefore, should address the questions of risk and provision of robustness in the context of its function and consequences of the damage it may suffer on account of any collapse (HSE Investigation Report, 1999). 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. The HSE Investigation Report (1999), HSE Research Report 204 (2004), and SCOSS Reports, pointed out that a sound structural appraisal should aim at providing information on the following aspects of the building:

- Substructure - Old buildings may not have been built to adequate standards. Building Control will demand exposure of the foundations at some selective points using trial pits;
- Nature and quality of the construction;
- Absence of temporary structures to support unstable elements;
- Lack of risk assessment at design stage, neglecting CDM requirements;
- Lack of any preliminary structural survey or site investigation;
- Poor planning of demolition sequences;
- Lack of demolition method statements;
- Lack of supervision while undertaking demolition activities

- Identification of the existing precast concrete floor and/or roof units and assessment of the effectiveness of any lateral tying within the floor and roof construction;
- 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;
- Identification of the existing lintel units and assessment of the effectiveness of any longitudinal tying which may have been introduced between consecutive units.

A structural appraisal should be aimed at assessing the real structural condition of an existing building. Such assessment should lead to a decision on actions essential for ensuring the structural adequacy of the building for its intended use at present or in the future (HSE Investigation Report, 1999). A structural appraisal should, therefore, identify the vulnerability of such buildings and recommend actions to be taken to reduce the potential risk. 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.

2.5.3 Reducing potential risks during refurbishment

Before commencing detailed design for any refurbishment work, those sections of the works that are to be modified should be carefully surveyed and documented. All buildings with floor slabs spanning one way or roof components supported on load-bearing masonry walls and without any provision for peripheral or internal horizontal ties, or undergoing building works for change in the use of the building, would require the building to comply with

Regulation 6 of Building Regulations 2000: Part A (Structure) as highlighted in HSE Investigation Report (1999). Generally, the size and function of a small dwelling are such that the consequences of failure of any such building may not be as significant as those of 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 (HSE Investigation Report 1999).

2.5.4 Controlling demolition and unplanned collapses

Demolition works can be considered among the most important activities to be carried out on site. The British Standard 6187 'Code of practice for demolition' provides a very useful reference for the identification and classification of demolition methods and techniques. Demolition activities are mainly done on projects where structural alterations are being done on the existing structure. These alterations could be very different depending on the size and type of refurbishment project. Some examples are:

- Removal of structural elements;
- Partial demolition of the building with a view to making extensions;
- Creation of new openings or enlargement of existing openings;

Demolition works are among the most dangerous operations to be performed on site due to the high level of risk to the structure and workers (Anumba et Al., 2004). 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. Such structural stability can be provided with different methods (adequate structural analysis; temporary support structures; proper demolition methods; schedule and equipments etc.). Unfortunately, more accidents and fatalities occur during partial demolition than during total demolition works especially while carrying out small demolition activities. This is primarily due to the need to ensure the stability of the retained part of the structure and the safety of any occupants. 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. Interaction between site workers and the people occupying such buildings needs to be fully considered because accidents during demolition works are mainly caused by partial or total collapses.

2.5.5 Appointment of a competent team

One of the most important considerations during structural refurbishment is that the workforce has to be properly trained and qualified to carry out refurbishment works (Egbu,1994). 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 the native language. The HSE Report 204 (Anumba et al, 2004) strongly recommends that workers are assessed for their ability to understand procedures and the safety instructions that are communicated to them. At the same time, workers involved in demolition activities have also to be specifically trained on each aspect of the work they are undertaking.

2.5.6 Measures to avoid collapse during refurbishments

Unplanned collapses during demolition usually occur because of inadequate understanding of structural behaviour. In one case, cutting the upper chord bracing of a truss bridge led to the sudden premature collapse of the bridge. Similarly, deterioration, brittle fracture or fatigue are some of the common problems leading to catastrophic structural collapse. These can be reduced considerably by inspecting dangerous cracks, rot, corrosion and other material changes. 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. There may also be a higher probability of the collapse being disproportionate, if caused by a local accident, a local explosion or vehicular impact (HSE investigation report,1999), Ellingwood, 2005). Sometimes thoughtless alterations can drastically change the structural capacity, (e.g., cutting of reinforcing steel or re-roofing without maintaining the required lateral support to the roof structure). 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 (see Section 2.4.3).

The concept of reducing the sensitivity of a building to disproportionate collapse came after the Ronan Point incident of 1968 and the subsequent investigations. BS8110 and referenced in the Approved Document Part A, recommend provision of measures 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, a building designed according to such a code is expected to have measures to make it reasonably robust and it would not suffer large scale collapse on account of a local accident or damage to a small area, or the failure of a single structural element. A pre-1970 building would not have any such designed provision and some improvements may be necessary to equip the building for its life after refurbishment (HSE investigation report,1999).

Any measures for improving a building's robustness should be derived from basic considerations and 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.

2.5.7 Compliance with statutory and regulatory requirements

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
- Environmental Protection Act 1990.
- Management of Health and Safety at Work Regulations 1992 (Management Regulations).
- Control of Substances Hazardous to Health Regulations1994 (COSHH).
- The Construction (Design and Management) Regulations 1994.
- 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 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. Investigation of the Ashford collapse (see Section 2.4.5) has highlighted the need for careful planning of any refurbishment work in old buildings. Detailed inspection and structural appraisal are essential before removing any part of such buildings so as to identify the load path in the structure and to avoid any distress to the key elements that might lead to progressive and catastrophic collapse.

Additionally, the work should include provision of measures to reduce the sensitivity of the building to disproportionate collapse, and ensure that it is suitable for its intended use during its life after refurbishment.

2.5.8 Communication

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 (Aumba 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. Effective communication also includes the need for feedback on unexpected discoveries about the structure and materials as the work progresses.

2.5.9 Decision making process

Decision making during refurbishment projects depends on the needs and requirements of the occupants and state of the building. Decisions are mainly taken by the design group consisting of the designer, structural engineer,

HVAC engineer, building owner (client) and various specialist contractors (Alanne and Klobut, 2003). 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). 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. Figure 2.1 illustrates the essential steps in the decision making process.

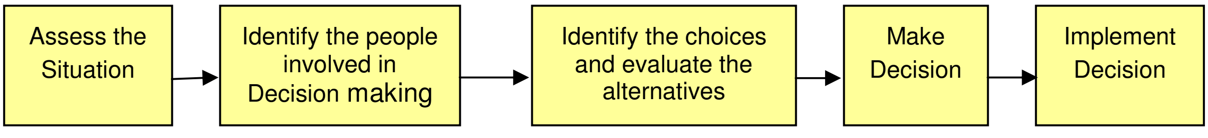


Figure 2.1: Decision Making Process

Table 2.1 presents the activities, sub-activities and potential decision making areas during refurbishment. This has been developed from the literature review.

Table 2.1: Activities, Sub-Activities and Potential Decisions-Making Areas During Refurbishment

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

Similarly, knowledge of the material and information about the structure play a major role in decision making. However, there are several other factors that need to be considered. These include the uncertainty and incompleteness of information, the need for engineering judgement, knowledge of the particular structure, experience with the behaviour of structures in general, and engineering knowledge to interpret the data involved.

2.6 The Need for a Decision Support System

Decision support systems (DSS) are tools that provide support to individuals or teams of people that need to make decisions in a given situation. They are often 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. Numerous decision support systems have been developed for use in industry. Some of these have been targeted at 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.

Decision support systems assist decision makers to confront uncertainties, ill-structured problems, through direct interaction with data and information. 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). 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.

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 highlighted earlier) suggesting that the management and technical solutions often adopted in these projects are inadequate. 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.

Experience and expertise can be captured and encapsulated in a decision support system that provides a sound technical framework for decision making. This affects the degree of confidence the end user can have for ensuring structural stability during the refurbishment activities.

Other reasons for seeking to develop a DSS for this domain include: the need to develop a practical tool that both clients and industry practitioners can readily utilise to improve safety in refurbishment projects, and the need to build on the findings of the previous HSE-funded project (Anumba et al, 2004).

It is intended that the proposed decision support system will provide decision support for experienced engineers while serving as a useful training tool for inexperienced workers involved in refurbishment projects. It will focus on what is required at each stage of the refurbishment process and cover issues related to management, labour, risk management, and working methods. Aspects of risk-based decision making informed the development of the system.

Prior to presenting the Decision Support system (DSS), it is important first to discuss the development of the new refurbishment process model on which it is based. This is the focus of the next chapter of this report

CHAPTER 3

REFURBISHMENT PROCESS MODEL (RPM)

3.1 Introduction

The recent research focus on construction as a manufacturing process has resulted in 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 duration of construction projects, it is also necessary to build-in checks to ensure not only efficiency, but also continued effectiveness. The opportunities for such checks are provided by the 'gateways' which punctuate the project process. Effective health and safety management systems such as the training of individuals, providing improved and more sophisticated information on which the decisions can be based would enhance the process to a large extent. This chapter describes the development of a generic process model for refurbishment, which enables the early consideration of safety issues.

3.2 Rationale for Refurbishment Process Model

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 led to the development of a generic project process, the Process Protocol (Kagioglou, et al., 1998, 2000.). In the dynamic, safety-critical situations presented by refurbishment sites, processes shift the emphasis from well-structured and well-defined 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. It was also evident from the previous study (Anumba et al, 2004) and the case studies presented in Chapter 2 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 creation of a safe system of work requires that the tasks are in the right sequence and allow a project to be carried out with minimum risk to everyone involved

3.3 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 (The RIBA Plan of Work, 1999) as reference points. The approach adopted involved discussing 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.

In the new refurbishment process model, it is assumed that the refurbishment project would start with identifying the need and scope of the refurbishment and continue to the post-refurbishment phase. Figure 3.1 illustrates the proposed refurbishment process model, which is presented as representing the refurbishment management activity zone of the Process Protocol. The detailed activities are presented in two levels at each phase. Appropriate figures are used to illustrate the various stages and phases so the associated textual description can be kept to a minimum. The corresponding work stages of the RIBA Plan of Work and Generic Construction Phases are also shown in Figure 3.1.

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 of two main stages: design stage and procurement stage. The next two phases fall within the refurbishment phase which is comprised of the demolition stage and 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. Figures 3.2 to 3.7 provide the details of the activities and sub-activities at each stage of the refurbishment process model. The project participants involved at each stage are shown in ovals below each activity.

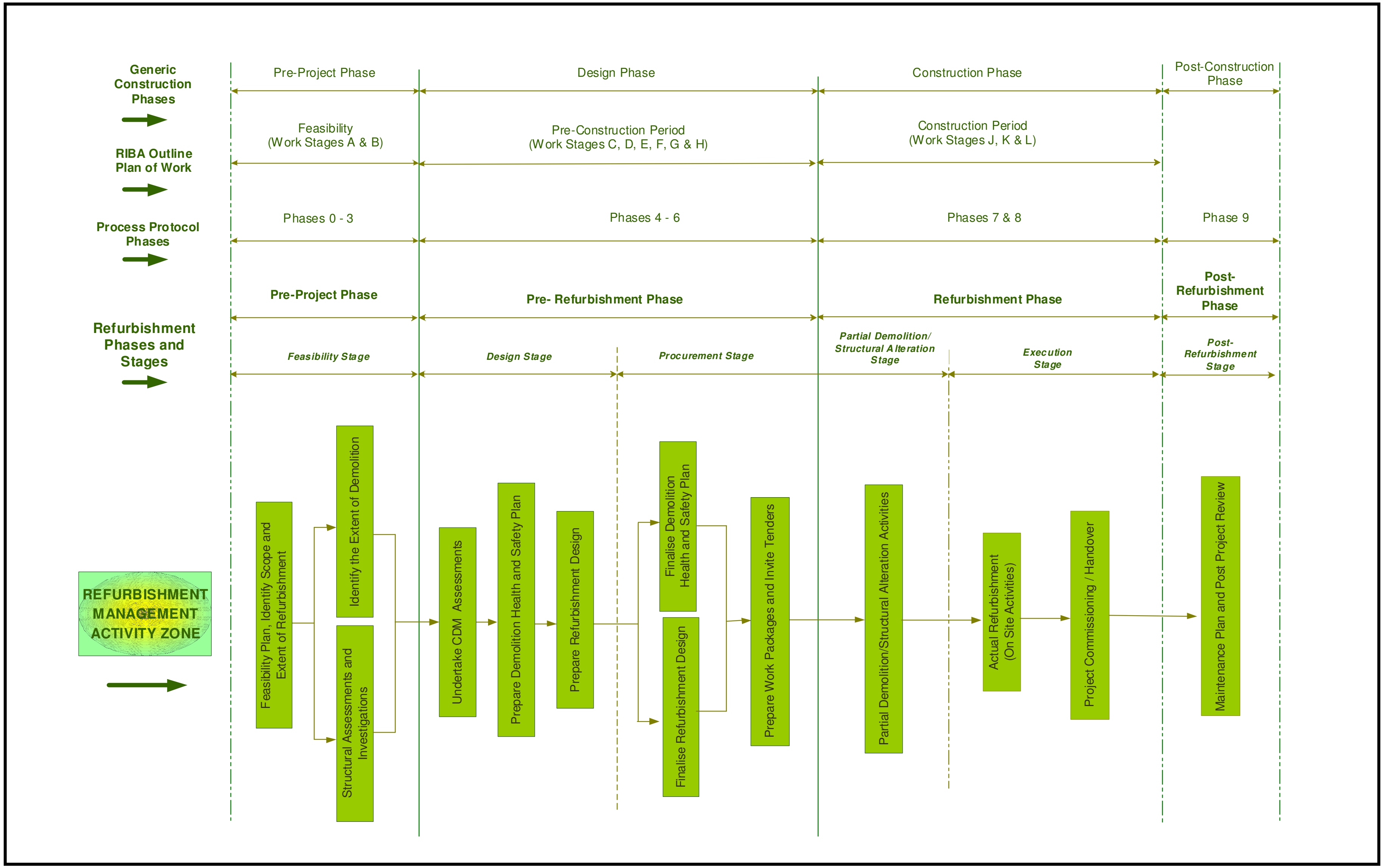


Figure 3.1: Refurbishment Process Model

The Pre-Project Phase (see Figure 3.2) has a Feasibility Stage, which has been further divided into three main activities. These, in turn, have been further divided into a set of second level sub-activities:

