Final Report

Delivering a Re-life Project

The research described in this report was carried out by:

Project Leader
Jay Yang, QUT

Program Leader
Ron Wakefield, RMIT

Researchers
Sujeeva Setunge, RMIT
Srikanth Venkatesan, RMIT
Mary Hardie, UWS
Graham Miller, UWS
Soon Kam Lim, QUT

Project Affiliates:
Bruce Carlyle, John Holland
Stuart Grierson, QDPW
Michael Gilligan, Rider Hunt

Research Program
Program C

Program Name
Delivery and Management of Built Assets

Research Project No
Project 2003-026-C

Project Name
Delivering a Re-life Project

Date
30 September 2006

[inside cover]

Distribution List

Cooperative Research Centre for Construction Innovation
Authors

Disclaimer

The Client makes use of this Report or any information provided by the Cooperative Research Centre for **Construction Innovation** in relation to the Consultancy Services at its own risk. Construction Innovation will not be responsible for the results of any actions taken by the Client or third parties on the basis of the information in this Report or other information provided by Construction Innovation nor for any errors or omissions that may be contained in this Report. Construction Innovation expressly disclaims any liability or responsibility to any person in respect of any thing done or omitted to be done by any person in reliance on this Report or any information provided.

Please direct all enquiries to:
Chief Executive Officer
Cooperative Research Centre for Construction Innovation
9th Floor, L Block, QUT, 2 George St
Brisbane Qld 4000
AUSTRALIA
T: 61 7 3864 1393
F: 61 7 3864 9151
E: enquiries@construction-innovation.info
W: www.construction-innovation.info

Table of Contents

PREFACE

The significant growth in the construction of new commercial office buildings over the past 30 years means that we now have a large stock of ageing buildings providing an opportunity for efficient re-life rather than demolition and new build, at the same time there is increased commitment to sustainability which encourages re-life options.

This project investigates the characteristics of re-lifing or refurbishment projects that impact upon the effective management of the construction process. This includes the identification and mitigation of risks, issues of decanting and interfering with existing tenants, identification of existing structure and services, work scheduling, occupational health and safety issues for construction personnel and tenants, demolition, waste and recycling, issues of quality and workmanship, cost planning and cost modelling technologies.

This report presents the preliminary findings of the Re-life Project, including the research context, the methods and approaches adopted by individual strands leading to the development of modules of Best Practice Guide.

EXECUTIVE SUMMARY

The project has identified and documented the issues impacting on re-life projects, design, engineering and procurement, and issues of decanting and sustainability. It has developed decision-making tools for assessing the condition of the existing building structure, the residual life, and modelling operating and maintenance costs, and the utility and productivity expected from the refurbished building. The project was planned to include four strands concentrating on following respective issues.

Ten issues critical to management refurbished projects are nature and scope of work (objective & market research), type of contract, market demand by location and type, perception of tenants, pre-commitment by tenants, key project risks (cost, quality and schedule), decanting, workplace health and safety issues, modifying existing documents and management of tenants. The design team has to bear in mind of client's/tenants' needs. Communication and understanding between project stakeholders are important to ensure smooth implementation of the project.

To evaluate remaining service life of specific components, an assessment of the current degradation state or functional use and the future patterns of degradation is important. State-of-the-art methods on residual service life estimation appear to be mostly conceptual and need significant forms of data. Seven key variables identified are condition assessment, defects – structural, defects – functional, status of structural health, life of elements and components of the building, performance monitoring and security. These variables were analysed and compared with other buildings in developing a generic approach. Residual service life methods have been evaluated to determine the underpinning factors.

In recycling and waste management, widespread willingness to operate more sustainably should be met with targeted guidelines for project stakeholders. Specific building materials where recycling rates are variable across the states need to be identified and 'state of the art' recycling information dispersed to all contractors. Secondary markets for reuse of components such as sinks, basins and cupboard need to be encouraged by state governments, whereas asbestos material needs to be addressed in detail, so that all waste from such buildings is not automatically directed to landfill.

The major challenge for floor space optimization is that of maximising the rentable floor space. Options available to the client in maximising floor space include removal or addition of floors and partitions, relocating services, cutting openings and relocating lift wells etc. In these situations, innovative structural strengthening schemes could be implemented to strengthen the existing structure after an initial structural appraisal. Five critical issues identified are structural appraisal, structural safety, structural strength, change of use of floors, relocate/renew services.

The Best Practice Guide is highly valuable especially to project partners for guided decision-making assistance when contemplating retrofitting office building projects in the future. This will provide building owners, developers and contractors alike a systematic tool to evaluate potential projects in a holistic way, rather than make hasty decisions on demolition and build new buildings, thus avoiding unviable technological, economical and marketing outcomes.

1.0 BACKGROUND RESEARCH

"A retrofit is the modification or conversion (not a complete replacement) of an existing process, facility, or structure. Such modification may involve additions, deletions, re-arrangement or not in kind replacements of one or more parts of the facility. Changes may alter the kind, quantity, cost or quality of the products or services being produced by the facility." (Sanvido, 1991).

The significant growth in the construction of new commercial office buildings over the past thirty years means that we now have a large stock of ageing buildings providing an opportunity for retrofit or re-life rather than demolition and new build, at the same time there is increased commitment to sustainability which encourages re-life options. Furthermore Caccavelli (2002) identifies that although in Europe 70% of total stock of buildings at 1200 million square meters of conditioned floor space is less than 25 years old which implies that they are relatively new buildings, but the retrofitting market has seen a considerable growth over the past 5 years.

Several reasons can explain this paradox:

- User requirements have considerably changed during the last decade (in terms of office equipment, communications, automation, quality of use and comfort);

- The property crisis, which has affected many European countries, has amplified the stock of not rented office spaces: buildings that do not offer all the amenities for comfort and flexibility, are difficult to sell or rent;

- Retrofitting a building costs is more or less half or one third of the cost of demolition and reconstruction;

- Office buildings in particular are classified amongst the buildings presenting the highest energy consumption (e.g. annual energy consumption in European office buildings averages 100-1000KWh/ m^2 of conditioned floor space).

However, the challenges of re-life as opposed to new build include:-

- Decisions on political, social, environmental and financial implications of re-life compared to new build;

- Feasibility studies assessing the condition of the existing building, the residual service life, and estimating construction costs, modelling of operating & maintenance costs, and the utility and productivity expected from the refurbished building;

- Architectural and engineering design to maximise the utility of the existing structure;

- Work scheduling is more complex both for the client, consultants and contractors in terms of forward capacity and production planning linked with design, procurement and decanting schedules;

- Re-life means additional challenges for demolition and waste handling and disposal, potential recycling, occupational health and safety, condition surveys and identification of services etc, sub optimal schedule & workflow patterns, especially when working around existing tenants.

Nevertheless, this implies that there is a new market developing which requires specific application tools that can help in making decisions on:

- Sustainability issues including indoor air quality, energy saving, waste handling, disposal, potential recycling and Occupational Health and Safety (OH&S);

- Condition of existing building and the residual service life;

- Associated risk and project delivery.

High construction costs and the increasing emphasis on sustainability are directing the attention of building owners towards alternative re-lifing solutions rather then demolition and new build. Effective decision making needs more data and modelling to allow comparison of such choices.

This project has adopted Delphi study and case study approach to help extract industry knowledge. Three suitable projects had been identified and studied to examine the characteristics of re-life projects and determine strategies to maximise the opportunities for sustainable and economic solutions.

Re-life is expected to form an increasing proportion of the annual capital budget, some estimates are as high as 50%, this has important implications for sustainability – if we are to reach the Koyoto targets then it is the existing building stock which must be improved. Waste minimisation and recycling can form a significant part of the equation, accounting for an estimated 0.5% of GDP. Our case studies will follow the lead of the national WasteWise construction program which has already decreased the amount of waste going to landfill by 90%(1)

The principal focus of this project is to provide a basis for making judgements on the economic and environmental viability of re-life projects and the formulation of appropriate procurement and delivery options to meet the industry needs.

2.0 RESEARCH CONTEXT

2.1 Introduction

A review of literature was undertaken to identify tools and or criteria that can help in the decision making process of retrofitting and re-using existing buildings rather than demolition and new build. An international approach was adopted for literature, the majority coming from Australia, UK, Europe and USA. A Matrix is used to summarise the methodologies and the assessment criteria used by these methodologies. Some construction management issues in relation to project delivery are also identified through the literature search. The literature review then becomes the basis of development of the project methodology.

2.2 Literature Review

A new generation of European methodologies and software tools is in use or under development that enables architects and engineers to make an accurate first assessment of a building's existing structural conditions, energy performance and other criteria with a final estimate of the total cost. These decision aid tools provide a global view of a building's renovation and refurbishment process and enable a user to make well targeted decisions and to assess different scenarios. Some of these tools and other research being carried out in USA and Australia are discussed next.

2.2.1 EPIQR

EPIQR is the result of a European research project in the IIIrd framework program. A multidisciplinary team with research institutes and private consultants from Switzerland, Germany, France, Netherlands, Denmark, UK and Greece participated in the project of developing a residential building refurbishment decision aid tool in 2002. The main objective of the project was to develop:

"a software with a structured diagnosis scheme covering the state of degradation of building of existing residential buildings, energy performance and indoor air quality and help users to make informed decisions. Also to construct a coherent refurbishment scenario and calculate a reasonable investment in the early stages of the refurbishment projects."

(Flourentzos et al, 2000)

The EPIQR method starts at the very beginning of a refurbishment project and ends by providing the user with enough information to set-up a successful refurbishment strategy. This structured diagnosis scheme enables architects and engineers to simultaneously handle the entire complex process of retrofit using the following criterions:

Physical state of degradation of building elements:

The assessment was based on building objects and types. This assessment is used as a knowledge base for the probable residual life span of building elements and to decide whether to be replaced or not.
Energy consumption:

The assessment is based on energy calculations for service hot water, heating and cooling energy, calculating energy saving potential and identifying suitable retrofit actions.

Indoor environment quality:

The assessment was based on thermal comfort, indoor air quality (humidity, pollutants and ventilation), lighting and noise.

The building is decomposed into discreet objects and elements e.g. the object roof covering is divided into types tiles, roof membrane etc. The diagnosis is performed during a building audit. The auditor observes the elements and objects and decides which of the degradation or deterioration codes a, b, c or d best fits the observed state of the building where ‘a’ representing good condition, ‘b’ representing some degradation or deterioration, ‘c’ representing degradation or deterioration that requires repair and ‘c’ representing service life is over requires immediate repair. In addition to the detailed description a number of pictures and sketches illustrate the four possible degradation states. A total of about 500 photos and sketches have been populated in the tool to help the user in this assessment. The actions for retrofitting are defined for each object with four intervention codes. The program then uses a few (7-10) dimensional coefficients such as façade areas, built area, area of foundation etc. to calculate each intervention. The actions are detailed in a way to allow costs to be classified according to elements as well as trades. Costs are calculated from unit prices and quantities. The cost include Actions based on include professional fees, incidental costs, value added tax are laid out. A similar coding system is used for functional obsolescence.

Energy calculation modules are then used to estimate the building energy balance and assess the energy conservation potential for space heating and cooling. Energy bills show the current state of the building energy consumption. The state is compared to the standard and best practices values of the country to saving potential.

For Indoor Environmental Quality (IEQ) EPIQR system uses questionnaires to collect data on occupant complaints and after analysis different possible actions of improvement are selected. The software performs a statistical treatment of the questionnaire and relates complaints with refurbishment work and energy retrofit measures.

A clear distinction is made between the diagnosis and decisions to be made which do not depend on diagnosis. The software allows the user to build different scenarios and each scenario shows different levels of improvements to the office building and all have variations in the projected budget cost. A radar graph summarises the building deterioration state and on the same graph the auditor can visualise the refurbishment cost and identify the most expensive actions. The software allows the user to select the most suitable refurbishment actions comparing which actions promote the greatest energy savings, increase indoor environmental conditions for occupants and is within the budget constraints of the building owner. The program calculates the scenario cost element by element and the first rough estimate can help the expert to converse with the owner to decide the retro fit strategy taking into account budget limitations. The users can modify the calculated cost and give their own estimate. The interface of the software is programmed in Microsoft Visual Basic 5 and the databases in MS Access. About 350 European residential buildings were used as case studies and audited in order to collect the input data for the work that was performed.

2.2.2 MEDIC

This tool is intended for use with EPIQR and is based on subdividing of the element into 50 elements. The remaining life span of the building elements is an important piece of information for financially and ecologically coherent refurbishment decisions. The aim of MEDIC is to:

"Calculate the remaining life span of a building element not as a deterministic unique value but as a probability distribution. The remaining life span can be used as a decision criterion refurbishment scenarios and life cycle energy or ecological assessments."

(Flourentzou et al, 2000)

The decision making is based on the combination of the priori probability based on the experience from a large number of previous investigations.

2.2.3 TOBUS

The European Commission (EC) launched a two year research program entitled TOBUS involving eight European Institutions in 2002. The main objective of the project was to:

"develop an evaluation tool and software for the assessment of retrofitting needs of office buildings in European countries and for estimating the costs to meet these needs in compliance with sustainable issues improved energy performance and indoor environment. The software can then be used to define the most cost effective actions, to elaborate consistent refurbishment scenarios and calculate a reasonable investment budget in the early stages of a refurbishment project."

(Caccavelli et al, 2002)

This software uses the same philosophy as EPIQR but with additional features to handle the complex installations of office buildings. TOBUS methodology involves description of each building element, a description of deterioration and corresponding refurbishment work, including costs, potential upgrading work, as well as related national standards and guidelines. The new features include additional element and types for the electromechanical installations air conditioning and ventilation, central heating, fire protection, Hydraulic systems and low current systems.

The residual life assessment of building envelope and electromechanical is diagnosed in a similar manner as EPIQR. Additional calculation modules are included for air handling units, ice and chilled water storage, low energy office equipment and sanitary water savings. There is an additional *Functional* *obsolescence of building services* criteria in which the assessment is based on user needs, Flexibility, Divisibility, Maintainability and Compliance with regulations. The auditor assesses the obsolescence for each project and each criteria and the tool offers a description text to assist the auditor. Hellenic office buildings were used as case studies to evaluate the potential energy savings and cooling.

2.2.4 Hotel refurbishment tool

A tool is being developed for the hotel building scenario with the main goal to prepare:

"a multimedia software for carrying out a hotel audit, supported by the necessary tools for making a first assessment of where and how to integrate the most cost effective energy efficient renovation practices"
(Balaras et al 2004)

The methodology and elements were similar to EPIQR and TOBUS but new modules that were important to the hotel industry were also included e.g. central solar systems, water and swimming pools etc.