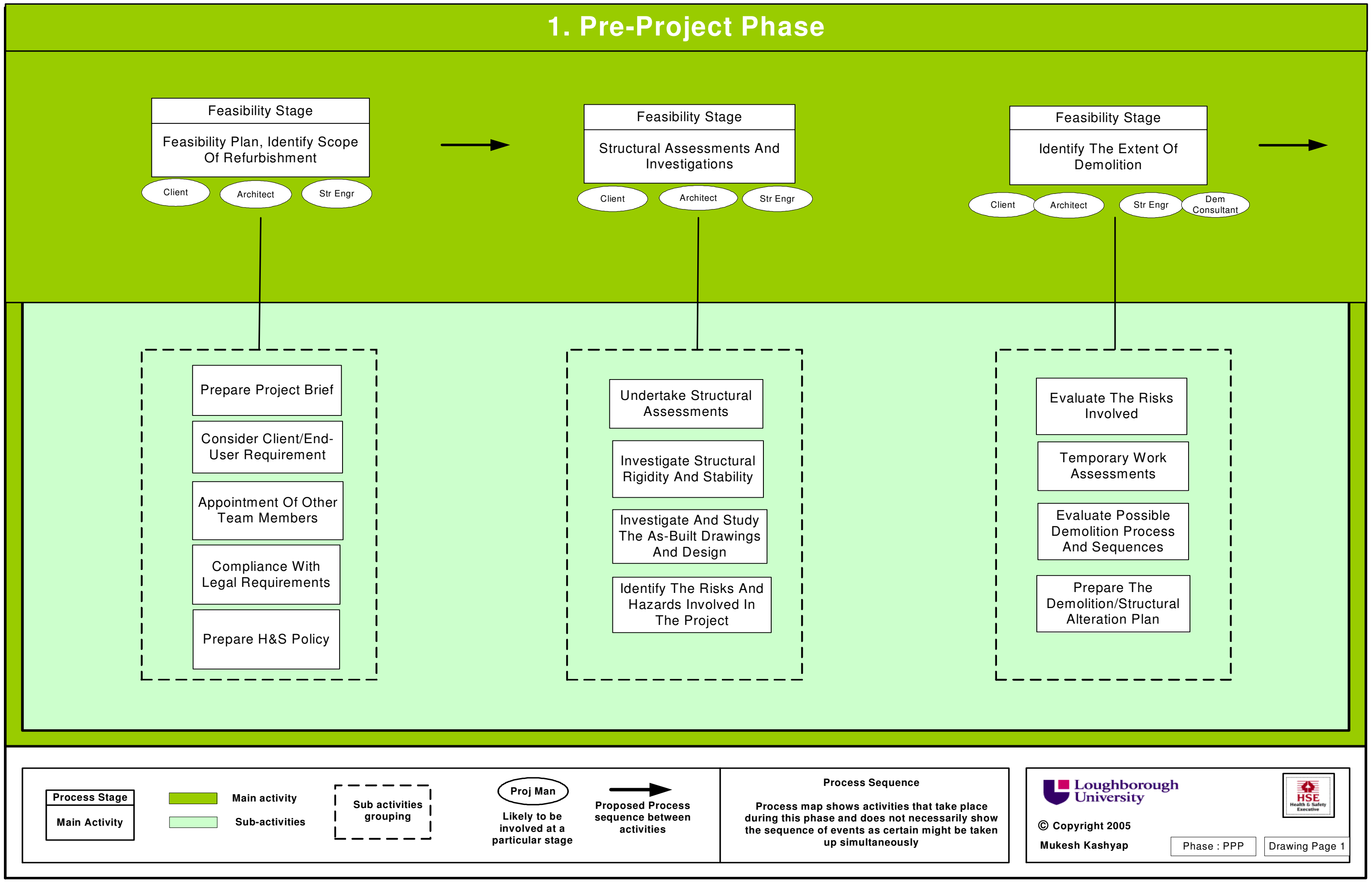


Figure 3.2: Pre-Project Phase
(First and second level activities during the Pre-Project Phase)

The Pre-Refurbishment Phase has two main stages: Design stage and Procurement stage. The Design stage (Figure 3.3) has been further divided into three main activities and second level sub-activities as shown below:

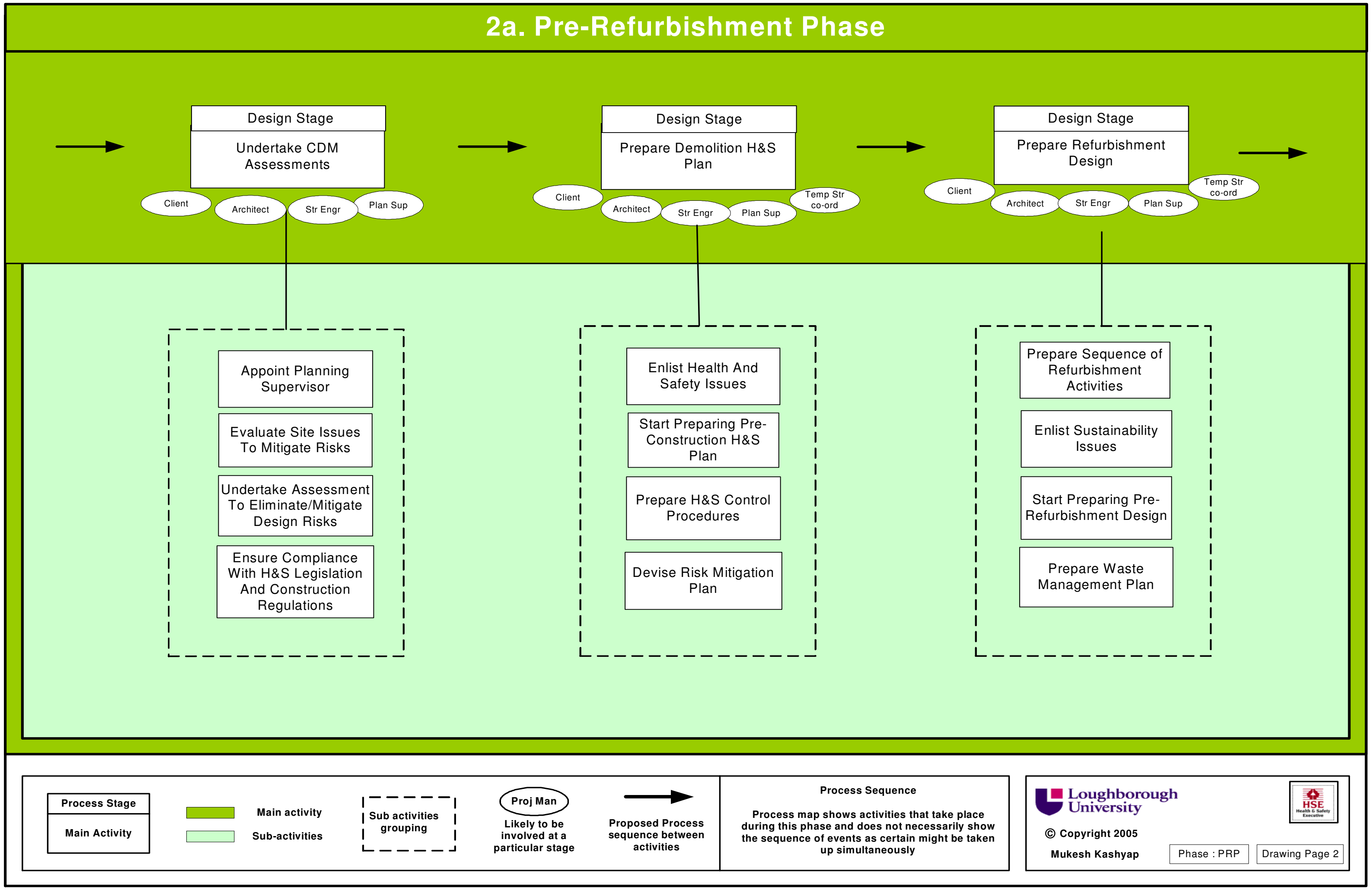


Figure 3.3: Pre-Refurbishment Phase – Design Stage
(First and second level activities during Design Stage)

The Procurement Stage of the Pre-Refurbishment Phase is further divided into three main activities and sub-activities (see Figure 3.4

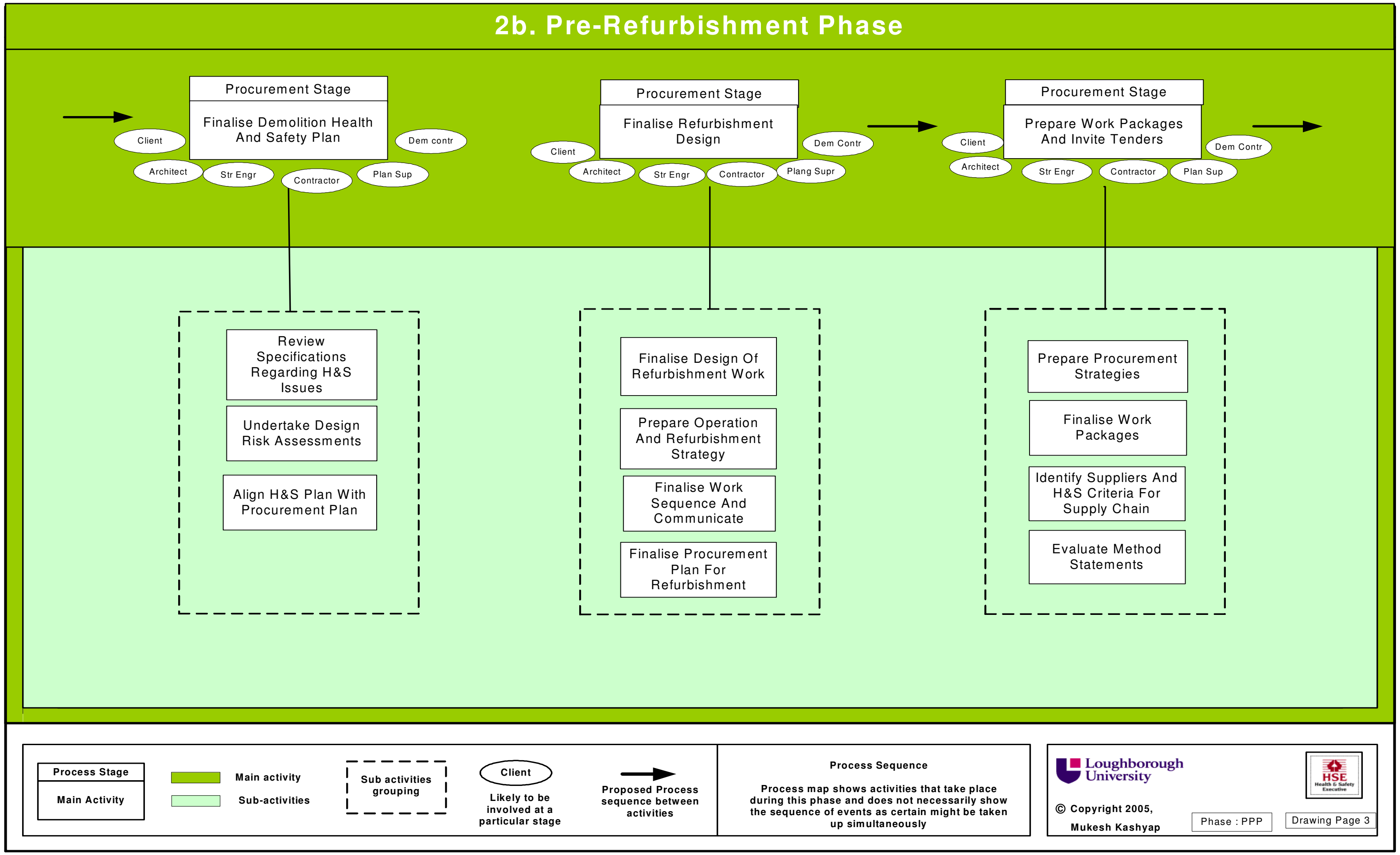


Figure 3.4: Pre-Refurbishment Phase – Procurement Stage

(First and second level activities during Procurement Stage)

The Refurbishment Phase (see Figure 3.5) has only onstage - partial demolition and structural alteration stage, which has demolition as the main activity. There are five sub-activities at this level.

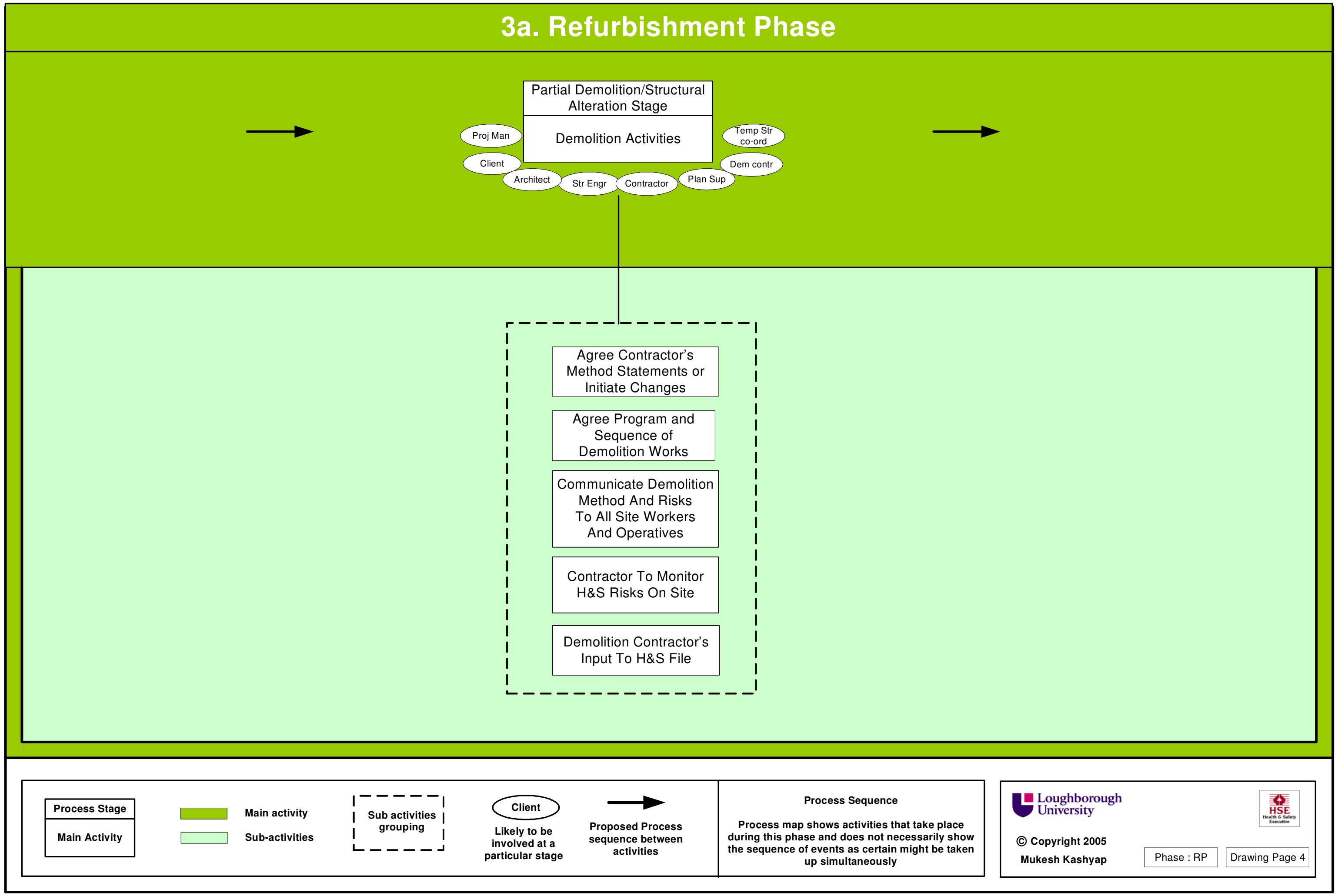


Figure 3.5: Refurbishment Phase – Partial Demolition/Structural Alteration Stage

(First level and second level activities during Refurbishment Phase)

The Refurbishment Phase (see Figure 3.6) also contains the main execution stage. This stage is further divided into two main activities – actual refurbishment and project commissioning/handover - and the associated second level sub-activities.

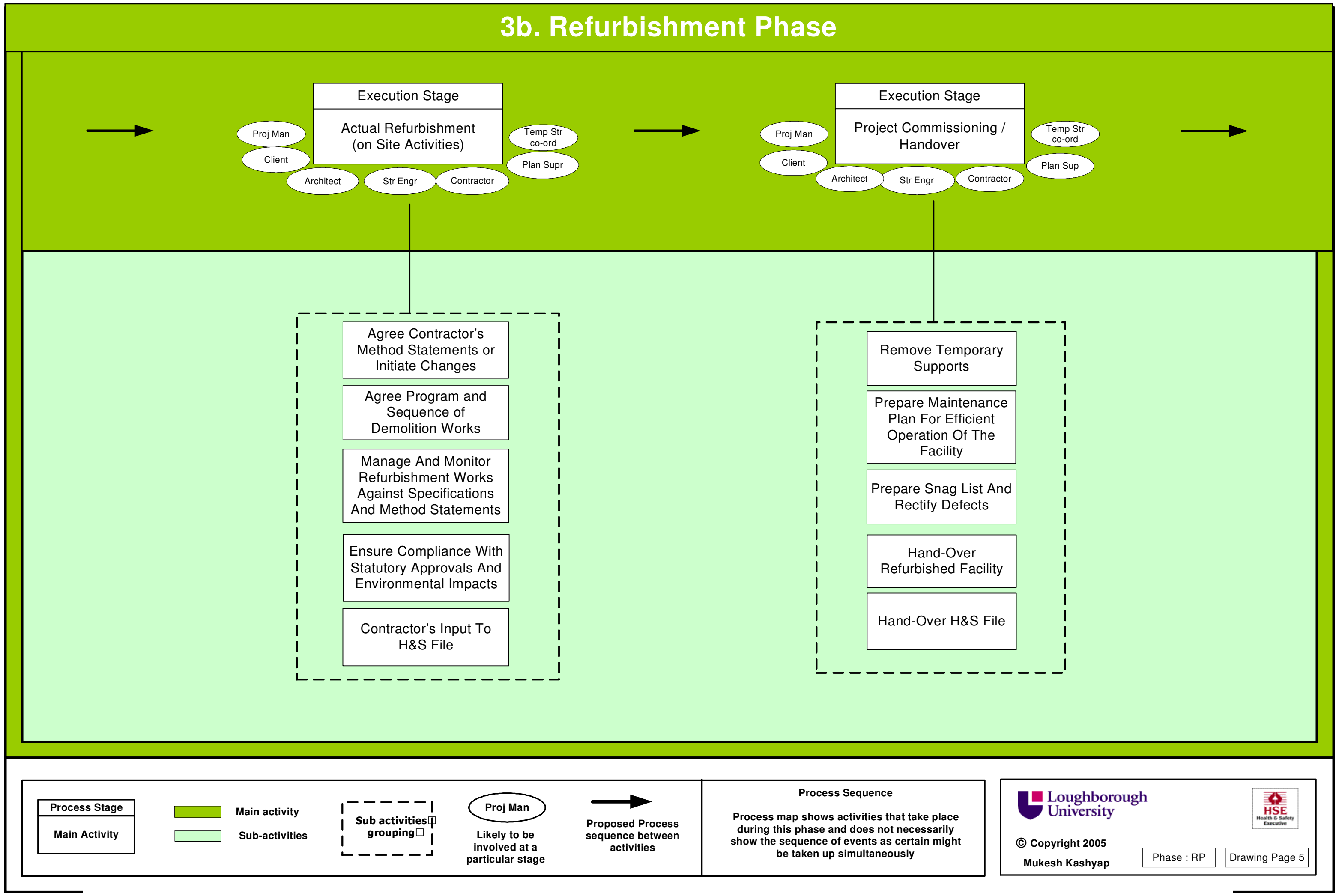


Figure 3.6: Refurbishment Phase – Actual Refurbishment and Handover Stage

(First level and second level activities during Refurbishment Phase)

The Post-Refurbishment Phase (see Figure 3.7) has the post-refurbishment stage as the main stage. This stage incorporates Preparation of maintenance plan and post-project review as the main activity, with a list of sub-activities:

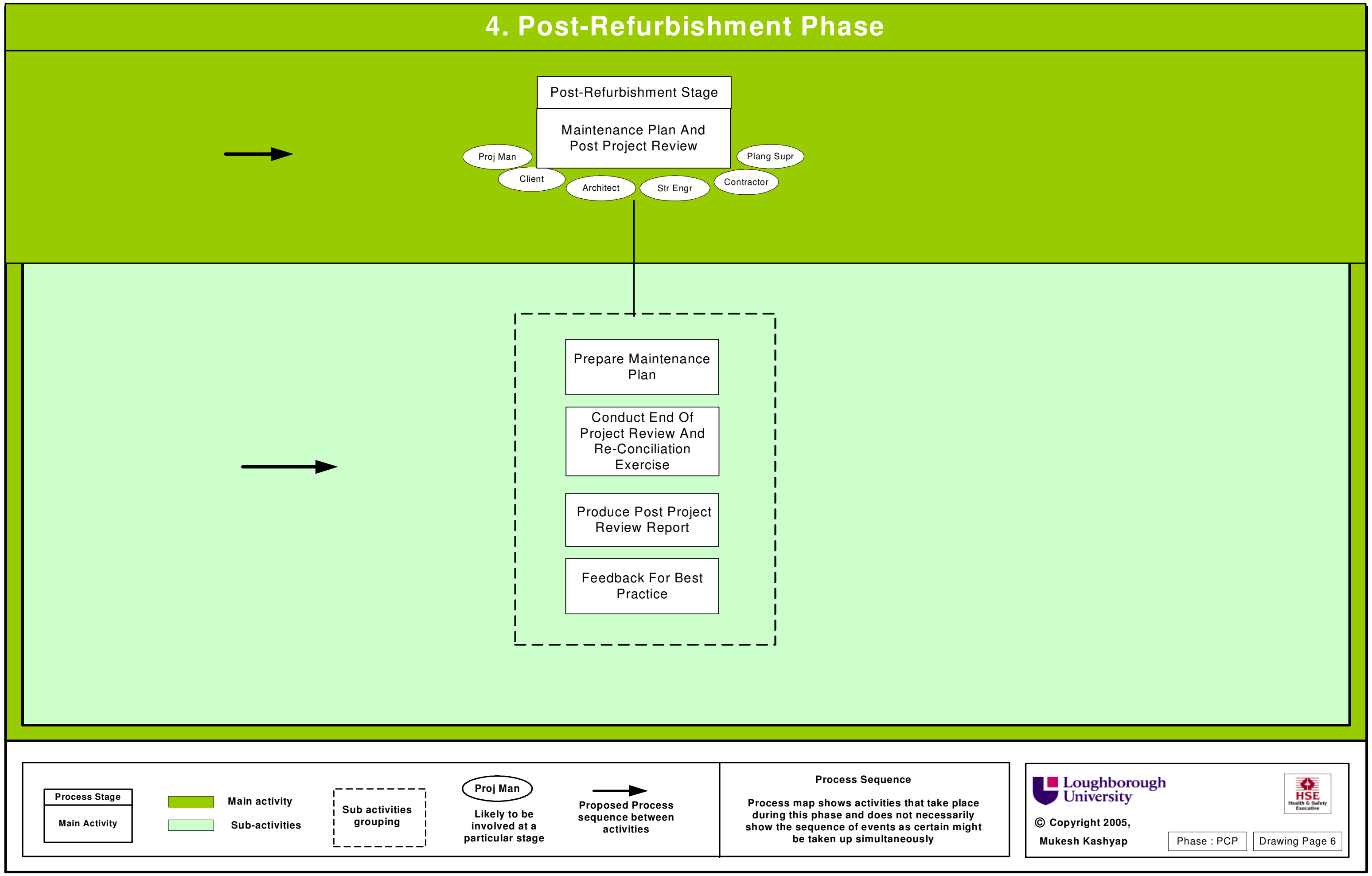


Figure 3.7: Post Refurbishment Phase – Post Refurbishment Stage

(First level and second level activities during Post-Refurbishment Phase)

3.4 Evaluation of the Refurbishment Process Model

3.4.1 Introduction

This section sets out the details of the evaluation of the Refurbishment Process Model (RPM). The evaluation and refinement of the RPM was iterative and hence required feed-back from industrial practitioners and continuous review of the model. The objectives, approaches adopted and the results of the evaluation are all presented in detail.

3.4.2 Objectives of the Evaluation

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

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

3.4.3 The Approach Adopted

The approach adopted in evaluating 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 workshops were held in Loughborough and Glasgow to evaluate the process model. These workshops were designed to elicit feedback from academics, researchers and industry practitioners on the appropriateness of the refurbishment process model. Table 3.1 summarises the number of participants at each of the evaluation workshops.

Table 3.1 No of participants at the evaluation workshops

Workshop	Workshop 1	Workshop 2	Workshop 3
No. of participants	7	11	31

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 regarding the activities and sub-activities at various stages of the process.

Workshop # 2

The second evaluation workshop was held at Loughborough University during a workshop in April, 2005, (see table 3.1). 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 were then distributed to the participants, which comprised 3 academics and 8 researchers. The eleven delegates provided feedback on the various components of the RPM.

Workshop # 3

The third evaluation workshop was held at Glasgow Caledonian University (GCU) under the auspices of the Centre for Built Environment (CBE), Scotland. The workshop started with presentations on the problems in refurbishment and how refurbishment could be made safer by adopting a safety-integrated process model. The workshop was attended by thirty one respondents, which included architects, structural engineers, contractors, planning supervisors and H&S advisors representing different sections of the construction industry (see Figure 3.8). Participants were then given detailed notes on the process model and invited to complete a questionnaire (see appendix A1). The questionnaire had a rating system that was based on the 5 point Likest scale with 1 representing the lowest and 5 the highest rating.

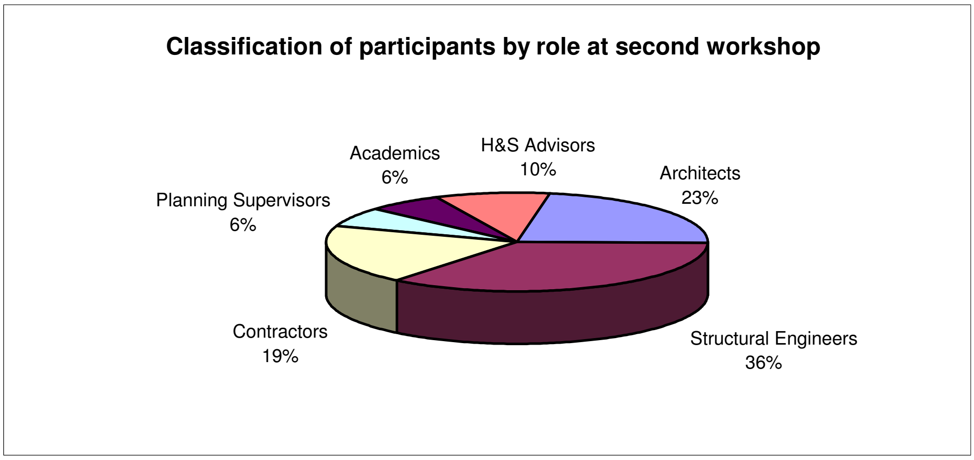


Figure 3.8 Classification of participants by role at second workshop in Glasgow

3.4.4 Analysis of the evaluation results of the process model

The responses were analysed under four categories (see Appendix A1 for evaluation questionnaire) to understand the effectiveness, functionality, scope and usability of the RPM in real life refurbishment projects. Seventy four percent of the respondents felt that RPM would be 'very effective' or 'quite effective', while 26% of the respondents felt that the deployment of a refurbishment process model could be 'effective', for modelling the refurbishment process.

Fifty eight percent of the respondents felt that the RPM can be 'very effective' or 'quite effective' for decision making in refurbishment. Twenty six percent felt it can be 'effective', whereas only 3% felt it would not affect decision making.

Fifty eight percent of the respondents felt that the RPM can be 'very effective' or 'quite effective' in reducing collapses in refurbishment projects, while 29% felt it could be 'effective', and 13% felt it could be 'somewhat effective'. On its coverage of all the key stages during refurbishment10% of the respondents felt it is covered to a 'great extent', while 55% felt that these are covered 'quite effectively'. Twenty nine percent felt it effectively covers all the stages, only 6% felt in negative. Seventy five percent of the respondents felt that format of the RPM is ''very easy' or 'quite easy' to understand. Table 3.2 presents the average rating and equivalent percentages from the evaluation questionnaire.

Table 3.2 Summary of responses to evaluation questions

EVALUATION QUESTIONS		Workshop 2		Workshop 3	
		Average Rating	Equivalent %age	Average Rating	Equivalent %age
EFFECTIVENESS					
1	How effective can the RPM be for the refurbishment process?	2.9	58	3.2	64
2	How effective can the RPM be in decision making relating to refurbishment?	3.1	62	3.5	70
3	How effective can the RPM be in reducing structural collapses in refurbishment projects?	3.4	68	3.6	72
FUNCTIONALITY					
4	To what extent does the RPM represent an improvement over your current refurbishment process?	3.0	60	2.7	54
5	To what extent do you think the RPM would facilitate planning for safety in Refurbishment?	3.2	64	3.45	69
6	To what extent is the RPM suitable for the refurbishment process?	3.4	68	3.0	60
COVERAGE AND SCOPE OF THE RPM					
7	In your views, to what extent does the RPM cover all the key stages of a refurbishment project?	3.5	70	3.6	72
8	How well covered are the activities addressed in the RPM model?	3.6	72	3.35	67
9	How well are the key problem areas addressed in the RPM?	3.4	68	3.5	70
EASE OF USE AND USER FRIENDLINESS					
10	How user friendly is the format of the RPM?	4	80	3.85	77
11	How easy is it to use the RPM?	3.8	76	3.8	76

3.4.5 Discussion

The fact that most of the evaluators understood the RPM and appreciated its usefulness was a very useful feedback. Feedback on the activities and sub-activities of the RPM included the following:

- It was suggested that demolition contractors/consultants should be involved right from the beginning at the feasibility stage.
- 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.
- Clients' need to be motivated towards sustainable refurbishment and waste re-cycling during the design stage;
- Prepare Health and safety policy to avoid any structural collapse should be prepared during feasibility stage;
- The sequence of some stage (e. g., conceptual design and detailed design) needed some modification and some sub-activities (e.g., investigate structural rigidity, preparation of waste management plan) were added.
- Roles of project participants for sub-activities should be mapped out, especially in scenarios where one key participant and/or when one of the key participants has taken up the role of another key player;
- Temporary works should be identified as an activity during 'Demolition Activities' and 'Actual refurbishment';
- Need to address the flexibility/overlapping of activities within RPM when applying and using with different situations and project stage;
- Respondents/Interviewees also suggested to give more emphasis to the contractors' team than to the client team.