2.2.5 Miscellaneous

The Cambridge Architectural Research (CAR) in UK did a scoping study for Energy Saving Trust (EST) in 2003 to explore the question of "when it makes more sense to demolish housing and build new than to refurbish and upgrade an existing housing?" CAR ran a workshop to canvass expert opinion on issues that can facilitate the decision making on refurbishment. These issues included energy efficiency, remaining functional life and health and technological constraints.

A similar tool called the Office Scorer was developed by the Building Research Establishment in UK in 2002 and funded by the dti (Department of Trade and Industry) to promote more sustainable construction. The tool compares major or complete re-development, and redevelopment within an existing façade. It enables the user to systematically compare and test the environmental and economic impacts of different building design concepts for offices. BRE has modelled a number of buildings over a 60 year life and evaluated the economic and environmental impacts of a range of factors including building elements degradation, ventilation and cooling system energy saving.

Software called the Facility Energy Decision System (FEDS) was developed by Pacific Northwest National Laboratory and funded by US Energy Management Program designed to help inform decisions on energy-saving retrofit projects.

"FEDS determines the optimum set of cost-effective retrofits from a current data base of hundreds of proven technologies. These include retrofits for heating, cooling, lighting, building shell, and hot water. Replacement or modification of the equipment for a retrofit operation varies from complete replacement to functional enhancements to fuel switching."
(FEDS website)

In Brisbane, Australia Qbuild uses an MAR to carry out maintenance or refurbishment on their buildings.

"The Maintenance Assessment Report (MAR) provides an objective technical assessment of a buildings maintenance needs. It contains advice on how to best address those needs, and is an important reference when developing maintenance strategies, plans and subsequent work programs for buildings"

(QBuild, 2003)

The report compares the assessed conditions with the pre-specified conditions. The report also identifies non urgent maintenance situations and proposes solutions in the form of planned maintenance tasks. The assessment is done by teams undertaking the site inspection phase but special instructions by clients in relation to specific assets can also be included in the assessment. The maintenance categories used in the assessment are Planned (condition based and mandatory or non-mandatory servicing) and Unplanned or Responsive (Routine & Breakdown and Incident related)

The maintenance task list contains details about each maintenance task including building identification, defect description, rectification tasks, calculated priortisation ranking, timeframes and indicative costs.

The assessment is made using a Maintenance Scorecard. This comprises of 4 graphs. The first two graphs indicate the facility's overall condition. The graphs use comparative results from specified and assessed condition of each element in the element groups. The conditions compared are actually the aggregated (i.e. rolled up) weighted averages of the specified and assessed conditions of the individual elements within each element group. The comparison is represented through a series easy to read symbols (ticks and crosses) with descriptions ranging from 'well exceeds specified condition' to 'substantially below specified condition'. The third graph indicates the spread over time of the financial demand of recommended planned tasks. The fourth graph (pie chart) shows the distribution of recommended maintenance costs over the next three years. Each segment of the graph represents the portion of the planned maintenance costs attributable to specific building groups.

The building elements groups used for the maintenance assessment for all the above buildings include:

- Air Conditioning
- Building Structure
- Communications and data
- External finishes
- Electrical Services
- External Structures
- Fixed Equipment
- Fire Protection System
- Furniture and Fittings
- Gases
- Hydraulic Services
- Internal Building Fabric
- Internal Finishes

- Loose Equipment
- Refrigeration and Environmental Control
- Security and Safety Systems
- Site improvements
- Transportation
- Mechanical Ventilation

However the MAR technique does not address some of the issues in relational to residual life and sustainability and risks associated with refurbishment projects.

Some of the issues that have not been addressed by the above tools and have been identified as being important for retrofit projects by previous researchers are discussed next.

2.2.6 Demolition waste

One of the elements identified as challenging for preparing estimates for retrofit projects identified in the ECI (2003) workshop on 'The Engineering and Management of Retrofit Projects' was refurbishment waste removal or recycling. Demolition waste is increasingly being seen as a valuable source of engineering materials in the UK (Lawson, 2001). The government of New South Wales, Australia is also proposing waste management reforms that prioritise waste management options into 1. avoiding waste, 2. re-using waste, 3. re-cycling waste and disposing waste. (Faniran,1998). For refurbishment projects the last three options are more likely to be considered for developing an estimate on managing waste.

Lawson et al (2001) identifies that waste materials from new construction are usually clean and relatively uncontaminated whereas demolition waste materials are often dirty or contaminated and are mixed with other materials. These create specific challenges for waste reduction and involve risk assessment, remedial measures and risk management. This includes: hazard estimation, hazard assessment, risk evaluation and risk estimation.

In order to have a robust tool for making decisions on a retrofit project it would be useful to integrate these criteria with other issues identified above e.g. the information on material degradation and functional obsolescence on building elements may be helpful for developing the costs associated with retrofit waste management and recycling.

2.2.7 Sustainable building structures

The decision making on material deterioration identified in the above tools may enable the decision makers to utilise the most efficient structural strengthening scheme using FRP composites. Current annual expenditure on structural maintenance is around two billion dollars in Australia. Overseas experience has shown that by using advanced composites, the cost of structural strengthening can be reduced by 17% (Thomas at al, 1996). Some of the benefits on using composites in structural retrofitting identified in the literature are:

- High chemical resistance to acids and bases
- Reduction in corrosion related problems
- No increase in the dead weight of the structure
- Ease of handling
- Little interruption in the use of the structure

The estimating of residual life and estimation of construction costs will have some measures of commonality with structure strengthening techniques. The matrix in Table 2.1 summarises all the above discussed methodologies and tools.

Table 2.1: Matrix of assessment criteria and methodologies used for building retrofits

No	System/ Tool	Authors	Methodology	Residual life criteria		
				Building element degradation including residual life	Functional Obsolescence of building	FRP structure strengthening
1	EPIQR	(Flourentzos et al, 2000)	Decision tool using a degradation coding system for residential buildings	✓		
2	MEDIC	(Flourentzou et al, 2000)	Residual life assessment of building elements using a probability distribution	✓		
3	TOBUS	(Cavacalli et al, 2002)	Decision tool using a deterioration coding system for office buildings	✓	✓	
4	Hotel Buildings Tool	(Balaras et al, 2004)	Decision tool using a deterioration coding system for hotels	✓	✓	
5	Refurbish or Replace - Context report	(CAR, 2000)	Report to identify criteria for making decisions on refurbishment	✓		
6	Office Scorer	(BRE, 2002)	Compares refurbishment with re-development	✓		

7	FEDS	FEDS website	Determines the optimum set of cost-effective retrofits			
8	MAR	(Qbuild, 2003)	Technical assessment of building maintenance	✓		
9	Minimising waste	(Faniran, 1998)				
10	FRP composites	(Thomas, 1996)				✓
11	Recycling & demolition waste model	(Lawson, 2001)				

No	Sustainability				
	Indoor environmental quality	Energy consumption	Electromechanical installations (Additional modules for energy consumption and other assessment)	Solar system and desalination installations (Additional modules for energy consumption and other assessment	Waste recycling and management
1	✓	✓			
2					
3	✓	✓	✓		
4	✓	✓	✓	✓	
5		✓			
6		✓	✓		
7		✓			
8					
9					✓
10					
11					✓

2.3 Research Niche

A world wide literature review of work on building retrofits was undertaken for this project. The issues identified included residual life, energy saving, indoor air quality, waste management, floor space optimisation, risk assessment, choice of procurement method. However, most of the tools in place throughout the world only address some of these issues. Therefore, there is an urgent need to develop a more integrated, robust and holistic tool that operates in a scientific way, instead of depending on information that has been gathered haphazardly.

2.4 Project Statement

Picking from the niche above, the project objectives are to investigate the characteristics of re-life projects that impact upon the effective management of the construction process, such as the identification and mitigation of risks, issues of decanting and existing tenants, identification of existing structure and services, work scheduling, occupational health and safety issues for construction personnel and tenants, demolition, waste and recycling, issues of quality and workmanship, cost planning and cost modelling methodologies.

Specific issues are:-

- Identify and document the issues that impact on re-life projects, design, engineering and procurement, and issues of decanting and sustainability;

- Develop methodologies for assessing the condition of the existing building structure, the residual service life, and modelling of operating & maintenance costs, and the utility and productivity expected from the refurbished building this will include investigation of the potential applications for new remediation processes such as fibre reinforced composites (FRC);

- Develop additional paper based module for the Value Alignment Decision Support tool that will provide particular advice for re-life projects, and appropriate pre qualification criteria for consultants and contractors;

- Identify the opportunities for designing out waste, waste avoidance, reduction, reuse & recycling, and construction programming to minimise waste generation.

2.5 Deliverables

Outcomes to be delivered upon completion of the project include:-

- A report identifying and describing issues particular to re-life projects that impact effective procurement;

- Additional paper based decision support tool for Value Alignment that specifically addresses the issue of ‘Re-life’ projects. The additional module will provide the user with a basis for making judgements on the economic and environmental viability of a re-life project and the formulation of appropriate procurement and delivery options;

- Best Practice Guidelines (written in plain English) providing an understanding of appropriate construction management practices for complex re-life projects dealing specifically with:

  1. Design, engineering and procurement
  2. Waste and recycling aspects of re-life
  3. Residual service life of such projects

- Three refereed Journal articles and three refereed conference papers.

2.6 Significance

The deliverable is highly valuable especially to project partners for guided decision-making assistance when contemplating retrofitting office building projects in the future. This will be provide building owners, developers and contractors alike a systematic tool to evaluate potential projects in a holistic way, rather than make hasty decisions on demolition and build new buildings, thus avoiding unviable technological, economical and marketing outcomes. With the potential savings resulted from such projects, positive chain effects are expected to happen in the property and construction industry whereby economical gains can be used for other input areas such as sustainable design and development, and associated political, social, environmental and financial benefits of such rational exercises will be brought to both clients and the general public alike.

The introduction of the newly-developed guidelines unique to the office building industry would mean that the CRC-CI will be spear-heading this field of specialization in the market. As such, it could substantially influence the decision-makers of other ‘re-life’ projects in regards to design, engineering and procurement, waste and recycling aspects and residual service life, thus bring further research and commercialisation opportunities for the CRC-CI. It is expected that the Guidelines, especially after the completion of the whole of life assessment of case study projects, will become a benchmark for all Australian re-life projects.

In a nutshell, the deliverable will bring about potential economic but more importantly intangible long term benefits to the project partners, as well as contributing to developing sustainable commercial building projects for the Australian community.

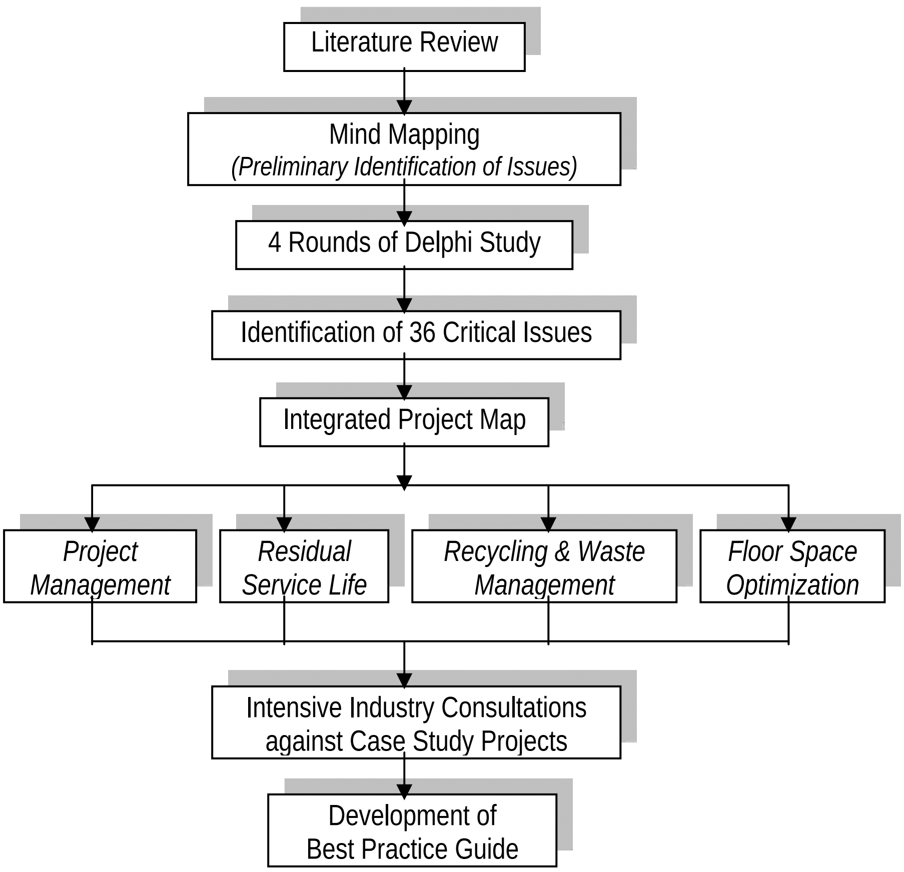
3.0 METHODS AND APPROACHES

3.1 Introduction

The literature review identifies a number of tools and criterion's being used by them when making decisions on refurbishment rather than building from grassroots. The most commonly addressed issues are residual life of building elements and objects including deterioration/degradation, functional obsolescence and Structural strengthening techniques, building sustainability including Indoor Environment Quality (IEQ), energy saving, and waste management and recycling, analysing & managing risks associated with refurbishment projects including the selection of right procurement methods. In the quest to have a robust tool previous researchers employed various methodologies ranging from developing a coding system to identify building degradation and comparing existing energy bills to best practice to identify the energy saving and using structured questionnaire targeted at building occupants to identify issues with indoor air quality and using unstructured interviews to identify risk issues associated with retrofit projects. However most of these tools only address individual issues and in some cases lack a scientific and holistic approach to decision making on retrofit projects.

The aim of the Re-life project is to incorporate all these issues into one holistic tool and provide a structured scheme instead of collecting haphazard in formation on retrofit projects.

Based on the literature review findings, the methods and approaches for development and validation of the tool could be summarized as follow:



3.2 Mind Mapping

Prior to round 1 of the Questionnaire in Delphi Study, a mind map of issues was identified following a comprehensive literature study and discussion with project team members. As a result of this, 48 issues were identified and incorporated into the Delphi Questionnaire.