3.4.5.1 Benefits of the RPM

From the evaluation, the benefits that the refurbishment process model offers to participants in refurbishment projects 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 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 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.

3.4.5.2 Limitations of the Evaluation

The main limitations of the evaluation were identified as:

- The evaluation 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;
- Although those who evaluated the RPM during second workshop were from small and large organisations, even more targeted feedback could have been elicited from smaller contractors involved in different types of refurbishment projects over a longer period of time.

Overall, the evaluation was a success as most of the evaluators appreciated the usefulness of the RPM and provided very useful feedback, which informed the further refinement of the process model. The next chapter describes the Decision Support System, which is based on the process model.

CHAPTER 4

THE DECISION SUPPORT SYSTEM (DSS)

4.1 Introduction

This chapter describes the development of the DSS to avoid structural collapses on refurbishment projects. It has been established that the 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. This is either because the decision maker could not get complete and correct information or the correct information was not available/made available to him.

4.2 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 capture, the HSE inspectors involved with refurbishment projects were of the opinion that the system should be able to prompt the end-users 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.

4.3 End-User Requirements

The first and foremost step in the system development was to identify the end-user requirements and develop a functional specification for the system. The term 'end-users' was taken to mean those participants in refurbishment projects who would use the system to improve on their current performance (see Figure 4.1). Areas where further guidance is required by the professionals involved during a refurbishment project were discussed and are discussed below. Identifying stakeholders and examining their respective interests in the various issues is an essential part of the overall decision-making process.

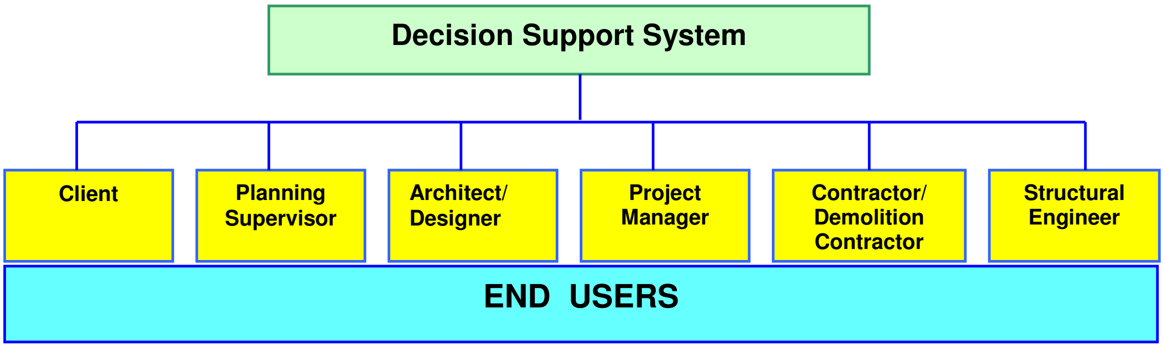


Figure 4.1: End-Users of the Decision Support

The end-user requirements were vital as the proposed DSS required a considerable commitment to safety and the proactive involvement of all parties such as clients, planning supervisor, designers architects and structural engineers, demolition contractors and general contractors in avoiding structural collapses on refurbishment projects from the earliest design stages. 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 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 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. The client has direct responsibility for ensuring the appointment of competent persons and the production of a health and safety plan for the project. Cclients can be classified in 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 the 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 experts depending on the scope and complexity of the project.

The requirements of clients as end-users of the DSS include the following:

- A reminder on 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;
- Hints on good H&S management practices on refurbishment projects.

The Planning Supervisor

The role of the Planning Supervisor is mainly concentrated on the design and planning phase of a refurbishment project. The Planning Supervisor has to be fully aware of all the information drawn from preliminary structural surveys as well as the preliminary work related to the development of demolition sequences and temporary works during the refurbishment project. The principal duty of the Planning Supervisor is to:

- co-ordinate the health and safety aspects of project design and planning (particularly the preparation of the Health and Safety Plan) and to ensure that the principles of prevention and protection are adequately applied.

The requirements of the Planning Supervisor with regard to support from the DSS include:

- Identification of the relevant Health and Safety regulations and legal responsibilities of all the project partners;
- A reminder of the roles and responsibilities of the Planning Supervisor at different stages of the project;
- Identification of the risks involved during demolition and refurbishment;
- Reminder of key safety issues from the preliminary structural surveys;
- Support in the preparation of the pre-tender Health and Safety Plan;
- Access to the refurbishment design and CDM assessments.

The 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 construction process. There can be a nominated Project Manager specifically appointed for the job or the client himself/herself, principal contractor or main contractor can act as project manager. But in all situations, whoever is managing the project, as project manager, should not only be aware of his duties and responsibilities but 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 on the duties and responsibilities of a Project Manager on a refurbishment project;
- Support in facilitating the co-ordination of safety information and communication;
- Assistance with risk identification and assessment;
- Guidance on Health and Safety requirements under the CDM regulations;
- Guidance on H&S issues that commonly occur on refurbishment project.

The Architect/Designer

The role of the Architect/Designer in a refurbishment project involves the design of the refurbishment works. Special attention needs to 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 on 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;
- 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. The detailed surveys, along with structural assessments of the key structural elements, will allow the Structural Engineer to utilise the information to design the demolition sequences and temporary works.

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 scope of structural alterations during the refurbishment works. The Structural Engineer is required to look for any signs of structural distress, any cracks in columns or beams, and excessive settlement or deflections. 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 on 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;
- Guidance on H&S issues that commonly occur 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 is required to select competent sub-contractors and a temporary works co-ordinator. He/she needs to communicate health and safety procedures to workers and set up suitable communication methods to overcome language barriers and convey the extra precautions required in refurbishment projects. The contractor has to inform the workers and, if necessary, provide training on health and safety prior to the start of the works.

The contractor's requirements with respect to the DSS are:

- A reminder on the duties and responsibilities of a Contractor with regard to health and safety on a refurbishment project;
- A reminder of the responsibilities of the Contractor in selecting skilled manpower for the project;
- Support in monitoring health and safety aspects of refurbishment activities;
- Guidance on H&S issues that commonly occur on refurbishment projects.

The Demolition Contractor

The Demolition Contractor is a specialist sub-contractor who is required to deploy a skilled workforce to undertake specific demolition activities. It is extremely important that all the additional investigations on the structural conditions of the building to be refurbished are carried out prior to the start of the demolition activities. The Demolition Contractor has to select the most suitable demolition techniques and equipment based on the available information and safety considerations. However, in smaller projects, demolition activities may be undertaken by the main contractor

The requirements of the Demolition Contractor as an end-user of the DSS include:

- A reminder on the duties and responsibilities of a Demolition Contractor;
- Information on key structural issues that might impact on the demolition sequence;

- Guidance on H&S issues that commonly occur on refurbishment projects;
- Guidance on the selection of the most appropriate demolition technique in a given situation.

The Temporary Works Co-ordinator

The Temporary Works Co-ordinator is a new professional role that is not mentioned in Health and Safety legislation. The earlier HSE-funded project recommended this new role and identified some examples of what is required in the role (Anumba et. al 2004). The temporary works co-ordinator appointed by the principal contractor is strongly recommended for every refurbishment project, which involves demolition activities or structural modifications/ alterations and co-ordinate temporary works so that stability is ensured throughout the interim stages of the building works. He/she is required to supervise the design of temporary works, plan and manage partial demolitions, and communicate all structural and design modifications that may occur during the refurbishment to all the relevant parties.

The requirements of the temporary works co-ordinator with regard to the DSS include:

- Reminder of the duties and responsibilities of a temporary works co-ordinator;
- Guidance on H&S issues pertaining to refurbishment projects;
- Communication of relevant safety information;
- Safety guidance in the design of temporary works;
- Health and Safety requirements under the CDM regulations.

Summary

Given the limited time available for the project not all the requirements identified above could be incorporated in the DSS. A set of general and role-specific guidance is provided for all project respondents. 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 provide to help files or websites that contain additional information. Further details of the DSS are provided in the subsequent sections of this chapter.

4.4 System Architecture

The system architecture of a software system is the design of the entire software system. The architecture of the prototype DSS for avoiding structural collapse in refurbishment projects is shown in Figure 4.2. The principal components of the architecture are discussed below:

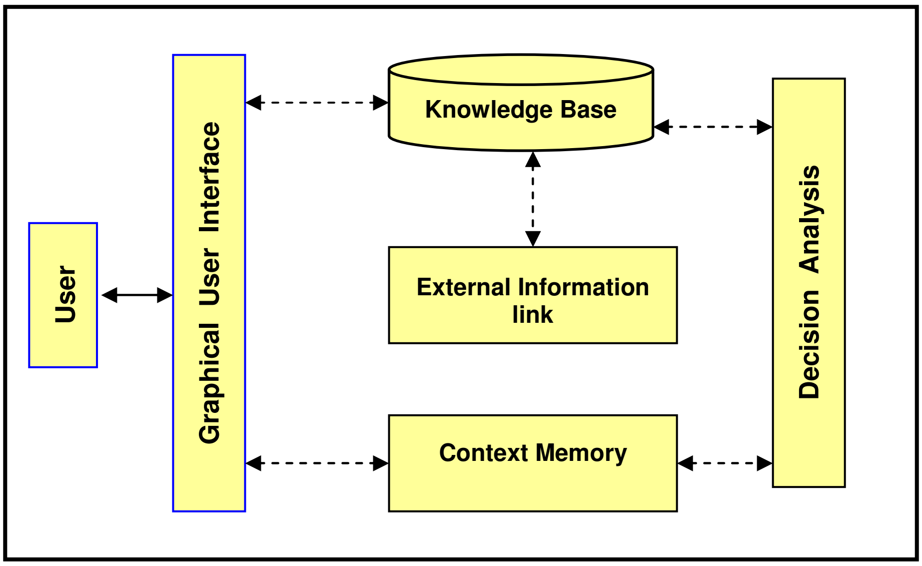


Figure 4.2: Architecture of the Decision Support System

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).

Decision Analysis: This module performs the reasoning function within the DSS and processes the user's inputs and makes recommendations on what action(s) the user should take. It also performs the safety evaluation within the DSS.

Context Memory: This module contains information on the current refurbishment project on which the user is working. The system uses this as the context for decision making at each stage of the refurbishment process. This information needs to be saved regularly 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. This shows that 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 4.3.

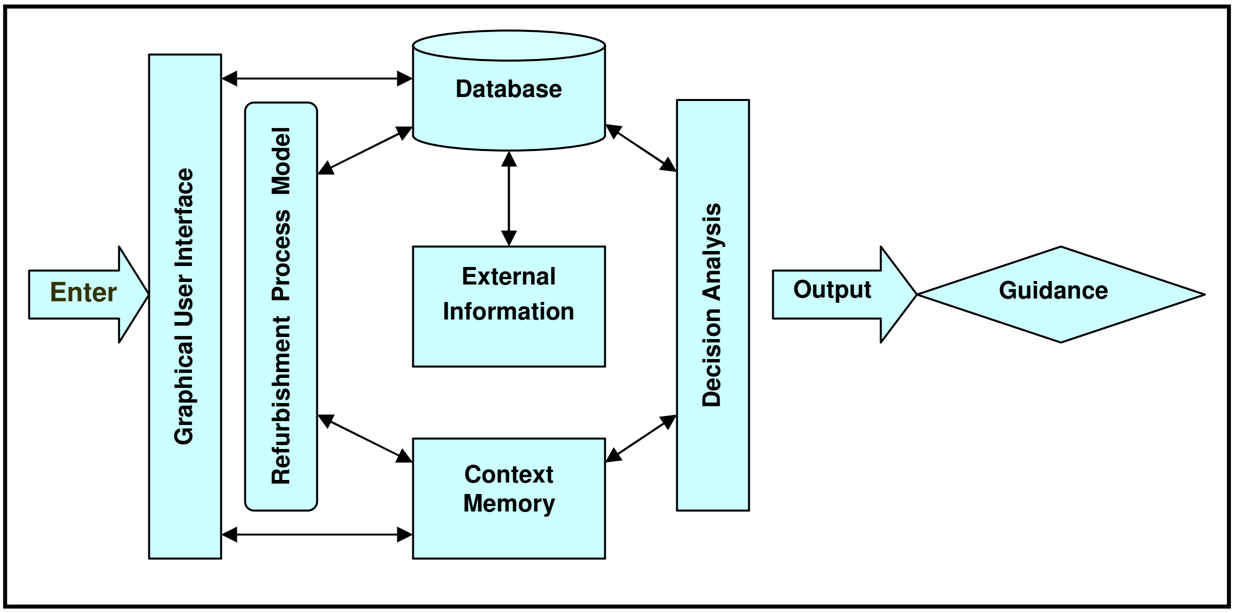


Figure 4.3: Interaction Flow for the DSS

4.5 System Development and Operation

Since prospective users of the DSS include engineers, managers, and site based staff, practicality and transportability were 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 Decision Support System is composed of two main parts: a knowledge base and a decision-making sub-system. 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.