3.3 Delphi Study

The Delphi Questionnaire was designed to allow a panel of industry experts to determine the most important issues of consideration of refitting commercial buildings. The process of determination involved four rounds of surveys, during which the industry experts were asked to consider, and reconsider, the relative importance of issues presented for consideration. A unique aspect of the Delphi Questionnaire is that the industry experts consider the issues individually, without discussion with other experts. These issues were considered in five categories:

1. Sustainability & Building Efficiency,
2. Project Management,
3. Residual Service Life,
4. Recycling & Waste Management, and
5. Floor Space Optimisation.

The Delphi Questionnaires were sent to 13 industry experts and were asked to consider the issues on a 5-point scale. 9 responses were received.

3.4 Identification of 36 Critical Issues

Following a thorough investigation through the Delphi study and the assistance from the industry through interviews, a total number of 36 critical issues relevant to retrofitting of office building projects have been revealed. The five top ranking critical issues are purpose of refurbishment, energy saving potential, cost analysis for sustainability and building efficiency, project cost risks and condition assessment; while the bottom four are project schedule risks, impacts of incorporating ESD design, waste transportation costs and recycling and recovery potential of waste.

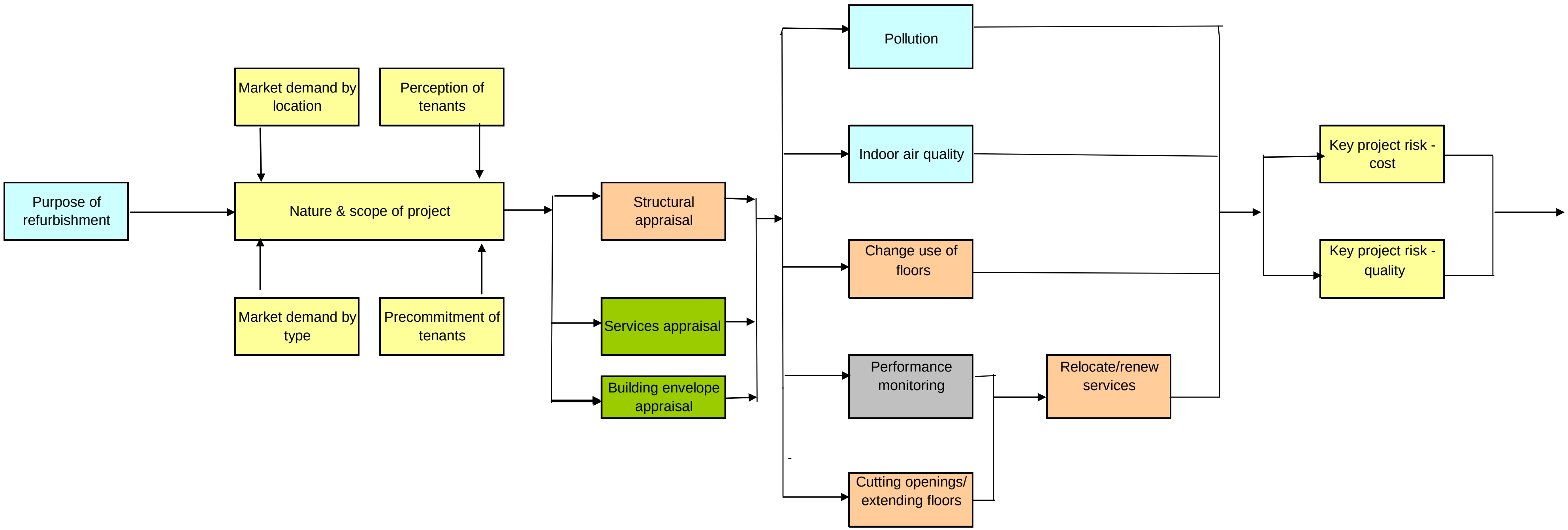
3.5 Development of Integrated Project Map

The 36 critical issues were carefully examined and articulated. As a result, the research team developed the integrated mapping of all these issues according to six major phases of project development, providing the integration of all four strands.

The major phases of project development are:

Phase 1 – Conception Phase
Phase 2 – Feasibility Phase
Phase 3 – Design Phase
Phase 4 – Procurement Phase

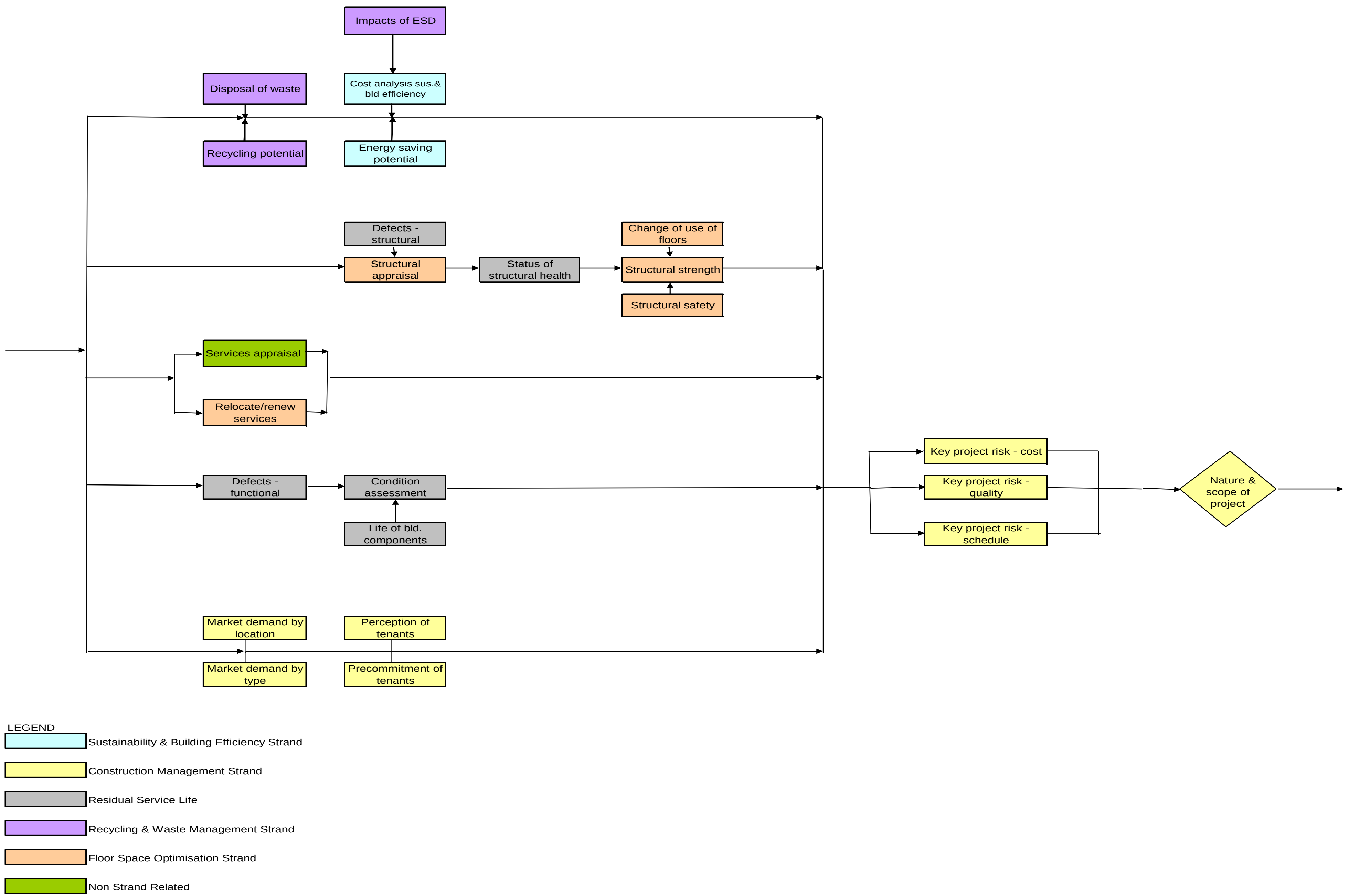
PROCESS MAP - PHASE 1 - CONCEPTION PHASE



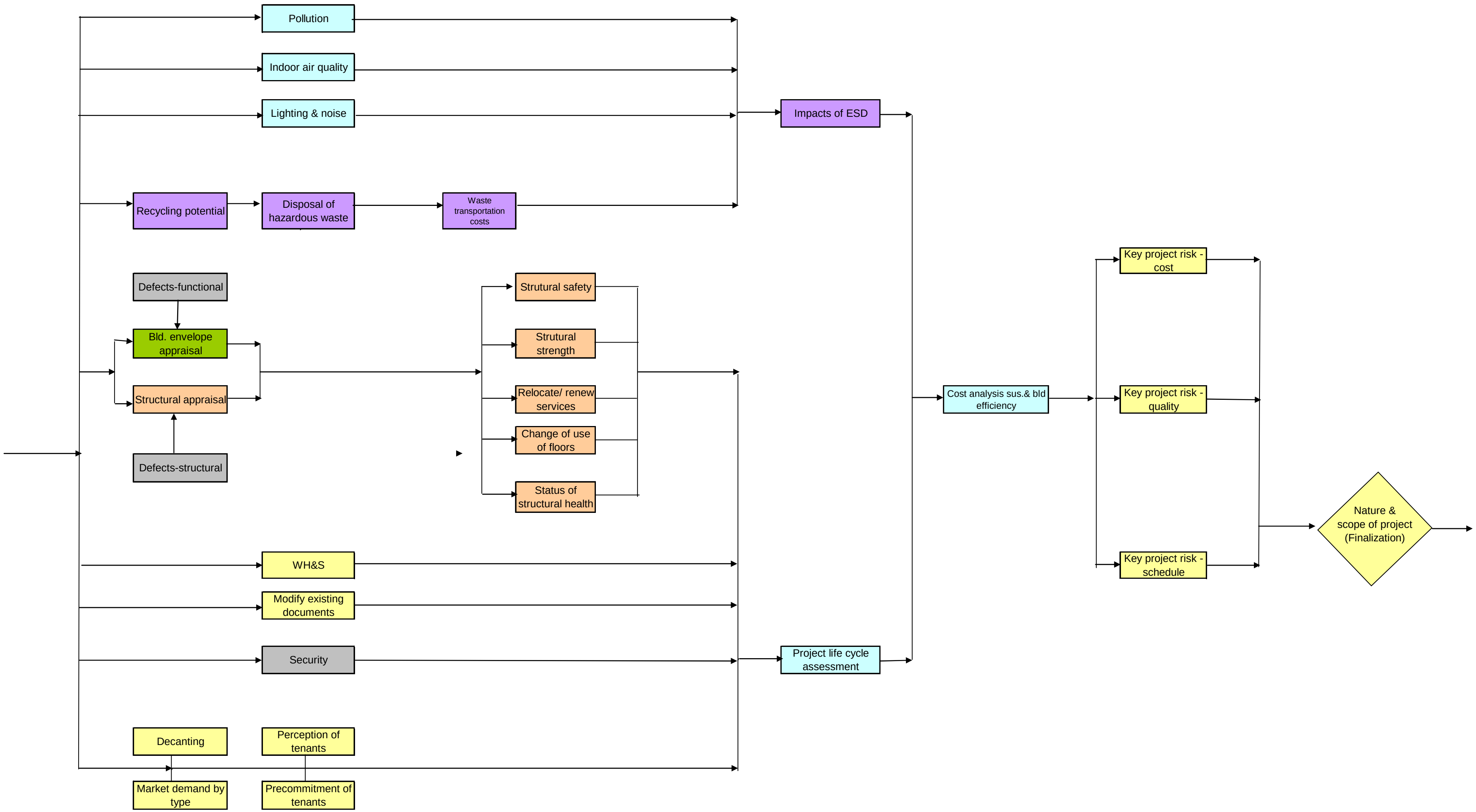
LEGEND

- Sustainability & Building Efficiency Strand
- Construction Management Strand
- Residual Service Life
- Recycling & Waste Management Strand
- Floor Space Optimisation Strand
- Non Strand Related

PROCESS MAP - PHASE 2 - FEASIBILITY PHASE



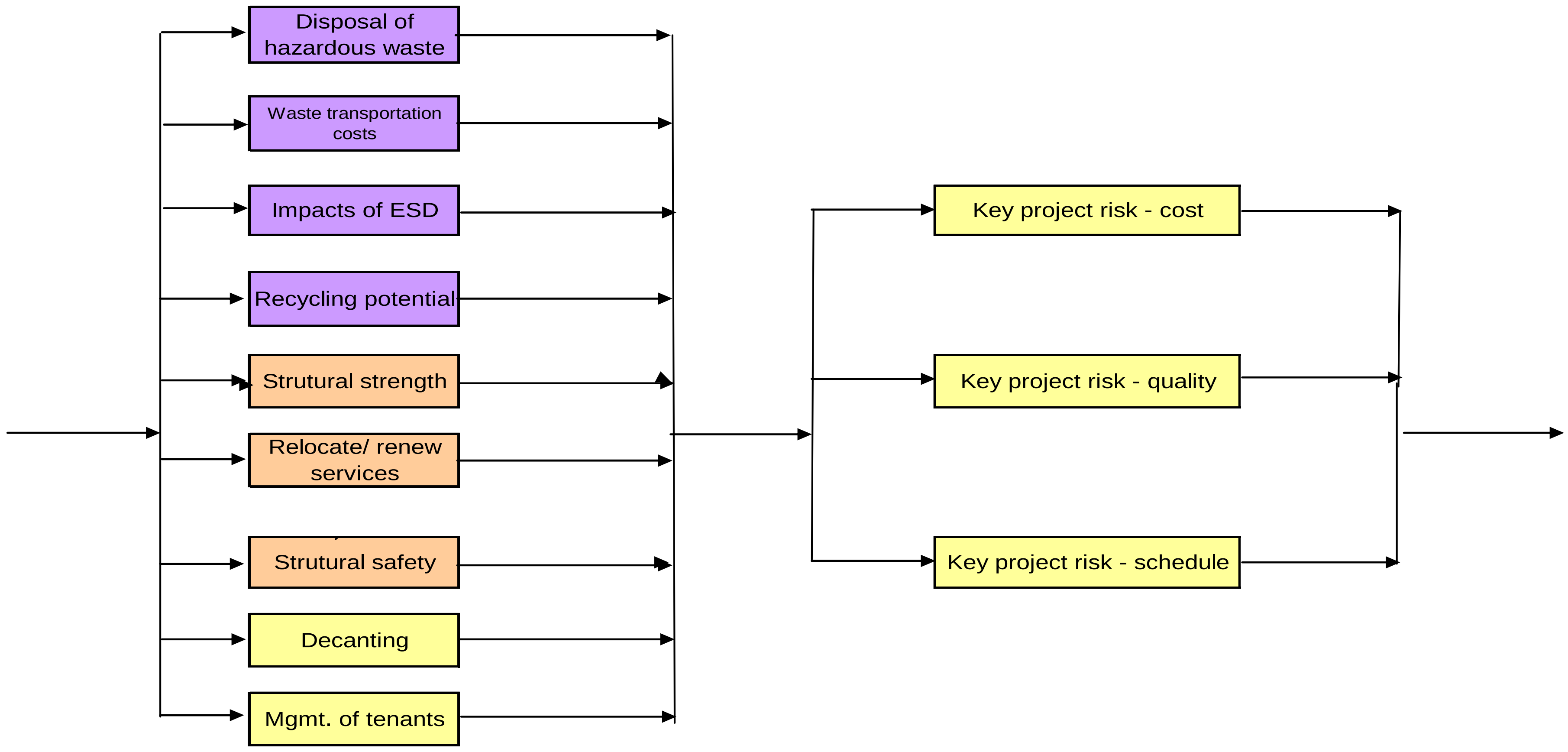
PROCESS MAP - PHASE 3 - DESIGN PHASE



LEGEND

Sustainability & Building Efficiency Strand	
Construction Management Strand	
Residual Service Life	
Recycling & Waste Management Strand	
Floor Space Optimisation Strand	
Non Strand Related	