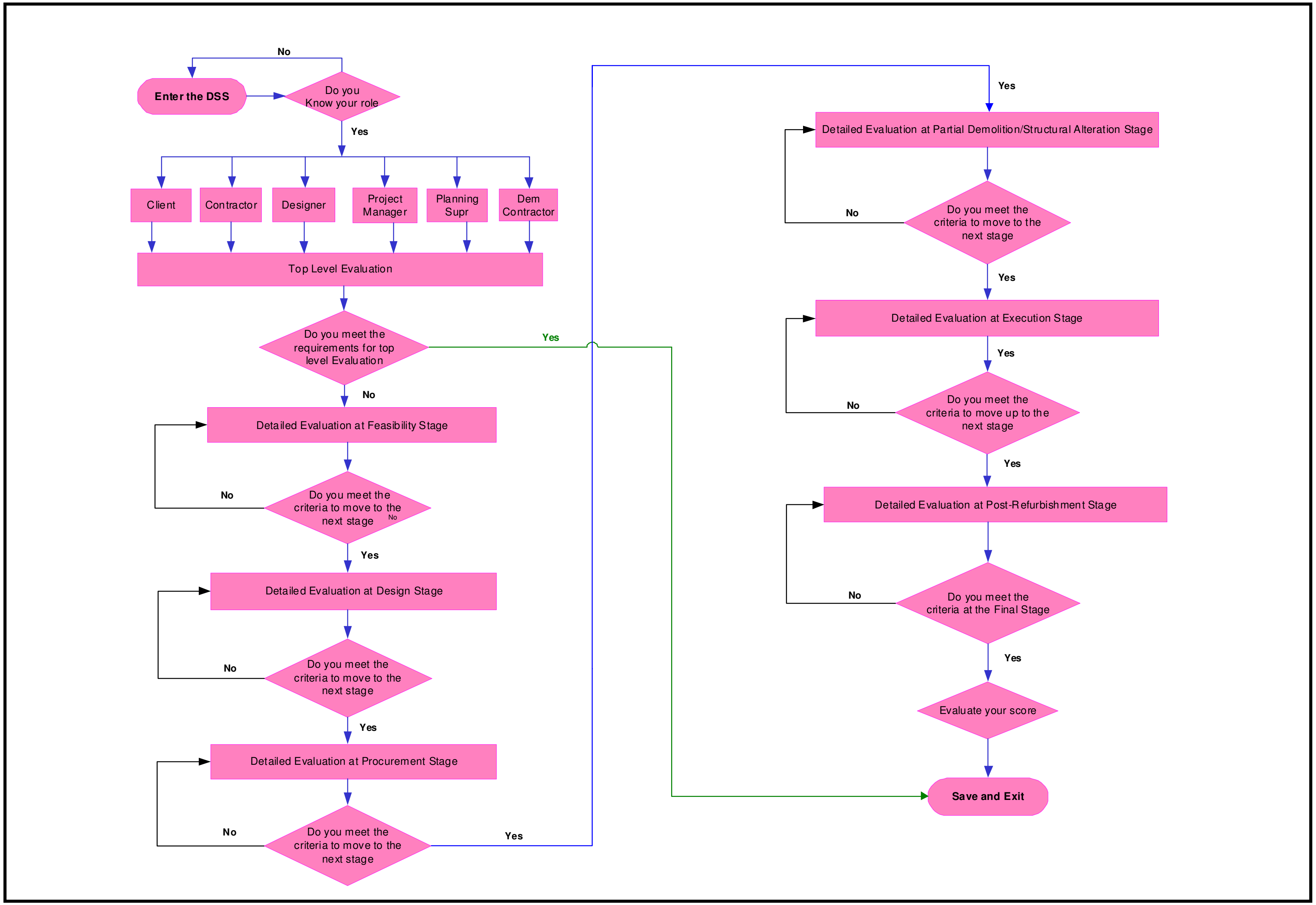


Figure 4.4 DSS Flow Diagram

Figure 4.5. illustrates the start screen of the decision support system and the iterative nature of the process as the system insists that certain safety conditions are fulfilled before the user (and the refurbishment project) moves to the next stage.

Figure 4.5: Decision Support System Start Screen

The end-user after logging into a particular category is prompted to look at the various stages of the refurbishment projects 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. Some of the screens from the system are shown below.

Figure 4.6 illustrates welcome screen, providing initial guidance to the end user about the system and how the DSS works.

Figure 4.6 DSS Welcome Screen

Figure 4.7 illustrates the log-in screen. Each user is required to log-in using a pre-assigned password and has to specify his/her role on the project, so that the appropriate guidance is provided. On completion of his/her session, the user can log-out. Where appropriate (e.g. when a user has more than one role or is the Project Manager), he/she can log back in as a different user.

Figure 4.7 The log in screen

Figure 4.8 shows the first main screen of the DSS where the user is required to go through the top level evaluation by either opting 'Yes' or 'No' and evaluate his score. Yes to all the 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 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 reveal the score after the evaluation.

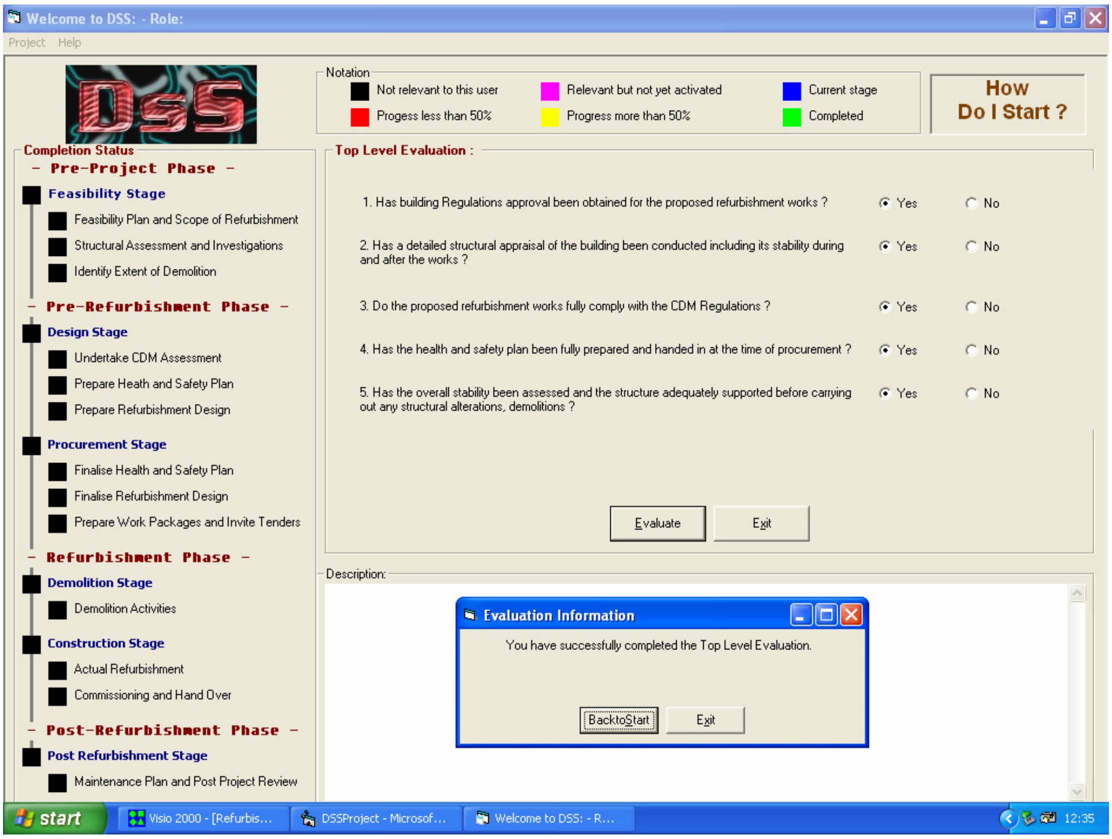


Figure 4.8 Initial DSS Screen

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 4.9). 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.

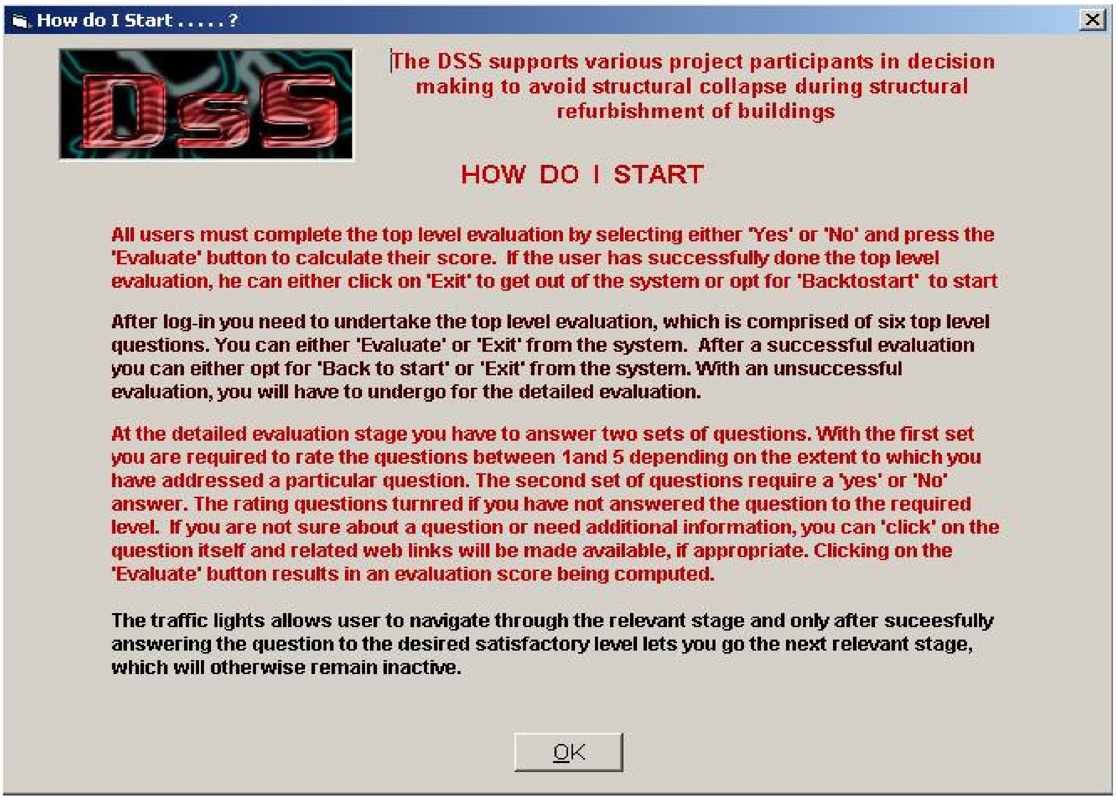


Figure 4.9 : How to start with DSS

Figure 4.10 illustrates the checklist screen for the 'Architect' during the 'Feasibility Plan and Scope of Refurbishment' stage.

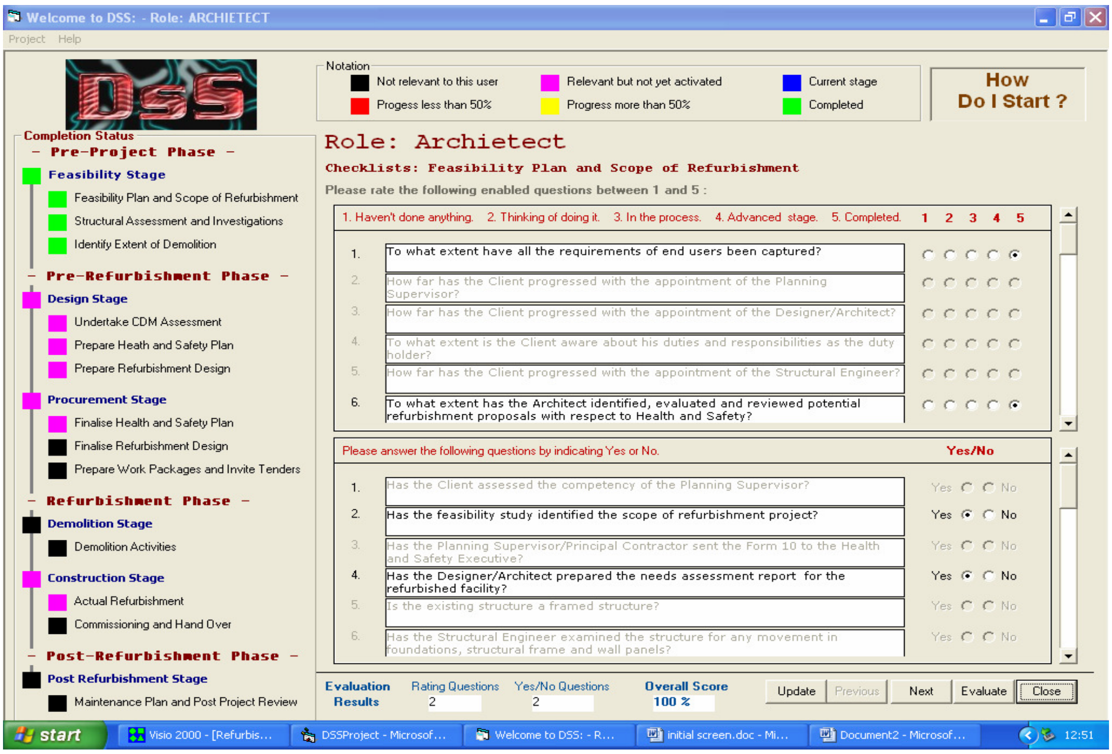


Figure 4.10 : Checklist Screen for the Feasibility Plan Stage

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 between 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 predetermined 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. 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.

There is also scope for end-users to request more information on aspects of the checklist. For example, if the user (e.g. client) is not sure of what his duties and responsibilities are, then the system can generate an alert box that gives further details. Figure 4.11 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 4.11 : More Information Alert Box

Figures 4.12 and 4.13 are intended to give a flavour of the system operation. They illustrate a number of key features of the system, but, for brevity, these are not described in detail. Figure 4.12 shows the external link to other resources and information on the Internet or elsewhere.