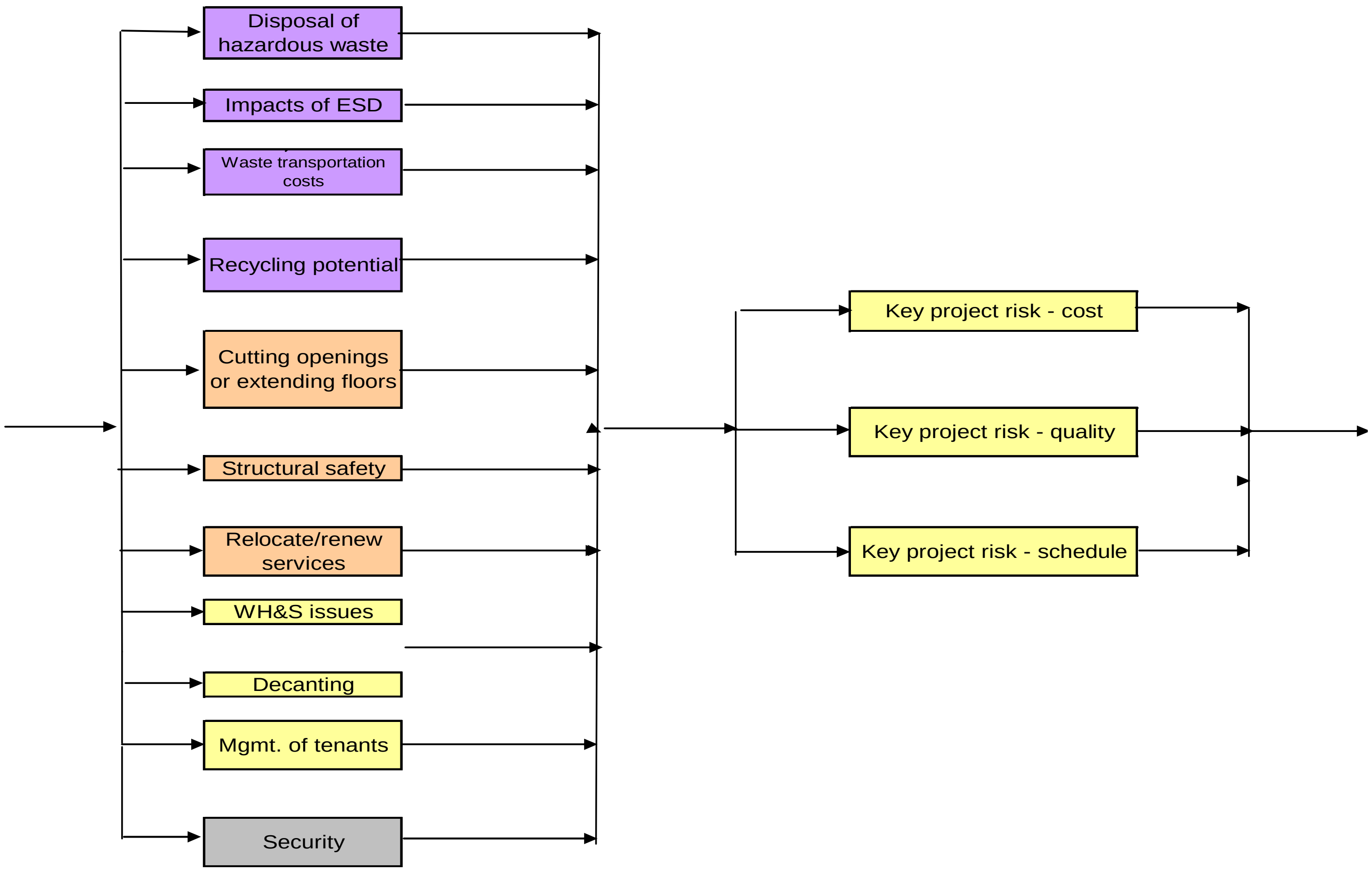
PROCESS MAP - PHASE 4 - PROCUREMENT PHASE



LEGEND

- Sustainability & Building Efficiency Strand
- Construction Management Strand
- Residual Service Life
- Recycling & Waste Management Strand
- Floor Space Optimisation Strand
- Non Strand Related

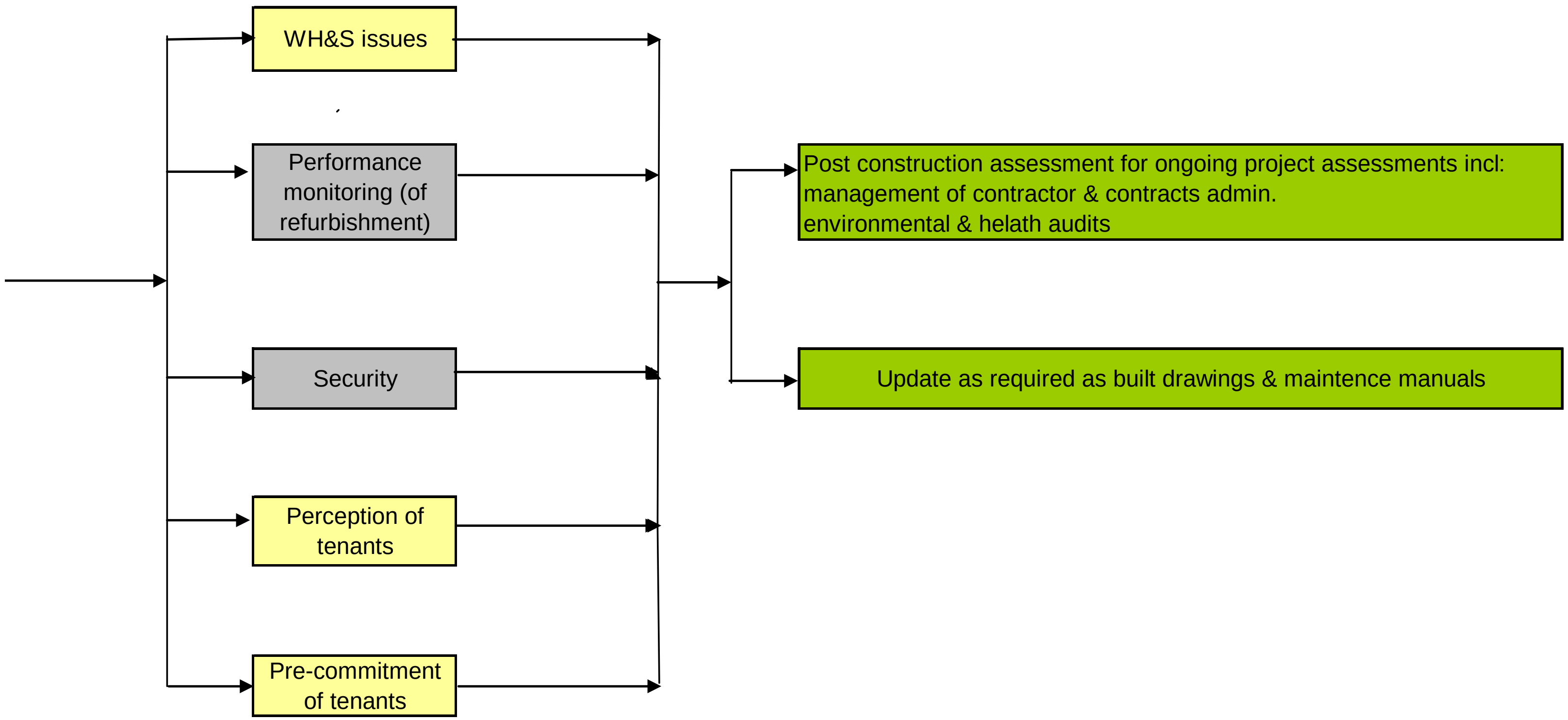
PROCESS MAP - PHASE 5 - CONSTRUCTION



LEGEND

- Sustainability & Building Efficiency Strand
- Construction Management Strand
- Residual Service Life
- Recycling & Waste Management Strand
- Floor Space Optimisation Strand
- Non Strand Related

PROCESS MAP - PHASE 6 - OPERATION



LEGEND

- Sustainability & Building Efficiency Strand
- Construction Management Strand
- Residual Service Life
- Recycling & Waste Management Strand
- Floor Space Optimisation Strand
- Non Strand Related

Phase 5 – Construction Phase
Phase 6 – Operation Phase

Subsequently, a research meeting was held to discuss this integration. This has provided a good understanding of the inter-connection of issues within the context of project development phases in relation to re-life projects.

3.6 Case Study Projects and Site Visits

Initially, three refurbishment projects have been identified and used as case study projects. Drawings had been secured from these projects and continued intensive industry consultations were held. The case study projects are:

1. 63 George Street Brisbane

   This refurbishment project aims to integrate two exiting office buildings, the David Longland Building which is occupied by Q-Super, and the former Health and Welfare Building, George Street, Brisbane into a single general office building. Both buildings are proposed to be refurbished to provide a consistent level of amenity, fitted out with new interior finishes and office accommodation, complete with all engineering services required to produce a building which meets the Government's present energy targets for sustainable development. The brief requested the establishment of a significant presence on the corner of the Government Precinct and to make it a place to be proud to work in.

   This project has been mainly used by the researchers to look into project management issues such as procurement of contract, decanting, workplace health and safety issues, management of tenants etc.

2. CH1 – Melbourne City Council Building

   This study includes refurbishment of a high-rise commercial building approximately 35 years old. It comprises of seven office levels and four car park levels, of which two of the car park levels are underground. The structure of car park composes of reinforced concrete slab supported on secondary and primary beams and concrete encased steel columns. The office levels have reinforced concrete flat slab supported on concrete encased steel columns. The design team of the building has proposed three preliminary design options to satisfy the client's needs.

   This project has been used for analysing those options and developing possibilities to maximize floor space which could be included in the options proposed by the design team. Strengthening of existing structure of the building due to the optimization of floor space is required and those data have been used to validate the matrix of mapping solutions to problems.

3. Sydney Law Courts

   The Queens Square Law Courts Building (also known as Sydney Law Courts) was completed in 1977. The building is twenty storeys high plus a small basement carpark. It is half owned by the Federal and half by the NSW government. The upper stories house federal courts and associated offices. There is a central floor with a common cafeteria. The lower floors are for state courts and their offices. The upper stories are getting a major replan and refurbishment, including layout changes to share harbour views with all occupants of the floor. The lower floors are having straight forward repair and refurbishment but no layout changes. The work is scheduled to continue for the next four years. The building remains operational throughout the refurbishment period.

Frequent site visits had been conducted and researchers were able to collect data for their respective strands. The data collected were used to check the robustness of the tool and to validate the linkages that have been developed at the development stage.

3.7 Intensive Industry Consultations:

According to the inter-relationship and disciplinary representation, each of the four strands was able to carry out intensive industry consultation, aimed at developing guidelines and best practices of determining residual life, floor space optimization, recycling and waste management, and overall project management.

The intensive industry consultations were conducted in following 2 stages:

1. During design
2. During construction and demolition

Industry experts' views were sought to build decision-making methodologies in the refurbishment projects. The methodologies developed were then validated again by the industry experts.

As a result, a series of information has been extracted from these intensive consultations. Projects milestones, such as technical reports on guidelines and journal/conference publications were prepared accordingly. Industry partners had been involved in providing information, lesson learned, as well as case study opportunities.

3.8 Development of Best Practice Guide

Based on data collection from field studies and verified against case study projects through intensive industry consultations, best practice guides covering all 36 critical issues were developed by respective strands. Project Management strand developed the format and structure. The format was agreed by all individual strands, and industry commented and agreed. For each issue, it outlined and considered its' causes, resulting problems, possible actions, and resulting benefits or outcomes.

Project management strand has coordinated the overall presentation of modules of the best practice guide in an integrated, systematic and standard output, user-friendly to the end users, the industry.

Thus, full development of modules of Best Practice Guide by all individual strands accordingly. A final alignment meeting was conducted to ascertain issues arising to the Best Practice Guide.

4.0 PROJECT MANAGEMENT

4.1 Introduction

To ensure the success of a refurbishment project, the management of the overall project is indispensable. This comprises planning and co-ordination at different project development phases such as conception, feasibility, design, procurement, construction and operation. The complex nature of refurbishment works demands a thorough application of project management knowledge into its implementation.

Ten major issues to be addressed in managing the refurbishment project were identified through a survey of experts using the Delphi process. For each of these issues further research were conducted to ascertain the best appropriate practice in managing the refurbishment project and its decision-making.

This section outlines the research work carried out by Project Management Strand, comprising the review of literature and research methodology leading to final outcomes of the development of best practice guide for each issue.

4.2 Preliminary Review of Literature

It is also evident from the literature review that due to the nature of retrofit projects the need of proper risk assessment including risk identifying, risk assessment, risk reduction and contingency planning and a structured scheme to choose a proper procurement method need to be part of an assessment scheme that evaluates retrofit projects.

Based on literature review, the below outlines issues relating to project management in retrofit projects.

4.2.1 Risk assessment of key project risks

As identified in the ECI (2003) workshop on retrofit projects the elements that need to be considered to in estimating and budgeting for retrofit projects are:

- Identify what exists on site and what condition is it in. Are there any modifications required, status of existing control and other equipment. These have been covered in detail in the form of residual life of elements, functional obsolescence, energy performance and indoor air quality.

- Dismantling, removal and recycling have also been discussed above.

- Total risk assessment – check original scope definition, assesses risks and decide how to deal with cost implications. The past and present research on risk assessment etc. is discussed next.

Refurbishment projects potentially contain more technical and economic uncertainties and risks than new build schemes, reflecting the nature of works within, and the increasing demands placed upon existing property (Reyers, 2001). To deal with this the most important issue with retrofit projects is risk management which is a set of methods and activities designed to reduce the disturbances occurring during project delivery (Skorupka, 2003). The aim of the risk management is to achieve project objectives that may include delivery within schedule and budget and in line with all quantitative and qualitative standards.

Gray (1999) pin points that the risk management system includes the following consecutive phases:

- Identifying risk,
- Analysing and
- Assessing risk and responding to risk.

Identifying risk begins by making a list of all the area that might cause the retrofit projects to delay or fail and their respective outcomes. The entire management team participates in this task and brainstorming can be used to ensure all aspects of the risks are covered.

Assessing and analysing risk:

The next step of risk assessment selects potential foreseen risk events that need attention because they exhibit a high probability of occurrence and have consequence of loss (Gray, 1999). Risk analysis starts with a matrix that summarises the chances, severity and the time the event is likely to occur. The matrix also identifies whether the project team would be able to detect that the event was going to occur in time to take mitigation action. A number of techniques have been used to identify and assess the impact of a risk event. A few of the most recognised techniques are Scenario Analysis, Ratio/ Range Analysis, Hybrid Analysis, Probability Analysis and Sensitivity Analysis. The risk assessment methodologies for retrofit projects are the same as for the other projects except that it is essential to recognise the additional risks associated with refurbishment projects (Cox, 2004).

Responding to risk:

When a risk is identified and assessed, a decision must be made concerning which response is appropriate for the specific event. Responses to risk can be classified as:

- Avoiding risk: pre-emptive action is required, including if necessary changes to the project plan or implementation strategy.

- Mitigate risk: reduce risk by limiting the exposure to them.

- Distribute risk: Transfer the risk to the party most capable to quantify and manage it.

- Absorb risk: strengthen your position so you can cope with the shock associated with some events.

Some of the risks identified by Cox (2004) that are specific to retrofit projects are:

- Resources with required specific knowledge are not available when needed to carry out feasibility and development phase work
- Documented information relating to existing services is not available.

- Risks associated with the use of unproven technology.

- Availability of construction

- Resources for fixed date works.

- Construction productivity is less than budgeted.

- Issuing of permits to work may cause significant delay to construction works.
  Other project risks identified by Reyers et al (2001) are:

- Health and Safety: an increased use of temporary works such as scaffolding, shoring systems and safety issues that would be expected in new build.

- Design constraints: there are often unique combinations of alternative design solutions and varying levels of specifications coupled with restricted component and material choice have different risk implication (Raftrety, 1994).

- Decanting and existing occupants of the building.

- Schedule risks identified at ECI (2003) workshop are:

  - Realistic shutdown and schedule planning. The resources involved to manage this.
  - Understanding the business drivers.
  - Building contingency into shutdown.
  - Delivery of equipment.
  - Other projects and their influences on strategy.
  - Operational constraints.
  - Allowing for accidents.
  - Adverse weather/timing.

- Cost risks (Gray, 1999) are:

  - Time cost dependency link
  - Cash flow decisions
  - Final cost forecasts
  - Price protection risks

- Adequacy of Definition – Risks are:

  - In-valid estimate/budget.
  - Impact assessment.
  - Adequacy of utilities.
  - Infrastructure required to support the project and its resources.

- Key Project Risks (Cox 2004) are:

- Unknowns/emergent work.
- Resources.
- Scope changes.
- Operating environment.
- Quality of information supplied.
- Plant condition.
- Material availability.
- Compatibility of materials.
- Adequacy of definition.
- Support from original equipment manufacturers.
- External influences.

A contingency plan is an alternative plan that will be used if a possible foreseen risk event becomes a reality. The contingency plan is used to mitigate the adverse impact of a risk event. Reyers (2001) identifies that contingency allocation for retrofit projects tended to be 70-80 percent higher than new built. In a study conducted by Reyers (2001) the provisional sums were reported to make 8-12 percent of the project cost for retrofit projects. This was up to 50% for higher than a new build project. There is reluctance to provide the project with a large contingency fund but failure to do so may end up in a situation where additional funding needs to be acquired.

Due to above list of significant uncertainty and risks it may be prudent to allocate specific contingencies to each element in addition to the provision of general contingency. These elements can be those aspects of the project where there is a perceived high degree of cost uncertainty. These may be a high as a percentage of the base cost but reduce the overall project contingency. These however need to be assessed as part of the risk assessment. As the estimate of the retrofit project is likely to have some additional cost vulnerabilities then effective cost control is even more important than new build.

Cox (2004) identifies that has potentially all the above features which make accurate estimation a challenge and makes it highly unlikely that the available quality will be better than 90% probability of being within plus/minus 20%.

4.2.2 Choice of right procurement method

A report published by CIRIA (2004) on refurbishing buildings identifies that the procurement method determines how much an input the client and members of the construction team have at different phases, who has the overall responsibility and who carries the major risk. There are two important considerations first project planning to minimise the disruption for existing occupants and secondly cooperative site operation between the project team and occupants. Hence when choosing a procurement method let it be traditional or DNC these two considerations should be taken into account. The existing value alignment tool outcome is also aimed at selecting the most appropriate project delivery approach.

4.2.3 Effective use of design and management contractors

Cox (2004) makes the following recommendation for efficient development and implementation of projects, in terms of effective use of design and management contractors:

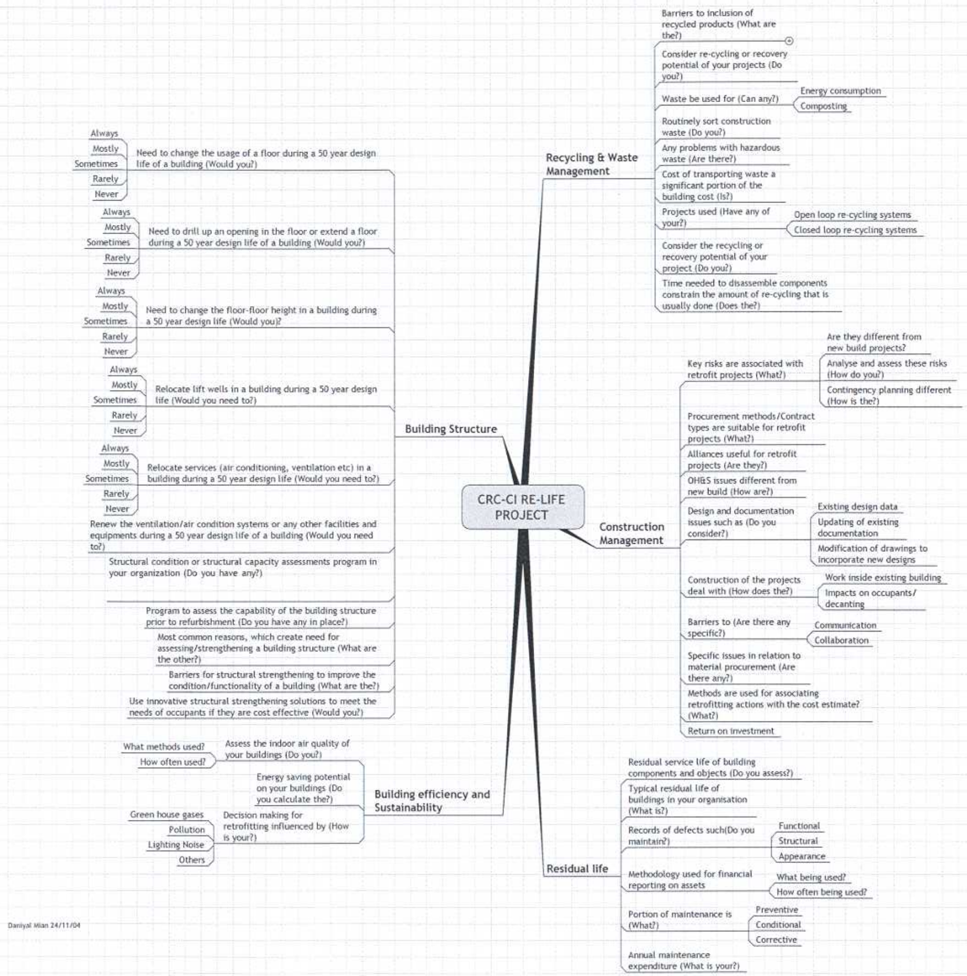
- Agree and define the roles and responsibilities between the contractor and the client.
- Examine competency levels – use historical experience.
- Look at the availability of the resource – can we get the right people at the right time?
- Transfer the experience and learning from other retrofit projects.
- Ensure that access can be gained to experienced retrofit project people and organisations.
- Consider constructability during the early stages, i.e. once the contract has been selected.
- Ensure that an appropriate contract, procurement and execution strategy is in place.
- The selection of the appropriate contractor. They must fit the size and complexity of the project.
- Undertake pre-qualification procedures – look at experience, track record, competencies, and key personnel.
- Make use of joint ventures – share the gain/pain.
- Look at the compatibility of the client and contractor culture – ensure that the "soft issues" are considered.
- Is access to senior management possible?
- Ensure the early involvement of the contractor.

4.3 Mind Map

A mind map (refer to next page) was developed and used to present the findings of the literature review. Based on literature review, 48 issues were identified and preliminarily categorized into the following five groups:

1. Project management
2. Residual service life
3. Recycling and waste management
4. Building structure
5. Building efficiency and sustainability

After reviewing the literature and thorough discussions with all the team members, it was decided that Delphi technique would be used to augment the



Mind map of questions for Delphi Study

issues identified in the mind map. Interrelationships between these issues would then be investigated that led to the development of process map.
This mind map of issues formed the basis for Delphi process and led to the identification of 36 critical issues at the subsequent stage.

4.4 Delphi Process

Based on the mind map, Delphi techniques were used to explore key issues relevant to commercial building refurbishments. The procedure for this Delphi exploration consisted of four electronic mailed questionnaire rounds completed over a three-month period. The 48 issues identified were incorporated into the Delphi Questionnaire.

The following 13 industry experts from several disciplines involved in the delivery of commercial refurbishment projects had been identified and invited to participate in this Delphi process. A total of 9 responses were received.

No.	Experts	Organisation
1.	Peter Wager dcinfo@davenport-campbell.com.au	Davenport Campbell & Partners
2.	Dale Lawrence dlawrence@sgaproperty.com	SGA Property Consultancy
3.	Darren Staunton dstaunton@cliftonconey.com	Clifton Coney Group
4.	John Paterson jsp@isisprojects.com.au	ISIS Projects
5.	John Oliver joliver@ridersyd.com.au	Rider Hunt Terotech Melb
6.	Brian Fitts/John Halliwell bfitts@skm.com.au	Sinclair Knight Merz
7.	Mick Pearce micpea@melbourne.vic.gov.au	City of Melbourne
8.	Derek Clements Croome d.j.clements-croome@reading.ac.uk	University of Reading
9.	Malcolm Bell Bell, Malcolm M.Bell@leedsmet.ac.uk	Leeds University
10.	Keith Jones K.G.Jones@greenwich.ac.uk	University of Greenwich
11	Greg O'Brien Greg.O'Brien@projectservices.qld.gov.au	Project Services
12	Ian Brown	John Holland Pty Ltd
13.	Paul Walhurst Paul.Warhurst@publicworks.qld.gov.au	QDPW

The first round of questions in this study was intended to provide expert confirmation of the important issues related to building retrofits, which were identified through a review of the previous construction literature. They were asked to rank the most significant issues. These issues were considered in five categories:

1. Sustainability & Building Efficiency,
2. Project Management,
3. Residual Service Life,

4. Recycling & Waste Management, and
5. Floor Space Optimisation.

The information collected from this first round was analysed and reported back to the survey participants who were then asked to re-examine their opinions in light of the overall results. Participants were not identified in the feedback, only their priorities and comments would be forwarded to the other participants. This process repeated 4 rounds which then crystallized into the identification of 36 critical issues.

4.5 Identification of 36 Critical Issues

36 most important or critical issues were identified following 4 rounds of Delphi process. Analysis of the feedback revealed the highest scoring issues in each of the 5 categories as follows:

- Sustainability & Building Efficiency – The issues are Energy Saving Potential (4.4), Pollution (4.2) & Indoor Air Quality (4.1).

- Construction Management – The issues are OH&S Issues (4.0), Key project risks – quality (3.9) and Key project risks – cost risks (3.8).

- Performance of the Existing Building – The issues are Defects – structural (4.3), Defects – functional (4.2), and Life of elements & components of the building (4.1).

- Recycling and Waste Management – The issues are Disposal of hazardous waste (3.8), Recycling & recovery potential of waste (3.2), Time taken for recycling (3.1) and Waste Transportation costs (3.1).

- Floor Space Optimisation – The issues are Structural Appraisal prior to refurbishment (4.6), Safety/reliability issues for structural strengthening (4.3) and Other issues for structural strengthening (4.0).

Round 1:

Overall, the highest scoring issues in Round 1 and the average scores for these issues are Structural Appraisal prior to refurbishment (4.6), Energy Saving Potential (4.4), Defects – structural (4.3) and Safety/reliability issues for structural strengthening (4.3).

Round 2:

In Round 2, 19 new issues proposed by Industry Experts in Round 1 were incorporated into the Delphi Questionnaire, making a total of 68 issues. The Questionnaire was sent to 11 industry experts and 11 responses were received. The results were analysed to determine the highest scoring issues in each of the five categories:

- Sustainability & Building Efficiency – The issues are Energy Saving Potential (4.4), Purpose of Refurbishment (4.3) & Cost analysis for sustainability & building efficiency (4.2).

- Construction Management – The issues are Key project risks – cost risks (4.1), OH&S Issues (4.1), Key project risks – quality (3.7) and Market demand for space by location (3.7).

- Performance of the Existing Building – The issues are Defects – structural (4.4) and Defects – functional (4.2), and Status of structural health (4.2).

- Recycling and Waste Management – The issues are Disposal of hazardous waste (4.0), Impacts of incorporating ESD (3.3), Waste transportation costs (3.0) and Recycling & recovery potential of waste (3.0).

- Floor Space Optimisation – The issues are Structural Appraisal prior to refurbishment (4.6), safety/reliability issues for structural strengthening (4.2) and Impact from factors on structural strengthening (4.0).