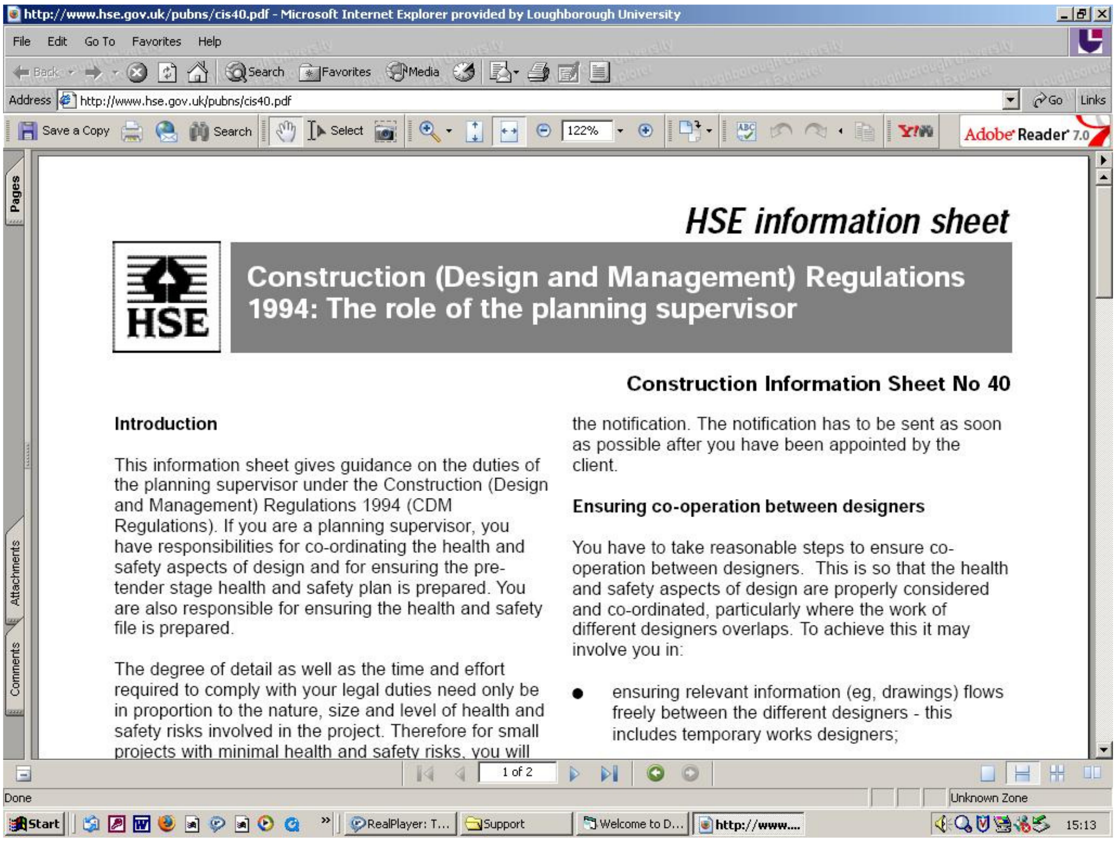


Figure 4.12: Screen shot showing external link for additional information

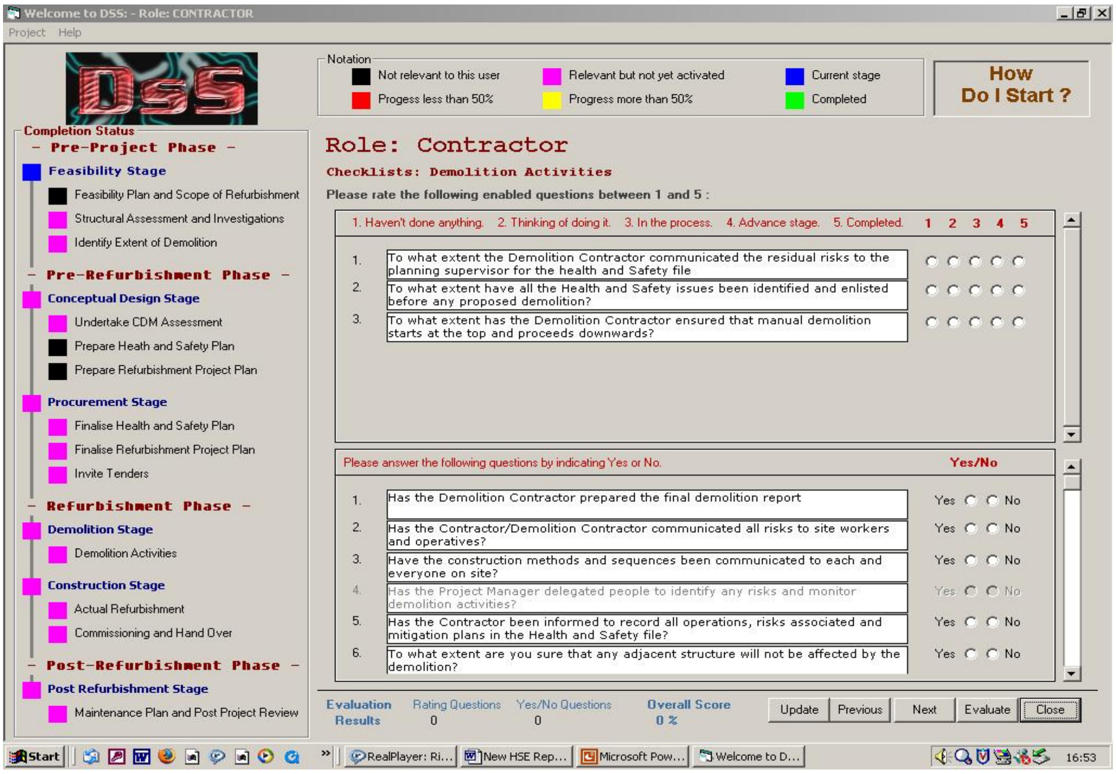


Figure 4.13 : The Checklist Screen for the Demolition Stage

Figure 4.14 illustrates the back-end database screen for the DSS while Figure 4.15 depicts the relationships between the various tables in the database.

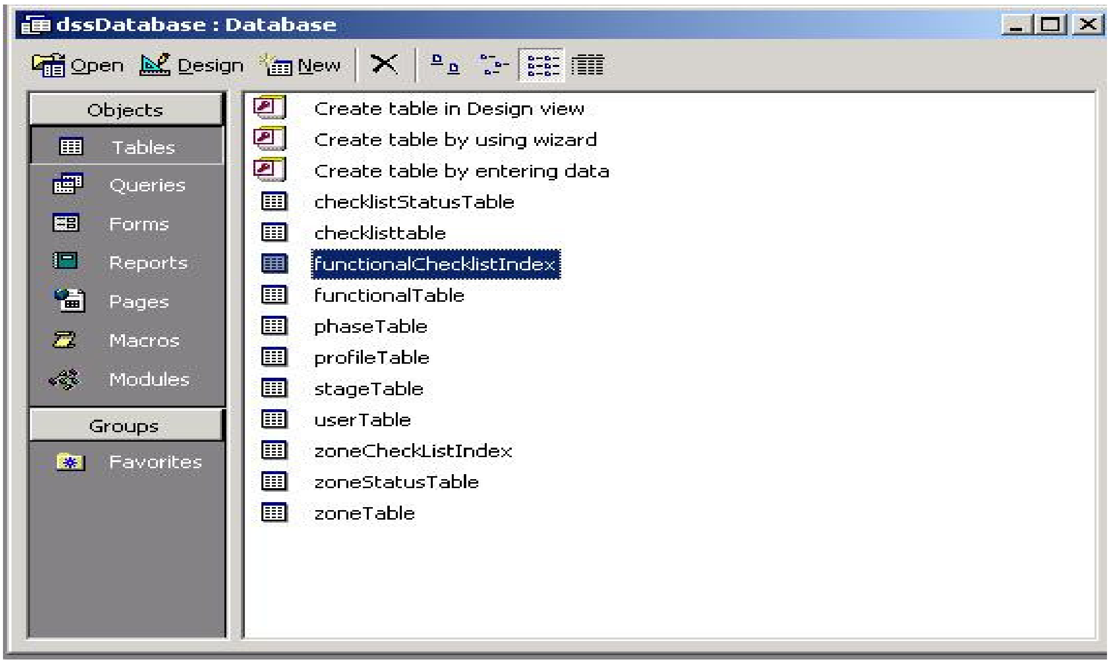


Figure 4.14 : The Back-end Database

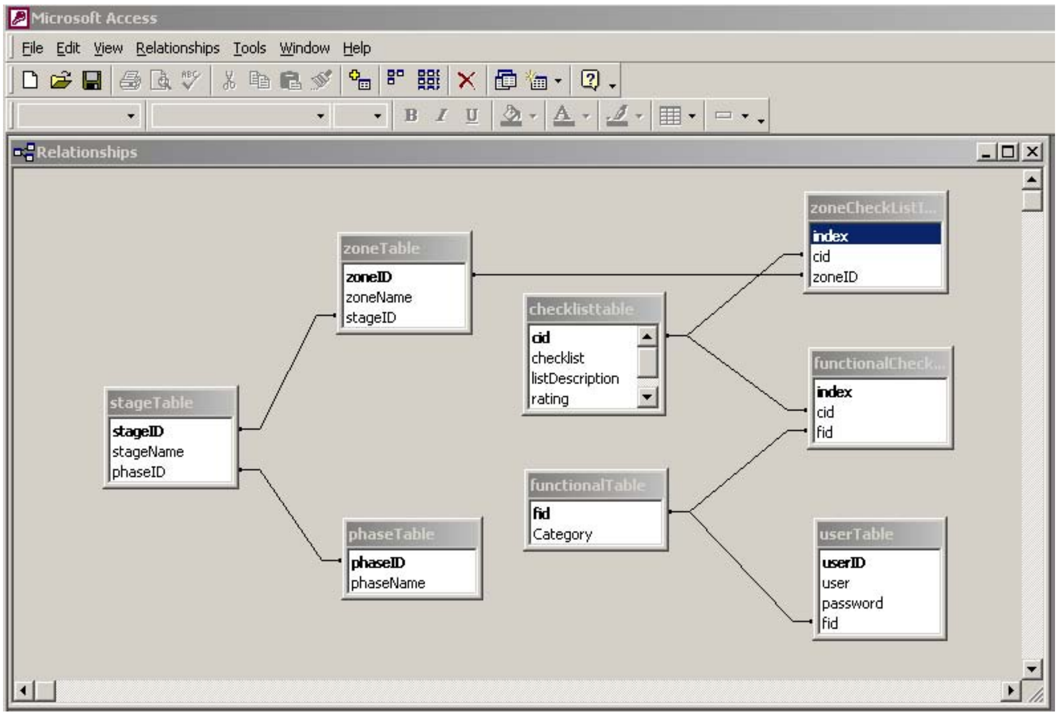
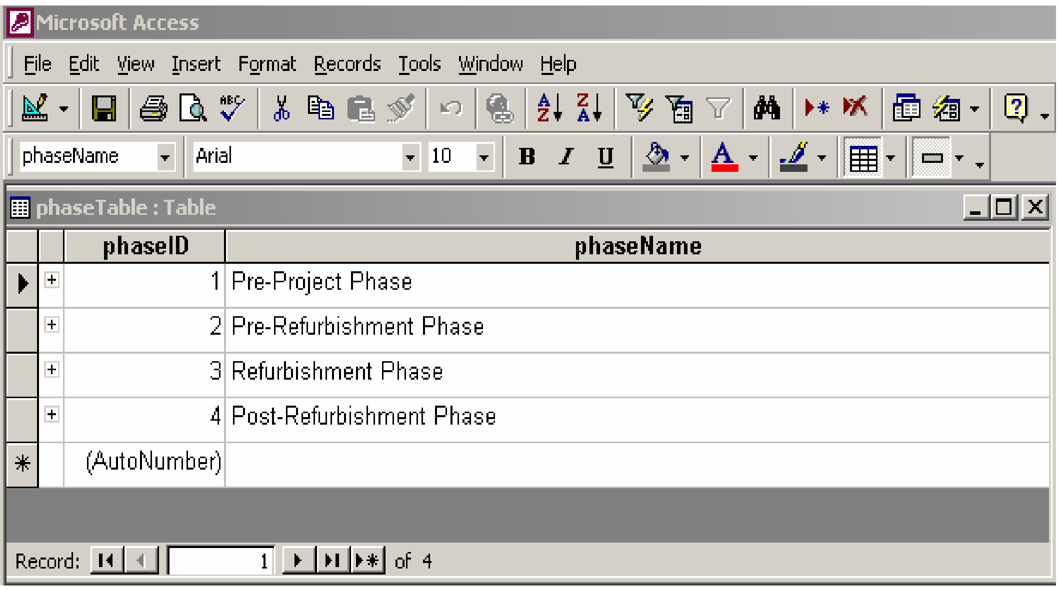


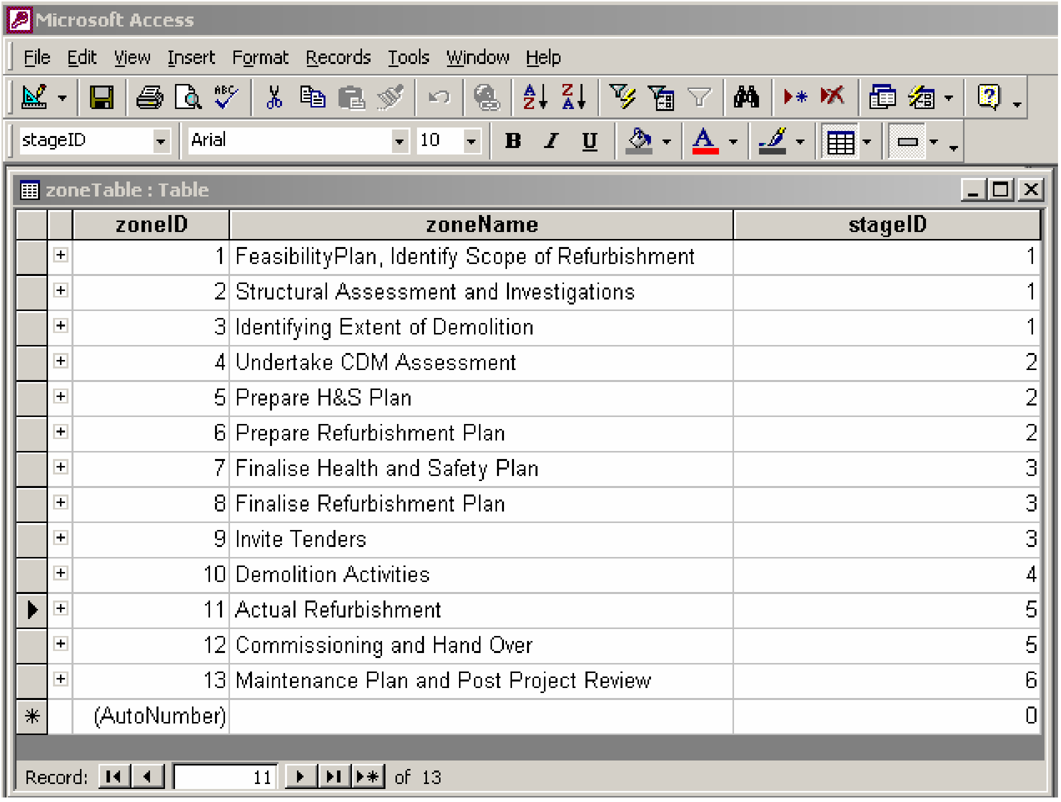
Figure 4.15 : Relationships Between Database Tables

Figure 4.16 provides details of one of the backend database phase table while Figure 4.17 illustrates the back-end database zone table in relation to other tables.



phaseID	phaseName
1	Pre-Project Phase
2	Pre-Refurbishment Phase
3	Refurbishment Phase
4	Post-Refurbishment Phase
(AutoNumber)	