Overall, the highest scoring issues in Round 2 and the average scores for these issues are Structural Appraisal prior to refurbishment, are Structural Appraisal prior to refurbishment (4.6), Energy Saving Potential (4.4), Defects – structural (4.4) and Purpose of the Refurbishment (4.3).

Round 3:

In Round 3, the industry experts again considered the 68 issues included in the Delphi Questionnaire. The Questionnaire was sent to 11 industry experts and 10 responses were received. The results were analysed to determine the highest scoring issues in each of the five categories:

- Sustainability & Building Efficiency – The same highest scoring issues from Round 2, namely Energy Saving Potential (4.5), Purpose of Refurbishment (4.5) & Cost analysis for sustainability & building efficiency (4.4).

- Construction Management – The issues are Key project risks – cost risks (4.3), Key project risks – quality (4.1), and OH&S (4.0).

- Performance of the Existing Building – The issues are Defects – structural (4.4) and Defects – functional (4.2), Status of structural health (4.2) and Condition Assessment (4.2).

- Recycling and Waste Management – The issues are Disposal of hazardous waste (4.1), Impacts of incorporating ESD (3.3) and Waste transportation costs (2.9).

- Floor Space Optimisation – The same highest scoring issues from Round 2, namely Structural Appraisal prior to refurbishment (4.9), safety/reliability issues for structural strengthening (4.2) and Impact from factors on structural strengthening (4.1).

Overall, the highest scoring issues in Round 3 and the average scores for these issues are Structural Appraisal prior to refurbishment (4.9), Energy Saving Potential (4.5), Purpose of the Refurbishment (4.5), Cost Analysis for sustainability and building efficiency (4.4) and Defects – structural (4.4).

Round 4:

In Round 4, the number of issues for consideration was reduced to the 36 highest scoring issues in Round 3. The Questionnaire was again sent to 11 industry experts and 10 responses were received. The results were analysed to determine the highest scoring issues in each of the five categories:

- Sustainability & Building Efficiency – The issues are Purpose of Refurbishment (4.8), Energy Saving Potential (4.4), and Cost analysis for sustainability & building efficiency (4.4).

- Construction Management – The issues are Key project risks – cost risks (4.4), OH&S (4.0) and Work inside existing building/decanting (4.0).

- Performance of the Existing Building – The issues are Condition assessment (4.3), Defects – structural (4.2) and Defects – functional (4.2).

- Recycling and Waste Management – The issues are Disposal of hazardous waste (4.1), Impacts of incorporating ESD (3.3) and Waste transportation costs (3.0).

- Floor Space Optimisation – The issues are Structural Appraisal prior to refurbishment (5.0), safety/reliability issues for structural strengthening (4.2) and Cutting openings or extending floors (4.1).

Overall, the highest scoring issues in Round 4 and the average scores for these issues are Structural Appraisal prior to refurbishment (5.0), Purpose of the Refurbishment (4.8), Energy saving potential (4.4), Cost Analysis for sustainability and building efficiency (4.4) and Key project risks – cost risks (4.4).

4.6 Integrated Process Map

The 36 critical issues identified were carefully examined and mapped against six major phases of project development. The major phases of project development are:

Phase 1 – Conception Phase
Phase 2 – Feasibility Phase
Phase 3 – Design Phase
Phase 4 – Procurement Phase
Phase 5 – Construction Phase
Phase 6 – Operation Phase

A major research meeting involving all individual strands was conducted to discuss and ascertain the integration of these critical issues into an integrated process map, providing a good understanding of the inter-connection of issues within the context of project development phases in relation to re-life projects.

This provided an important basis for further investigation of each and every critical issue by individual strands in a structured and co-ordinated way, leading to commonly desired over-arching outcomes.

Subsequently, individual strands looked into each and every critical issue pertinent to their respective strands, based on three case study projects.

4.7 Development Processes

Following final round of Delphi process, there were 10 issues identified as pertinent to Project Management strand. The issues are:

1. Nature & scope of work (objective & market research)
2. Nature & scope of work (type of contract)
3. Market demand by type & location
4. Perceptions of tenants
5. Pre-commitments by tenants
6. Key project risks (cost, quality and schedule)
7. Decanting
8. Workplace safety & health issues
9. Modifying existing documents
10. Management of tenants.

To further investigate each of these issues, 3 rounds of interviews involving 16 industry experts were conducted. On an average, each interview took between 1 – 11/2 hours. Each and every interview was recorded and transcripted.

Knowledge was progressively extracted after rounds of intensive industry consultations, completing all modules of construction project management issues according to the integration map.

For verification of outputs, a series of appointments with the key stakeholders (eg. occupants, architects and engineers) involved were arranged in order to test the findings against decision making patterns as they happened. The table below shows the details of the experts involved:

Position	Company	Venue	Date & Time
Senior Associate	Quantity Surveyor	Level 3, 179 Ann Street, QLD.	19 May 2006 10:30 – 11:30 am
Construction Manager Building	Contractor	Level 4, John Holland Office, Oxley Building	30 May 2006 2:30 – 3:30 pm
Business Dev. Manager	Contractor	Level 4, John Holland Office, Oxley Building	4 June 2006 9 - 11am
Senior Program Manager	Local Authority	80 George St.	5 June 06
Managing Director	Property Consultant	ANZ Centre, Lvl 12, 324 Queens St.	9 June 2006 1:00 – 1:45 pm
Principal Interior Architect	Local Authority	Level 3, 315 Brunswick St,	15 June 2006 2 - 3 pm

		Fortitude Valley	
Asset Manager	Property Consultant	NZ Square, Level 3, 200 Adelaide St.	19 June 2006 2 - 3 pm
Construction Manager Building30	Contractor	John Holland Office, Oxley Building	31 July 2006 3:00 – 4:30 pm
Asset Manager	Property Consultant	NZ Square, Level 3, 200 Adelaide St.	9 August 2006 10:30 – 11:30 am
Principal Interior Architect	Local Authority	Level 3, 315 Brunswick St, Fortitude Valley	17 August 2006 11am - 12 noon
Senior Program Manager	Local Authority	80 George St.	30 Aug 06 11am -12 noon
QSuper (Tenant)	Local Authority (Tenant)	6th Floor, Govern. Accom. Office, QSuper.	5 Sept 06 9 – 10 am
Project Manager	Contractor	Board Room, Level 4, L Block, QUT.	6 Sept 06 1 – 2pm
Site Manager	Contractor	Board Room, Level 4, L Block, QUT.	
Architect	Local Authority	Room 5, Level 5, Side, 80 George St.	12 Sept 06 12:30 – 2:00pm
Project Manager	Local Authority	Room 5, Level 5, Side, 80 George St.	19 Sept 2006 10am – 12 noon

4.8 Module Formulation and Templates

To have integrated, systematic and standard outputs of research findings by all strands, a sample template was developed by Project Management strand; in a user friendly and easily understood format. Guided by 36 key issues along 6 project development phases, each issue is progressively addressed on its':

1. causes,
2. resulting problems,
3. possible actions and
4. resulting benefits or outcomes.

All strands were informed accordingly and explained of the sample template. Modules of the best practice guide on each issue were developed at the end of the research findings by individual strands.

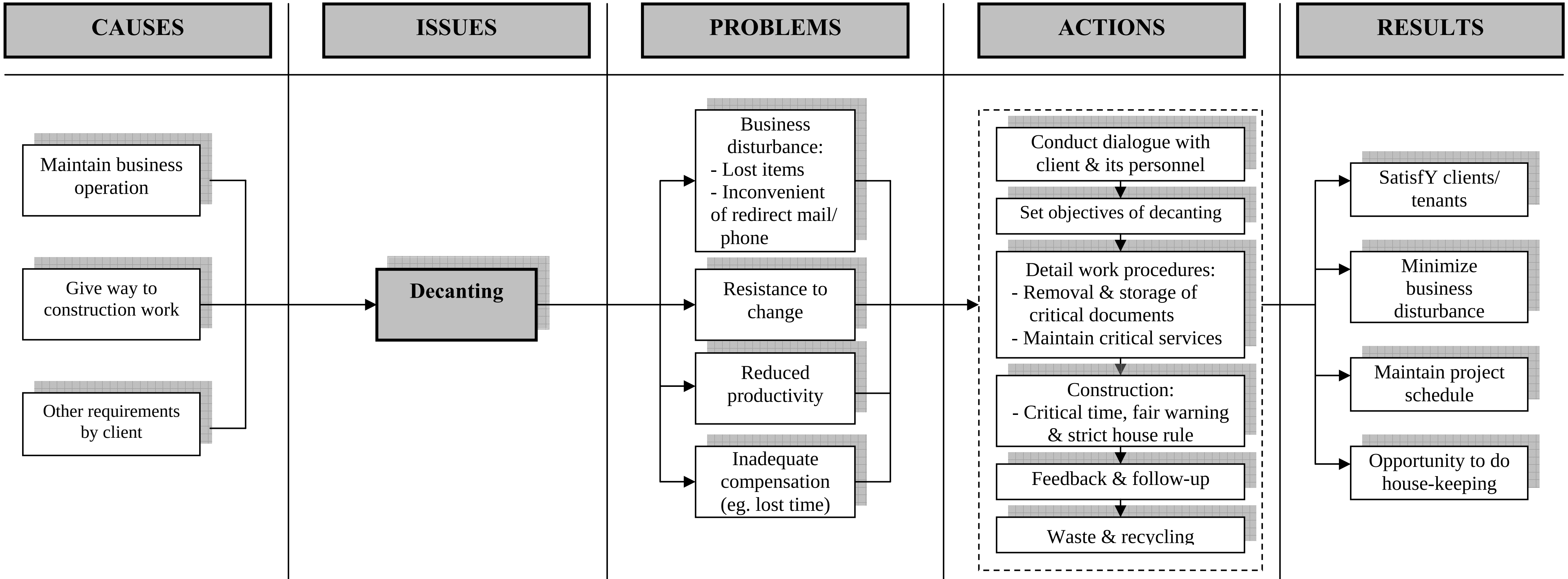
4.9 Best Practice Guide

Accordingly, issues considered in project management strands have been mapped into the project development life cycle. These were then condensed into decision modules.

Sample Best Practice Guides for Decanting and Management of Tenants are included overleaf. These are intended as checklists for use when planning and carrying out a commercial refurbishment project. It is not intended that they comprehensibly cover all aspects of project management but rather a general guide for the team that will conceive, plan, manage and operate a construction refurbishment project.

ISSUES IN PROJECT MANAGEMENT AGAINST DEVELOPMENT PROCESS

	Re-life Project Development Phases					
ISSUES in CM	**Conception**	**Feasibility**	**Design**	**Procurement**	**Construction**	**Operation**
• Nature & Scope of Work *(Market Research)*	√	√	√ (Finalization)			
• Nature & Scope of Work *(Type of Contract)*	√	√	√ (Finalization)			
• Market Demand by Location & Type	√	√	√ (By Type)			
• Perception of Tenants	√	√	√			√
• Pre-commitment by Tenants	√	√	√			√
• Key Project Risk (Cost, Q, Schedule)	√ (Cost & Q)	√	√	√	√	
• Decanting			√	√	√	
• WH & S Issues			√		√	√
• Modify Existing Documents			√			
• Management of Tenant				√	√	



RECOMMENDATION ON KEY ACTIONS

DESIGN PHASE:

Conduct Dialogue: Contractor to initiate, conduct, and maintain dialogue with client and at times, involve participation of professional removalist and identify specific needs of client and his personnel during decanting period.

Set Objectives: Contractor, in consultation with client, sets objectives on how to conduct decanting process with considerations of time, procedure, priority, noise, power interruption and other associated disturbances.

Consultants should consider decanting as key objectives in this process.

Detail Work Procedures: Need to consider removal and storage of critical documents, security, safety and maintain critical services and minimize disturbances.

PROCUREMENT PHASE:

Contractual Issues: Client or contractor needs to negotiate with the removalists, identify special needs, and arrange for long-lead items.

Methods of construction are to be outlined clearly to the tenants including detailed work procedures and programming.

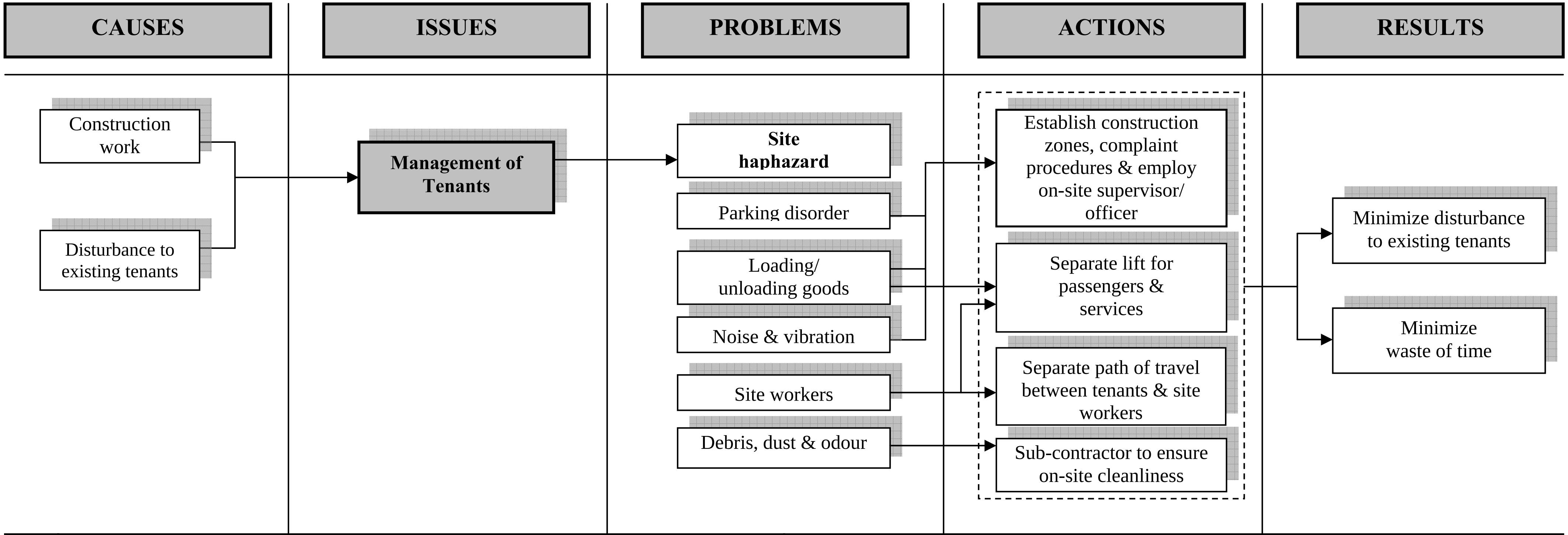
CONSTRUCTION PHASE:

Relationship Diagram: Needs to be established in order to provide a clear picture of management to existing tenants as the point of reference in case of any emergency or arising matters during decanting.