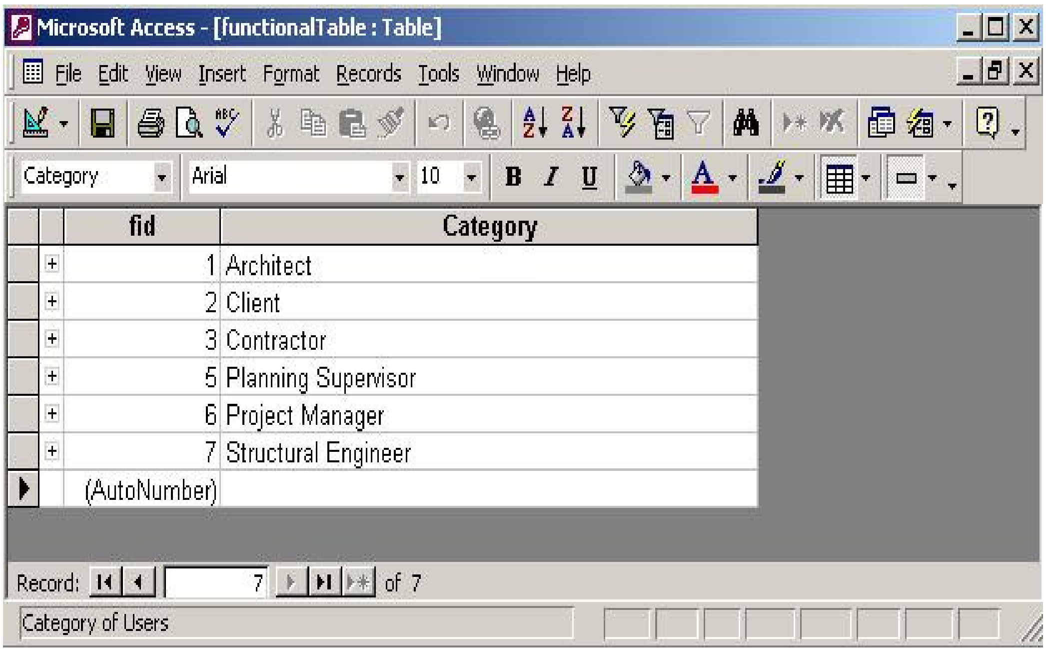
Figure 4.16: Back-end Database Phase Table



zoneID	zoneName	stageID
1	FeasibilityPlan, Identify Scope of Refurbishment	1
2	Structural Assessment and Investigations	1
3	Identifying Extent of Demolition	1
4	Undertake CDM Assessment	2
5	Prepare H&S Plan	2
6	Prepare Refurbishment Plan	2
7	Finalise Health and Safety Plan	3
8	Finalise Refurbishment Plan	3
9	Invite Tenders	3
10	Demolition Activities	4
11	Actual Refurbishment	5
12	Commissioning and Hand Over	5
13	Maintenance Plan and Post Project Review	6
(AutoNumber)		0

Figure 4.17 : Back-end Database Zone Table

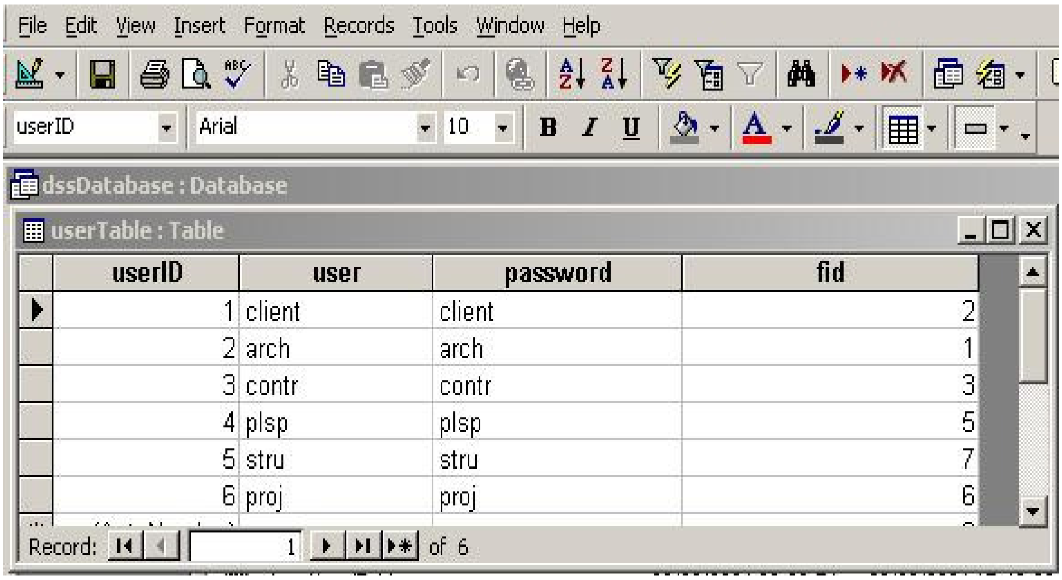
Figure 4.18 shows the backend functional table featuring the various end users of the system.



fid	Category
1	Architect
2	Client
3	Contractor
5	Planning Supervisor
6	Project Manager
7	Structural Engineer
(AutoNumber)	

Figure 4.18: Back-end Database Functional Table

Figure 4.19 shows the user table with user names and passwords to log-on to the system which can easily be changed if required.



userID	user	password	fid
1	client	client	2
2	arch	arch	1
3	contr	contr	3
4	plsp	plsp	5
5	stru	stru	7
6	proj	proj	6

Figure 4.19: Back-end Database User Table with username and password

4.6 Evaluation Of The Decision Support System

4.6.1 Introduction

The systematic and thorough evaluation of decision support systems (DSS) is a critical aspect of software development. Omission of this step may lead to reliance on a system with outputs of uncertain quality. It is only by carrying out an evaluation that the strengths and weaknesses of the system can be truly assessed (Miles et al, 2000). Thorough testing requires considerable effort because of the problems associated with getting suitable evaluators, and practically carrying out the evaluation. In the light of this, an evaluation of the DSS was undertaken using industry practitioners and researchers.

4.6.2 Objectives of the Evaluation

The main objective of the system evaluation was to assess the functionality of the DSS and identify the scope for further refinement. Other objectives of the evaluation were to:

- Assess the effectiveness, and coverage of the DSS;
- Explore the applicability and usability of the DSS as part of a safety integrated process for refurbishment.

4.6.3 The Adopted Evaluation Approach

it is important that engineering researchers subject their research through evaluation procedures as recommended by Miles et al. (2000). System evaluation was undertaken by presenting the DSS to HSE inspectors and by conducting evaluation workshops with 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 industrial 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 4.1)

Table 4.1 Number of participants at workshops

Workshop	Workshop 1	Workshop 2 Hands-on use of the DSS
No of participants	27	7

First workshop

The first workshop was held in Glasgow with the help of 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 4.20). The participants represented large and small organisations. 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 4.6.4

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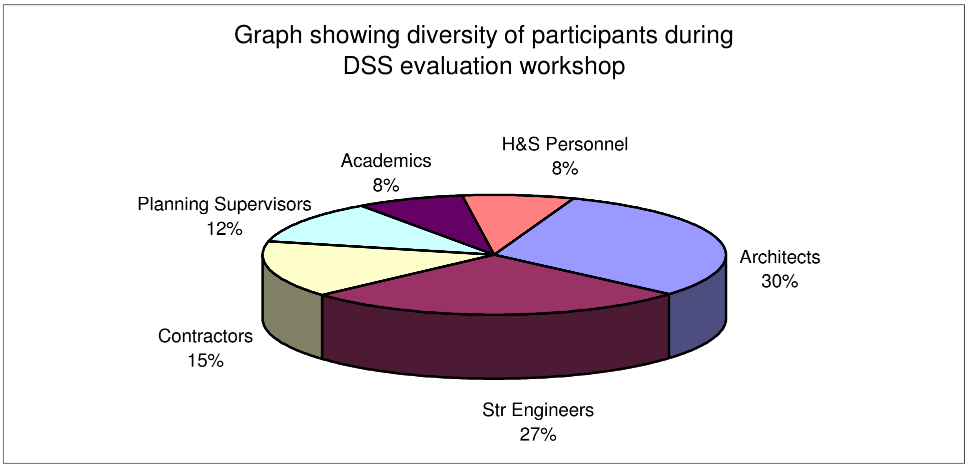

Figure 4.20 Classification of participants by role at first workshop

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, planning supervisors (see table 4.1) The small number of evaluators (7) was deliberate, so that the each evaluator had adequate time and guidance on the use of the system.

4.6.4 Analysis of the evaluation results on the DSS

This section summarises the feedback received from the evaluators of the DSS. Seventy six percent of the respondents felt that the use of the proposed DSS can be 'very effective or quite effective' for decision making in refurbishment projects. Only 4% felt it would not affect decision making. Fifty nine percent of respondents felt that the DSS can be 'very effective' or 'quite effective' in reducing collapses in refurbishment projects, while 13% felt that it would not have any positive impact.

Seventy one percent of the respondents felt that the DSS provides a significant improvement over current practices with 3% feeling that the DSS presents opportunity for considerable improvements. Only 13% of the respondents felt that the DSS does not represent an improvement over their current practices. Another 13% of respondents felt DSS represents only a minor improvement over their current practices. All the respondents felt that the DSS is suitable for the refurbishment process; 55% of the respondents considered it to be 'quite effective'.

All the respondents felt that most of the refurbishment activities are adequately covered in the DSS. Seventy six percent of the respondents felt that the activities are covered 'extremely well ' or 'quite well', while 24% felt that the DSS covers refurbishment activities to 'some extent'. Seventy five percent of the respondents felt that the format of the DSS is 'very easy' or 'quite easy' to understand.

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.

Table 4.2 provides the average ratings with respect to the specific questions in the evaluation questionnaire.

Table 4.2 Summary of responses to evaluation questions

EVALUATION QUESTIONS		Workshop 1		Workshop 2	
		Average Rating	Equivalent %	Average Rating	Equivalent %
EFFECTIVENESS					
1	How effective might the DSS be in decision making relating to refurbishment?	3.2	64	4.0	80
2	How effective/well does the DSS fit into your current work practice?	2.8	56	3.5	70
3	Do you think the DSS can be effective in reducing structural collapse in refurbishment projects?	3.2	64	4.0	80
FUNCTIONALITY					
4	How suitable is the DSS for existing refurbishment process?	2.9	58	3.7	74
5	How appropriate are the questions/issues addressed in the DSS?	3.0	60	4.0	80
6	To what extent does the DSS represent an improvement over your current refurbishment process?	2.6	52	3.0	60
COVERAGE AND SCOPE OF THE DSS					
7	How well does the DSS cover the duties of the key players and key stages of a refurbishment project?	3.3	66	3.85	77
8	How well are the activities addressed in the DSS ?	3.3	66	4.0	80
9	How well are the key problem areas addressed in the DSS?	3.4	68	3.8	76
EASE OF USE AND USER FRIENDLINESS					
10	How easy is it to use the DSS?	3.5	70	3.85	77
11	How consistent is the user interface in the DSS?	3.1	62	3.4	68
12	How easy is it to navigate different parts of the DSS?	3.3	66	3.3	66
13	How useful are the prompts/help facilities in the DSS?	3.6	72	3.7	74

As evident from the comparisons, the ratings and equivalent percentages improved considerably after the respondents could work independently with the DSS software.

4.6.5 Discussion

4.6.5.1 Overview of the Evaluation

The evaluation of the DSS can be considered successful. This was manifested by the positive responses obtained from the evaluators. The fact that most of the evaluators understood the DSS and appreciated its usefulness provided very useful feedback The benefits and limitations of the evaluation are summarised below:

4.6.5.2 Evaluation Benefits

The benefits of the 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 provided an insight into the how the system could be improved.

4.6.5.3 Limitations of the Evaluation

The main limitations of the system evaluation are discussed below:

- The evaluation could not involve the deployment of the DSS on a real life was refurbishment project, as this was outside the scope of this project.

- The DSS evaluated at two workshops comprised a wide spectrum of industry practitioners, however, only a few were small contractors.

4.7 Summary

This chapter has described the development and evaluation of the Decision Support System (DSS) for avoiding structural collapses on refurbishment projects only Details of the system operation were also presented, enhanced by the inclusion of the numerous screen dumps. The system evaluation involved a cross-section of practitioners. Many of the evaluators were of the opinion that the DSS would benefit tremendously from being Web-based, with direct links to additional information sources, including the HSE's portal.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Summary

This research project has 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 avoidance of structural collapses. The main causes for structural collapses during refurbishment projects are unplanned demolition, lack of detailed structural appraisal, unavailability of 'as built' drawings, and not having competent team members to safely undertake the work. The complexity of refurbishment projects and the fact that in many instances clients, contractors and sub-contractors often take up refurbishment jobs without involving specialists and competent personnel further adds 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.

5.2 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. Some of the main conclusions that can be drawn from the research include:

- Approaches to avoiding structural collapse on refurbishment projects are highly variable and depend, to a large extent, on the experience and competence of the project team;
- There is need to improve the decision-making process in refurbishment projects by providing information on structural safety and integrity, and highlighting the key problem areas that need to be considered;
- Forethought must be given in undertaking any partial demolitions and absolute care taken during structural alterations that may interfere with the structural stability of the facility being refurbished;
- Detailed structural appraisals, including a review of the ‘as-built’ drawings and appropriate site investigations, should be carried out by structural engineers;
- End-users require decision support that is relevant to their particular context but which also gives them the flexibility to be kept informed of the responsibilities of the other team members;
- Refurbishment projects involving partial demolition activities and/or structural alterations require the appointment of competent and qualified professionals who can ensure the integrity of the structure right from the feasibility stage through interim stages to the actual refurbishment execution stage;
- There is need for a Refurbishment Process Model, which provides for a structured sequence of activities during the refurbishment project life cycle and incorporates multiple feedback processes at the various stages;
- The use of a Decision Support System (DSS) to prevent structural collapse can enhance safety in refurbishment projects while also facilitating collaborative working.

5.3 Recommendations for Further Work

Despite the generally positive feedback from the respondents in the evaluation of the DSS, and subsequent refinement undertaken there is still scope for improvement and further research, as follows:

- There is scope for exploring the use of the DSS on a real project (as this was outside the scope of the current project); 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;
- The DSS can be further improved through conducting a more focussed evaluation involving smaller contractors as the potential end-users of the system;
- There are significant advantages to making the DSS Web-based and further work can be undertaken in this area;
- The management of refurbishment projects remains generally under-researched and there is need for more work, particularly with regard to accident causality and other problems not necessarily related to structural collapses;
- The communication of safety information needs to be studied in more detail. 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 other workers (including site operatives, whose first language may not be English).

5.4 Summary

This research project has made a contribution to the area of decision making during structural refurbishment by developing a DSS that draws on an integrated knowledge base to provide context-specific information throughout all stages of refurbishment project. The literature review, development of refurbishment process model, development of the DSS and the associated evaluations provided useful insights and outputs that all parties involved in refurbishment projects can utilise to ensure the avoidance of unplanned structural collapses.