Construction Work: Consider physical work on site with scheduling requirements, notices, “Do’s and Don’ts” and strict house rules. Fair warning is to be given by contractor from time to time. Clear communication protocol between tenants and contractors including feedback and follow-up.

Needs to ensure that tenants are committed to the task of packaging their items in designated boxes.

Waste: Recycle bin installation and service, cleaning and removal of debris from construction site.



RECOMMENDATION ON KEY ACTIONS

PROCUREMENT PHASE:

Contractual Issues: The contractor needs to ensure that a clause on client's or existing tenants' agreement on management of tenants is provided in the contract. Whereas, client is to ensure that the contractor will perform all necessary to minimize disturbances to existing tenants including the employment of on-site supervisor to manage material delivery, parking, noise, cleanliness after construction and the related.

Methods of Construction: The contractor is required to outline and describe the methods of construction, including operation hour, method of material delivery, management of parking while construction in progress, and collection of debris by taking into considerations the nature of client's business, critical time and other necessary cautions as prescribed by the client.

CONSTRUCTION:

Establish Construction Zones: Set up hoarding or fencing and clearly identify street passing restrictions to the tenants and pedestrian.

Establish Complaint Procedures: As a communication platform to deal with constructive and truthful complaints by exiting tenants during construction period.

On-site Supervisor: He/she is to be stationed on-site when & during construction. The supervisor is to act in between the contractor and existing tenants to facilitate smooth operation during construction, including material delivery, parking and noise.

Separate Lift & Path-way: Allocation must be made for services lift and separate path - way between contractor and existing tenants to avoid accidents and for courtesy.

On-site Cleanliness: Sub-contractor will be responsible for cleaning the construction debris. This will ensure a pleasant and hazard-free site that shall help pacify the existing tenants and raise their cooperation.

Apart from site and office notices, it is advisable that the contractor pays courtesy visits to existing tenants to explain work that is going to be carried out. Good working relationship with existing tenants is important.

The contractor is to put up notices surrounding construction site to inform the tenants or public before hand.

Strict house-keeping rules are to be observed by all parties. Adhere to smoking restrictions. Common sense prevails wherever possible.

4.10 References

Balaras, C.A. (2004),' Decision support software for sustainable building refurbishment', Ashrae Transactions, 110, 592-601.

BRE & dti (2002), 'Office Score: Refurbishment support tool for office building' **www.officescorer.info/** accessed on 12/09/04.

Caccavelli, D. et al (2002), 'TOBUS- a European diagnosis and decision making tool for office building upgrading', Energy and Building, 34, 113-119.

CAR report (2003), 'Report to the Energy Saving Trust (EST) titled' Refurbish or replace', UK.

CIRIA (2004), 'Good practice guidance for occupied buildings' UK.

Cox, F. (2004), 'The Engineering and Management of Retrofit Projects in Process Industries', ECI, UK.

ECI (2003), 'Workshop on the 'Engineering and management of retrofit projects', UK.
Faniran, O. (1998), ' Minimising waste on construction project sites', Engineering Construction and Architectural Management, 5(2), 182-188.

FEDS system website **www.pnl.gov/FEDS** accessed on 12/09/04.

Flourentzos, F. et al (2000), 'Eqipr-Tobus: A new generation of refurbishment decision aid methods'.

Flourentzou, F. (2000), 'MEDIC- a method for predicting residual service life and refurbishment investment budgets', Energy and Buildings, 31, 167-170.

Gray, C. (1999), 'Project Management: The managerial processes, McGrawHill.

Nigel, L. et al (2001), 'Recycling construction and demolition wastes- a UK perspective', Environmental Health and Health, 12(2).

Qbuild (2003), 'Maintenance Assessment Report for 111 George Street', QDPWH, Brisbane.

Reyers, J. et al (2001), 'The assessment of risk in conservation refurbishment projects', Structural Survey, 19(5), 238-244.

Sanvido, V. et al (1991), ' Managing Retrofit projects', Technical report # 25, Computer Integrated Construction Research Program.

Skorupka, D. (2001), 'Risk Management in Building Projects', AACE International Transactions, 19.1-19.6.

Thomas,J. et al (1996), ' Field application of a carbon fibre sheet material for strengthening reinforced concrete structures', Internal SAMPE symposium, Anaheim.

5. RESIDUAL SERVICE LIFE

5.1 Introduction

Most of the public asset buildings in Australia that are around 40 years old have undergone significant changes in their functional use and utility. With the recent technological advancements and changing user expectations, the asset owners are facing a major issue; whether to refurbish the existing building and bring it back to its life or to completely demolish and rebuild? The option of demolishing and rebuilding seems to have practical issues like decanting, access during construction, recycling of wastes and unforeseen costs besides many others. It is also noted that the refurbishment costs in many cases are approximately half of the costs of new construction. Furthermore, with the increasing focus on the sustainability of the built environment, the option of bringing back the serviceable life (Re-life) of buildings (with minimum investments) is finding favour amongst asset owners. In achieving the re-life option, one of the important considerations is to ascertain the residual service life (RSL) of the building as a whole or some of its components. In generic terms, the residual service life is an estimation of the remaining useful service life of a building or component taking into account of its present condition and future functioning.

This chapter addresses two main issues: Condition assessment of the existing performance of buildings and estimating the residual service life of elements and components in a building. For this purpose, two case study buildings one in Melbourne and another in Sydney were investigated. The refurbishment project stages were divided into six phases as explained in the earlier chapters. Delphi study undertaken identified seven key variables that influence the performance of the existing building. Each of these variables was investigated with regard to the project development phases. Out of these variables five of them are considered to influence the residual service life. Therefore the best practice guidelines are restricted to five variables. The subsequent sections present the review of literature, research methodology and sample methods of estimating RSL in the re-life of buildings.

5.2 Review of Literature

In 1999, the International council for Research and Innovation in Building and Construction (CIB) published a report describing an agenda for sustainable construction (CIB, 1999). In the summary of the report it is stated that:

“The pursuit of sustainable development throws the built environment and the construction industry into sharp relief. This sector of society is of such vital innate importance that most other industrial areas of the world society simply fade in comparison. Proper housing and the necessary infrastructure for transport, communication, water supply and sanitation, energy, commercial and industrial activities to meet the needs of the growing world population pose the major challenge. The Habitat II Agenda lays stress on the fact that the construction industry is major contributor to socio-economic development in every country. The construction industry and the built environment must be

counted as two of the key areas if we are to attain a sustainable development in our societies."

It is to be noted that the sustainability of the built environment requires an estimation of the durability of the building elements and components taking into account of the environmental issues and economic issues. Frohnsdorff, 1996 & Frohnsdorff and Martin, 1996 have further stated the need for undertaking service life design approach. Subsequent research efforts culminated in the form of residual service life models such as the ISO, 15686 Part 1, 2000 and Part 2, 2001, MEDIC (Method d Evaluation de sc'nearious de Degradation probables d'Invessissements Correspondants) by Flourentzou, *et. al* (2000) and in the form of conceptual methodologies as demonstrated by Bamforth, 2003. Note that these models or methods require significant forms of data that are not readily available to the user. One of the issues is that the history of the building maintenance is documented in some form that needs to be processed before the aforementioned methods could actually be applied. This presents considerable challenges in linking the past history of the building components, ascertaining their present condition and in using these informations to reliably predict RSL. Furthermore, the definition of RSL seems to vary across the range of methods. Thus a generic approach towards estimating RSL is generally lacking. Although the ISO methods were intended to cover a wide variety of situations and conditions, it appears that the model needs further improvement (Hovde and Moser, 2004).

On the European front some of the decision-making software tools developed includes TOBUS, (Flourentzos et al., 2002) MEDIC, EPIQR (Flourentzos et al., 2000) and INVESTIMMO, 2001 being the most commonly reported in the literature (Steelcase 2005, Flourentzou et al 2000). The tools, EPIQR (for apartment buildings) and TOBUS (for office buildings) have been developed for the assessment of retrofitting needs of buildings. The use of these tools can facilitate a quick and accurate diagnosis of the condition of the existing building in terms of its major area including construction, energy performance, indoor environmental quality, and functional obsolescence. The main advantages of using these tools are the ability to evaluate various refurbishments and retrofit scenarios, and cost of induced works, in the preliminary stages of a project (Rey 2004, Chan, 2001).

In EPIQR and TOBUS, deterioration of building materials and components are described by the use of a classification system with four classes. The prediction of the period of passing into the next deterioration state is of high interest as this is directly connected to higher refurbishment costs. The prediction of qualitative deterioration states are important and correspond to key moments in the element's life where some refurbishment action has to be taken (Rey 2004, Chan, 2001).

European countries have used another software tool entitled MEDIC (noted earlier) to predict the future degradation state of building. MEDIC is intended for use with EPIQR and is based on a subdividing of the building into 50 elements. MEDIC calculates the remaining life span of a building element not as a deterministic unique value but as a probability distribution. It can help the owner of a building to decide the most judicious moment to undertake refurbishment to achieve his short and long term financial needs (Steelcase 2005, Alkhrdaji& Thomas 2002). Following the footsteps of EPIQR an TOBUS, a decision-making tool for long term efficient investment strategies in housing maintenance and refurbishment – INVESTIMMO has been developed in European countries. It has been aimed at evaluating housing maintenance and refurbishment options, which covers expectations of tenants, housing market, and quality of building upgrading and environmental impacts in addition to the factors identified in TOBUS (Chan, 2001).

From the review of literature, it was clear that these tools can be used to evaluate the general state of buildings with respect to some of the aspects of building re-life projects such as service life, functional obsolescence, energy consumption and environment impacts. However, no reported work presents a comprehensive guideline that provides clear information on condition assessment procedures and modelling the RSL of elements and components. Detailed information on some of the above methods is complied in Appendix – B1.

5.3 Identification of Issues to be considered in Optimising Floor Space

A review of published work was conducted to identify the issues, which requires to be considered in the decision making of re-life projects (Rey 2004, Lam 2004, Dascalaki, E., & Balaras 2004). Based on the review and consultation with industry following issues were identified and were included in the DELPHI questionnaires.

- Condition assessment
- Defects – Structural
- Defects – Functional
- Status of structural health
- Life of elements and components of the building
- Performance monitoring
- Security (access, IT systems, surveillance etc.,)
- Defects – Appearance
- Maintenance – Preventative
- Disaster recovery (Physical, commercial)
- Churn management
- Functional change of use
- Technological change of use

Out of these, seven issues were identified by the experts as the most relevant in the performance of existing building. These seven issues are:

- Condition assessment
- Defects – Structural
- Defects – Functional
- Status of structural health
- Life of elements and components of the building
- Performance monitoring
- Security (access, IT systems, surveillance etc.,)

Out of these, evaluation of defects – structural, defects-functional and status of structural health are required for condition assessment and determining the life of elements and components of building. Therefore this report describes the condition assessment procedures and procedures for estimating the residual service life.

5.4 Condition Assessment of Existing Building (Elements and Components)

A condition assessment may deem to be necessary due to any of the following reasons:

- Concern about the structural capacity of the element or existing building.
- Functional use
- Maintenance issues
- Failure to meet user expectations
- Non-compliance with code / safety regulations
- Safety issues
- Change of loading conditions
- Change of load transfer mechanism
- Evidence of deterioration
- To aid a decision on whether to repair or demolish and rebuild

The first step in condition assessment is to ascertain the breakdown of components and elements in a building. Then for each of the component / elements relevant performance requirements in the form of Key Performance Indicators (KPI's) can be established. Standardised rating scale applicable to all the elements and components must be adopted. This is explained for some sample elements:

<u>Typical Components and Elements in a building:</u>

A. Building Structure

B. Building Services

C. External Services

D. Site Infrastructure

E. Floor space

This can be further sub-divided as follows:

A. Building Structure

- Sub structure
  - Foundations, stumps
  - Load bearing structures (Floors and walls)
  - Basement (include car parks and other structures if applicable)

- Super structure
  - Façade
  - Columns
  - Beams

    - Slabs
    - Deck, balconies
    - Floor finishes
    - Internal wall, finishes
    - External wall, finishes (other than façade)
    - Steps, stairs and ramps
    - Roof, gutters & downpipes
    - Windows / skylights
    - Doors, windows
    - Ceilings
    - Partitions

- Fixtures and fittings
    - Sanitary fixtures
    - Internal fixtures and fittings
    - External fixtures and fittings
    - Appliances
    - Insulations

B. Building Services

- Hydraulic
    - Water supply
    - Sanitary & waste plumbing
    - Gas supply
    - Stormwater
    - Other plumbing, piping

- Mechanical
    - Heating systems
    - Cooling systems
    - Package units
    - Refrigeration plant
    - Extraction systems
    - Other ventilations
    - Lifts
    - Cranes, Hoists.

- Electrical
    - Lighting
    - Power (generation, distribution)
    - Switch boards
    - UPS
    - Special equipments
- Fire protection
- Communications
    - Telephone
    - Computer
    - Stored data
- Security
- Essential services
- Meters

C. External Services

- Storm water drainage
- Sewer drainage
- Water supply
- Gas supply
- Electrical services and switch boards
- Fire hydrants and hose reel
- Lighting protection
- Special services

D. Site Infrastructure

- Roads, footpaths and paved areas
- Vehicle access and parking
- Line marking
- Signage
- Boundary walls, fence and gates
- Outbuildings and covered areas
- Landscaping
- Earthworks
- Trees
- Playground, Childcare facilities
- BBQ
- Verandah

E. Floor Space

For discussion on floor space refer to separate headings.

It is hoped that the above generic classification is useful in the breakdown of building elements and components. Further sub classification may be necessary depending on the building under investigation. The above informations have been compiled from different sources. Consequently individual acknowledgements have been avoided.

A typical rating scale (from 2 - “excellent” to 10 - “unserviceable”) for assessing the existing condition can be adopted as shown in Figure 5.1. Key performance indicators for each element can be set out and a typical tabular column for elements and components similar to the one shown in Table 5.1 can be obtained.