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Appendix A1

Evaluation Questionnaire for
Refurbishment Process Model (RPM)

Evaluation of the Refurbishment Process Model (RPM) for Refurbishment

A. Background information

1. Type of organisation (e.g., client, design, contracting) _______________________

2. Role of the respondent (e.g., architect, contractor, designer) _______________________

B. Evaluation of Refurbishment Process Model(RPM)

(Please tick the box that best represents your assessment of the question)

1. EFFECTIVENESS	RANKING 1 not effective at all 2 somewhat effective, 3 effective 4 quite effective, 5 very effective				
	1	2	3	4	5
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	RANKING 1 not at all 2 minor extent, 3 some extent 4 quite an extent, 5 to great extent				
	1	2	3	4	5
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	RANKING 1 not at all 2 somewhat, 3 quite well 4 very well, 5 Extremely well				
	1	2	3	4	5
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. EASE OF USE/USER FRIENDLINESS	RANKING 1 not at all easy 2 somewhat easy, 3 neither easy nor difficult 4 quite easy, 5 very easy				
	1	2	3	4	5
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 (a) In your view, are there any activities that need to be added? Yes / No

If yes, could you please suggest ______________________

____

(b) In your view, are there any stages to be added? Yes / No

If yes, could you please suggest ______________________

____

(c) In your view, are there any sub-activities that need to be added or deleted? Yes / No

If yes, could you please suggest

____

7. What aspects of RPM did you particularly like?

____

8. Please feel free to provide any further comments/suggestions regarding the RPM

____

____

Appendix A2

Evaluation Questionnaire for Decision Support System (DSS)

Evaluation of the Decision Support System (DSS) for Structural Refurbishment

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	RANKING 1 not effective at all 2 somewhat effective, 3 effective 4 quite effective, 5 very effective				
	1	2	3	4	5
How effective might the DSS be in decision making relating to refurbishment?					
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	RANKING 1 not at all 2 minor extent, 3 some extent 4 quite an extent, 5 to great extent				
	1	2	3	4	5
How suitable is the DSS for existing refurbishment process?					
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	RANKING 1 not at all 2 somewhat, 3 not sure 4 quite well, 5 very well				
	1	2	3	4	5
How well does the DSS cover the duties of the key players in a refurbishment project?					
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?					

	RANKING 1 poor, 5 very easy/very consistent/ very useful				
	1	2	3	4	5
How easy is it to use the DSS?					
How consistent is the user interface in the DSS?					
How easy is it to navigate the various parts of the DSS?					
How useful are the prompts/help facilities in the DSS?					

7. 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?

____

7. 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 ?

____

8. Do any new issues/questions need to be added? Yes / No

If yes, could you please suggest ______________________

____

9. 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 ☐

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

____

____

Thank You

Appendix A3

List of Checklist Questions from the DSS

S. No	checklist	Client	Proj	Arch	Plan Sup	Cont	Stru Engr	Zone ID	list Description
1.	To what extent have all the requirements of end users been captured?	No	No	Yes	No	No	No	1	Has the Client's brief or requirements for the refurbishment project been met by the Designer's drawings and/ or specifications?
2.	How far has the Client progressed with the appointment of the Planning Supervisor?	Yes	No	No	No	No	No	1	The clients has duty to appoint a competent planning supervisor under CDM regulations. Please refer to HSE information sheet no 39 and 40 for more information.
3.	Has the Client assessed the competency of the Planning Supervisor?	Yes	No	No	No	No	No	1	The client is supposed to appoint a competent planning supervisor. Please refer to Health and safety at work Inspectorate information document: CDM to understand the role of the planning supervisor.
4.	How far has the Client progressed with the appointment of the Designer/Architect?	Yes	No	No	No	No	No	1	The Designer could be the Architect, Engineer or any person who carries out this function in the process.
5.	To what extent is the Client aware about his duties and responsibilities as the duty holder?	Yes	No	No	No	No	No	1	The clients have specific duties to carry out under CDM regulations. For more information please refer to HSE information sheet 39.
6.	Has the feasibility study identified the scope of refurbishment project?	No	No	Yes	No	No	No	1	
7.	Has the Planning Supervisor/Principal Contractor sent the Form 10 to the Health and Safety Executive?	No	No	No	Yes	No	No	1	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.
8.	How far has the Client progressed with the appointment of the Structural Engineer?	Yes	No	No	No	No	No	1	
9.	Has the Designer/Architect prepared the needs assessment report for the refurbished facility?	No	No	Yes	No	No	No	1	
10.	To what extent has the Architect identified, evaluated and reviewed potential refurbishment proposals with respect to Health and Safety?	No	No	Yes	No	No	No	1	
11.	Is the existing structure a framed structure?	No	No	No	No	No	Yes	1	
12.	To what extent has the Structural Engineer identified existing structural distress, deformation and deterioration in the building elements?	No	No	No	No	No	Yes	1	

S. No	checklist	Client	Proj	Arch	Plan Sup	Cont	Stru Engr	Zone ID	list Description
13.	To what extent has the structure been investigated for stability, integrity, and distortion?	No	No	No	No	No	Yes	1	
14.	Has the Structural Engineer examined the structure for any movement in foundations, structural frame and wall panels?	No	No	No	No	No	Yes	1	
15.	To what extent has the Client been able to furnish information relating to design, construction, maintenance and history of the use of the building?	Yes	No	No	No	No	No	1	
16.	Has the Structural Engineer examined 'as built drawings', structural design and construction details of the existing structure?	No	No	No	No	No	Yes	1	
17.	To what extent have the condition of the foundations, roofs, walls and floors been assessed?	No	No	No	No	No	Yes	1	
18.	Has the Designer/Architect prepared drawings from site surveys in case no such drawings are available?	No	No	Yes	No	No	No	2	
19.	Does any damaged or deteriorated structure have strength less than 85% of full strength?	No	No	No	No	No	Yes	2	
20.	Are any of the floors, beams pulling away and/or appear to have a sag or cracks?	No	No	No	No	No	Yes	2	
21.	Has the Structural Engineer quantified the severity of any damage and geometric location of the damage?	No	No	No	No	No	Yes	2	
22.	Is there any record/prediction about the remaining service life of the damaged structure?	No	No	No	No	No	Yes	2	

S. No	checklist	Client	Proj	Arch	Plan Sup	Cont	Stru Engr	Zone ID	list Description
23.	Is there structural continuity between key structural elements?	No	No	No	No	No	Yes	2	
24.	Has Structural Engineer assessed the structural stability of the structural members?	No	No	No	No	No	Yes	2	
25.	Have the load paths been identified during the structural appraisal?	No	No	No	No	No	Yes	2	
26.	Have all load bearing elements been assessed for load carrying capacity?	No	No	No	No	No	Yes	2	
27.	To what extent have the load bearing elements been assessed for the presence of any cavities, chases or other sources of potential failure?	No	No	No	No	No	Yes	2	
28.	Have the vertical load bearing components been strengthened?	No	No	No	No	Yes	No	2	
29.	To what extent have the method statements been prepared for safe working?	No	No	No	No	Yes	No	3	
30.	Do the method statements identify hazards, risks and provide solutions?	No	No	No	No	Yes	No	3	

S. No	checklist	Client	Proj	Arch	Plan Sup	Cont	Stru Engr	Zone ID	list Description
31.	To what extent does the risk assessment include full risk assessment including risk of collapse?	No	No	No	No	Yes	No	3	A guide to risk assessments
32.	Does the risk assessments outline sequence, method of dismantling and demolition?	No	No	No	No	Yes	No	3	
33.	To what extent the method statements include detailed design of temporary supporting structures?	No	No	No	No	Yes	No	3	
34.	Have the designers considered wind load conforming to BS 6399?	No	No	Yes	No	No	No	3	There are evidences where gable walls have collapsed as a result of not conforming to the BS 6399.
35.	To what extent has the contractor conducted safety induction for all the workers and explained the method statements?	No	No	No	No	Yes	No	3	
36.	Has the Project Manager got the safety plan, method statements, risk assessments and refurbishment plan readily available before the work commences?	No	Yes	No	No	No	No	3	
37.	Has the Project Manager assessed all the site logistics?	No	Yes	No	No	No	No	4	
38.	To what extent have the Designers/Architect undertaken an environment impact assessment?	No	No	Yes	No	No	No	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
39.	To what extent have all the project respondents complied with (Design and Management) regulations 1994	No	Yes	Yes	No	Yes	No	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. You may refer to following HSE website for more information on Construction Design and Management Regulations.
40.	Is any of the project respondents ICE Health and Safety Registered?	No	Yes	Yes	No	Yes	Yes	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.
41.	To what extent has the Designer prepared the design risk assessment?	No	No	Yes	No	No	No	4	
42.	Has the Designer provided all the relevant and sufficient information to enable the Planning	No	No	Yes	No	No	No	4	

S. No	checklist	Client	Proj	Arch	Plan Sup	Cont	Stru Engr	Zone ID	list Description
	Supervisor prepare the pre-tender H&S plan								
43.	Has the Planning Supervisor prepared the pre-tender health and safety plan?	No	No	No	Yes	No	No	5	If The Planning Supervisor 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.
44.	To what extent has the Designer detailed the potential problems during and after the structural alterations?	No	No	Yes	No	No	No	5	
45.	Has the Structural Engineer/Designer identified the elements which might be adversely affected during any additions and/or alterations?	No	No	No	No	No	Yes	5	
46.	To what extent has the Planning Supervisor prepared Health and Safety control procedures?	No	No	No	Yes	No	No	5	
47.	Has the Planning Supervisor prepared a risk mitigation plan?	No	No	No	Yes	No	No	5	
48.	To what extent has the Client provided all the information to enable the Planning Supervisor prepare the pre-tender H&S plan	Yes	No	No	Yes	No	No	5	
49.	Has the project manager prepared the sequence of refurbishment activities?	No	Yes	No	No	No	No	6	
50.	To what extent has the Designer reviewed specifications relating to Health and Safety issues?	No	No	Yes	No	No	No	7	
51.	Has the Planning Supervisor been involved in the review process of method statements	No	No	No	Yes	No	No	7	
52.	To what extent has the Project Manager aligned Health and Safety plan with the procurement plan?	No	Yes	No	No	No	No	7	
53.	Has the Contractor ensured the structure is left in a stable condition at all stages of the project?	No	No	No	No	Yes	No	7	Not likely to collapse due to other loadings, such as wind, storm, and vibrations due to traffic and movement of construction plants?
54.	Has the Planning Supervisor identified safe practices and procedures?	No	No	No	Yes	No	No	7	
55.	Has the Planning Supervisor determined safe site transport arrangements and identified access points, egress routes and rescue procedures and	No	No	No	Yes	No	No	7	

S. No	checklist	Client	Proj	Arch	Plan Sup	Cont	Stru Engr	Zone ID	list Description
	practices?								
56	Has the Project Manager prepared any procurement strategy suitable for refurbishment?	No	Yes	No	No	No	No	8	
57	Has the Contractor prepared an operation and maintenance plan?	No	No	No	No	Yes	No	8	
58	Has the Project Manager finalised the sequence of works?	No	Yes	No	No	No	No	8	
59	Has Project Manager got safety plan, method statements, risk assessments and refurbishment plan readily available before the work commences?	No	Yes	No	No	No	No	9	
60	Has the Project Manager identified Health and Safety criteria for the supply chain?	No	Yes	No	No	No	No	9	
61	Have all the work packages been awarded to the most preferred contractors	No	Yes	No	No	No	No	9	
62	To what extent have the Project Manager and/or Construction Manager reviewed method statements?	No	Yes	No	No	No	No	9	
63	To what extent has the Contractor responded to any reviewed method statements?	No	No	No	No	Yes	No	9	
64	Has the Contractor/Demolition Contractor communicated all risks to site workers and operatives?	No	No	No	No	Yes	No	10	
65	Have the construction methods and sequences been communicated to each and everyone on site?	No	Yes	No	No	Yes	No	10	Construction methods in this context would include demolition, and dismantling elements of the project as part of the work.
66	Has the Project Manager delegated people to identify any risks and monitor demolition activities?	No	Yes	No	No	No	No	10	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
67	Has the Contractor been informed to record all operations, risks associated and mitigation plans in the Health and Safety file?	No	No	No	No	Yes	No	10	
68	To what extent are you sure that any adjacent structure will not be affected by the demolition?	No	Yes	No	No	Yes	No	10	

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69	Has the Client ensured that the report of the survey is available and s/he has informed the utility companies?	No	Yes	No	No	Yes	No	10	
70	Does the Demolition Contractor understand methods of construction and stress patterns?	No	No	No	No	Yes	No	10	
71	Has the Demolition Contractor knowledge of typical failures and collapse hazards from previous failures and experiences?	No	No	No	No	Yes	No	10	
72	Have all the affected walls and floors been adequately supported, shored or braced before demolition?	No	No	No	No	Yes	No	10	
73	Have the gable walls been braced and tied properly?	No	No	No	No	Yes	No	10	
74	To what extent has the Demolition Contractor ensured that manual demolition starts at the top and proceeds downwards?	No	No	No	No	Yes	No	10	
75	Has the Project Manager ensured that inspections to detect hazards and unsafe conditions are carried out on a daily basis or other appropriate levels?	No	Yes	No	No	No	No	10	
76	Is the structural steel being removed column length to column length?	No	No	No	No	Yes	No	10	
77	Is the opening cut into floor extending the full span of the floor between supports?	No	No	No	No	Yes	No	10	
78	Has the Demolition Contractor prepared an asbestos removal report	No	No	No	No	Yes	No	10	
79	Has the Demolition Contractor prepared the final demolition report	No	No	No	No	Yes	No	10	
80	To what extent have all the Health and Safety issues been identified and enlisted before any proposed demolition?	No	Yes	No	No	Yes	No	10	
81	To what extent have all the Health and Safety issues been identified and enlisted before any proposed demolition?	No	Yes	No	No	Yes	No	10	

S. No	checklist	Client	Proj	Arch	Plan Sup	Cont	Stru Engr	Zone ID	list Description
82.	To what extent the Demolition Contractor communicated the residual risks to the planning supervisor for the health and Safety file	No	No	No	No	Yes	No	10	
83.	Is the Project Manager managing and monitoring the construction work against the job specifications and method statements?	No	Yes	No	No	No	No	11	
84.	Has the Designer ensured compliance with statutory approvals?	No	No	Yes	No	No	No	11	
85.	Has the Project Manager made input to Health and Safety file?	No	Yes	No	No	No	No	11	
86.	To what extent have the daily inspections to detect hazards and unsafe conditions been carried out?	No	Yes	No	No	Yes	No	11	
87.	Has the Project Manager prepared the snag list and handed this over to the contractor?	No	Yes	No	No	No	No	12	
88.	Has the Contractor finalised procedures and plans to hand-over the refurbished project/facility?	No	No	No	No	Yes	No	12	
89.	Has the final Health and Safety file been handed over to the Client?	No	No	No	No	Yes	No	12	The CDM Regulations require the preparation of a Health and Safety File, which is handed to the client at the end of a project. For more information please refer to following web site.
90.	Has the Health and Safety plan handed over to the Client?	No	No	No	No	No	No	12	The major issues are to be 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.
91.	Have you conducted the end of project review to produce end-of-project review report?	No	Yes	No	No	No	No	13	
92.	Has the maintenance plan been prepared for efficient operation of the facility?	No	No	No	No	Yes	No	13	
93.	Has the feedback from the project been used for best practice guidance notes?	No	Yes	No	No	Yes	No	13	

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