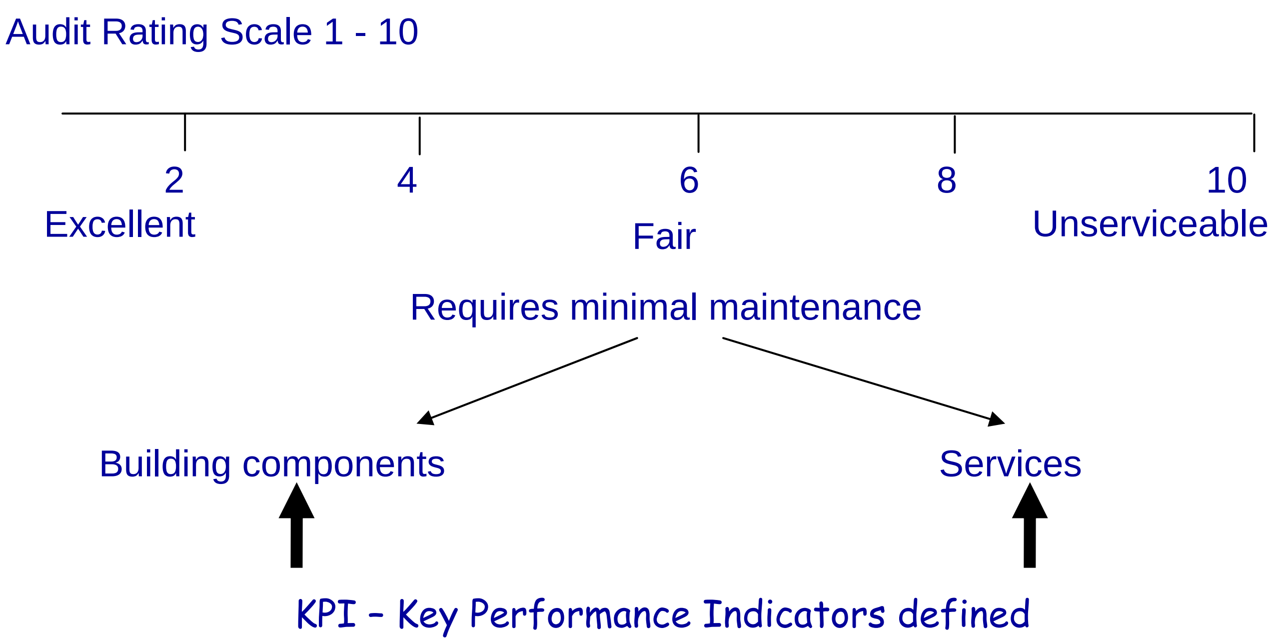


Figure 5.1: Typical rating scale for assessing the existing condition of the element.

Table 5.1: Exisiting condition of typical refurbishment elements.

System / Component	Equipment number	Equipment	Make	Model	Serial number	Level	Room	Condition	
Cubicle No.3		Hand basin No.1	Caroma	Ceramic		3		6	
		Hand basin No.2	Caroma	Ceramic		3		8	Severe damage observed
4th floor		Windows	Glass			4	Thru out	6	The window tinting is deteriorating
1st floor	HYD008F	Fire hose reel & hose	Chubb			1		4	
		Fire extinguisher	Chubb	2 Kg Co2		1	West side	4	
2nd floor		Hand drier	World	A 48	11554	2	North side	6	

The widely used approach of condition assessment is to categorise the elements into four condition states such as:

Condition A – Element in “good” condition. Element is as new, fully functional.

Condition B – Element in “fair” condition. Element is not as new, however no major signs of distress or defects, remains functional with or without minor problems.

Condition C – Element in "serious" condition. Element is not new, has major problems in the beginning to advanced stage, functional use is restricted or needs significant support.
Condition D – Element in "needs replacement" condition.

The above classification has been used in most infrastructure rating schemes In many countries. A disadvantage of the above classification is the subjectiveness of the descriptions. They do not consider the consequence of an element being rated in a particular condition. For example, a phone or a computer in a cubicle may be in "needs replacement" condition but the failure to replace will not have any dire consequence. However this classification is easily applicable to any condition assessment procedure.

A detailed procedure of condition assessment with consequence index for each element has been presented in Appendix – B2.

5.5 Life of Elements and Components in Existing Building

The predicted service life of a building can be assessed in one or more of the following ways:

(a) Assess by reference to previous experience with the same or similar construction in similar occupation or climatic circumstances.
(b) Assess by measuring the natural rate of deterioration over a short period of use or exposure and estimating from the measurement when the durability limit will be reached.
(c) Assess by interpolation from accelerated tests that have been devised to shorten the response time to the action of an agent. The science of accelerated testing is complex: care should be taken not to produce different effects by changing the natural intensity of agents.

"Prediction of service life will normally apply to components and small scale assemblies. Whole buildings and large assemblies are more often one-off designs that make previous experiences of durability less relevant and because of their size it is less easy to test their performance under controlled conditions.

Whatever method is used to assess it, the predicted service life is unlikely to be a precise figure because the effect of an action in any building is not likely to be accurately predictable. More reliable predictions can be made when there is a correlation between the results of different assessments.

In cases where the prediction of service life cannot be very accurate it may nevertheless serve as a useful purpose when items are being ranked in order of durability. The interpretation of data from tests requires skill and experience and knowledge of building maintenance. It is often necessary to rely on an informed opinion for service life prediction."

The above statements provide credence to the uncertainties associated in modelling residual service life. None the less an attempt has been made here in to estimate the residual service life of a building façade based on the case study building in Melbourne.

5.5.1 Brief description of residual service life methods

5.5.1.1 ISO Factorial Method

By far the widely accepted and widely criticised RSL method is the ISO factorial method. The method is based on the formula noted in below:

$$ESL = RSL \times f_A \times f_B \times f_C \times f_D \times f_E \times f_F \times f_G \qquad \text{(Equation 6-1)}$$

Where,
ESL = Estimated Service Life
RSL = Reference Service Life (This shall be denoted as RFSL for clarity)
f_A : Quality of component
f_B : Design Level
f_C : Work execution
f_D : Indoor environment
f_E : Outdoor environment
f_F: In use conditions
f_G: Maintenance

It is expected that any one (or combination) of these factors can affect the chosen service life. Thus suitable factors can be assumed (or derived) to estimate the ESL. Hovde and Moser, (2004) have shown that the ISO methods can be used to incorporate a probability distribution for these factors and thus specify a distribution for ESL rather than deterministic estimates. Even under the conditions of rigorous analysis it has not been possible to verify the accuracy of these predictions (Hovde and Moser, 2004). Thus the shortcomings in the ISO approach have prompted other researchers to develop new methods or models. One such model developed by Flourentzou, et.al, 2000 is discussed in the next section.

5.5.1.2 MEDIC method

The MEDIC method is based on a typical classification of a given element into four degradation schemes that quantify the past and future degradation behaviour. Thus the predictions are based on the combination of a priori defined probability distribution curves. Note that developing these curves requires considerable level of expertise and judgment. The application of this method has been demonstrated in the next section.

5.5.1.3 BAMFORTH'S method

Bamforth, 2003, stated that the service life can be defined by *the time to achieve a maximum acceptable probability of the serviceability of a limit state being reached*. That is the margin against safety is no longer achievable. This method although conceptually sound, does not specify the time at which the serviceability criteria would be reached.

Thus all the methods described thus far, seem to have significant shortcomings despite their scientific basis. The application of these methodologies to case study buildings is discussed in the next section.

5.5.2 Application of residual service life methods to case study building

5.5.2.1 Description of case study building

The case study building is a 40 year old office building of 7 occupied floors built over an older 4 level car park. It is believed that a majority of services within the building are at or beyond their economic life time and they have been in subsistence maintenance for quite some time. The building in its present stage is believed to be below standards in terms of acceptable indoor air quality levels, lighting, and energy consumptions besides some other issues. Consequently, the need to redevelop the building or demolishing and rebuild are presently being considered by the decision making authorities.

Structural aspects of the building in its present condition appear to be sound. However, signs of cracking, efflorescence, water stains, corrosion of reinforcement, spalling in concrete and minor deflections in slabs are noticeable. The facades have exhibited pronounced problems over the years and subsequent maintenenace actions has been undertaken. The façade of the building has been constructed from precast panels with a washed sand finish. The windows are inset into the precast as picture windows approximately 2 m high The authors collected the inspection reports, mainteneance reports, drawings and all relevant data on the condition monitoring of facades that dates back to late 1980's. Photo 5.1 presents typical elevations of the building.

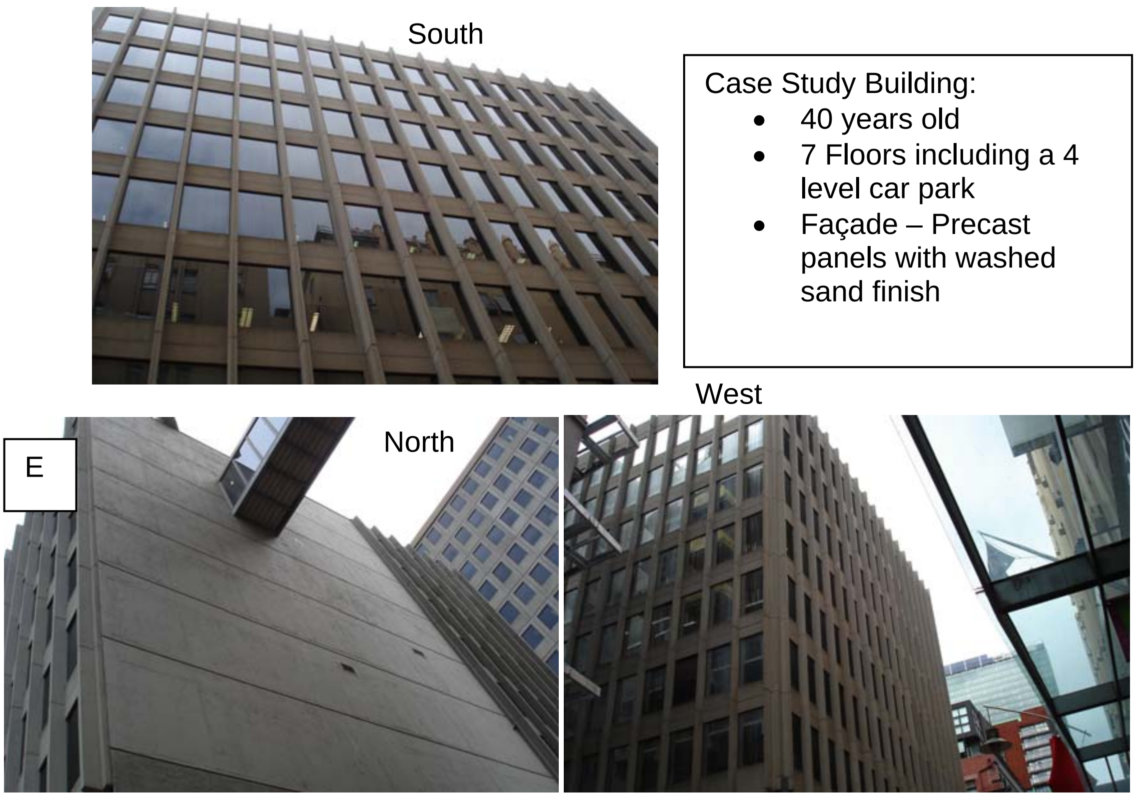


Photo 5.1. Typical elevation of case study building and facades

5.5.2.2 Residual service life of case study building façade and north walls using iso factorial method

5.5.2.2.1Estimation of reference service life

Referring to the formula recommended in the ISO method, it is clear that the “Reference Service Life” (RFSL) forms one of the key inputs in estimating the RSL. The valuable informations collected were processed to identify a reference service life for building façade and walls. The methodology was published in Venkatesan et al., 2006 and is presented in below for clarity.

One of the reports in the case study building describes the major defects observed in building façade some 10 years ago. Initially visual inspections using binoculars had been undertaken, followed by close up inspections and tests using approved abseiling techniques. Electronic cover meter tests were then conducted over selected regions to determine the depth of cover to the reinforcement. Concrete samples had been extracted at different levels for laboratory examinations. Results and observations were then collated and analysed in arriving at a decision.

During the visual inspection, spalls such as the ones presented in Photo 5.2 had been observed. In several cases this disintegrated loose spall had been observed. In addition, other defects such as cracks due to concrete shrinkage, exposed reinforcements and honey combing had been observed. Test results from cover meter and carbonation tests indicated that the average depth of carbonation was greater than the average cover at various locations. The tests considered the relationship between the depth of carbonation and the thickness of cover to the reinforcement as an important indicator of durability and cause of corrosion. Additional tests such as chloride ion concentrations were also undertaken to identify the most probable cause of distress. Samples from nearby sites were also extracted and tested. It was then concluded that carbonation was the single most dominant factor that led to the development of loose spalls. The authorities considered the threat of disintegrated loose spalls at significant heights from the ground level as a public safety issue. Based on this criterion of public safety, major repairs were undertaken some 10 years ago.

From the above discussions, it can be noted that the decision of repairing facades has been based on the public safety issue. It is appropriate to state this as a limiting condition. That is the façade has reached the limiting condition of public safety. This observation is not an opinion but an analysis of what has happened in the case study building. Thus the Bamforth model for this case study façade can be developed (as shown in Figure 5.2).

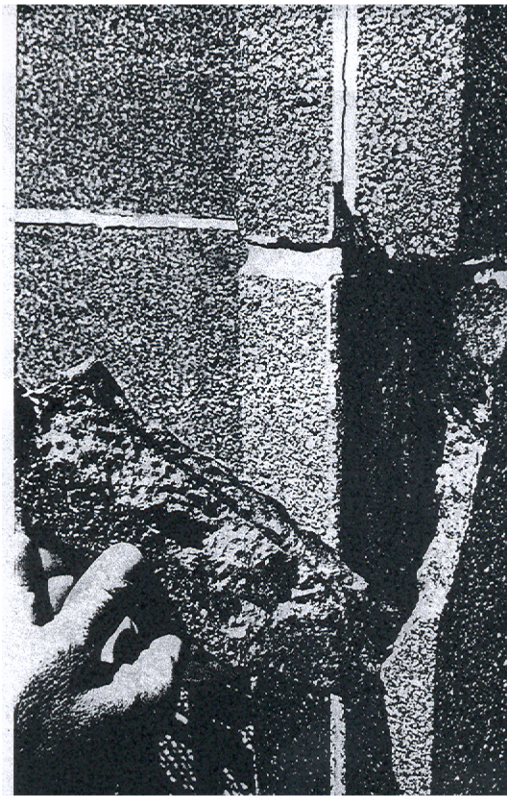


Photo 5.2: Typical loose spalls in case study building facades, year 1996.

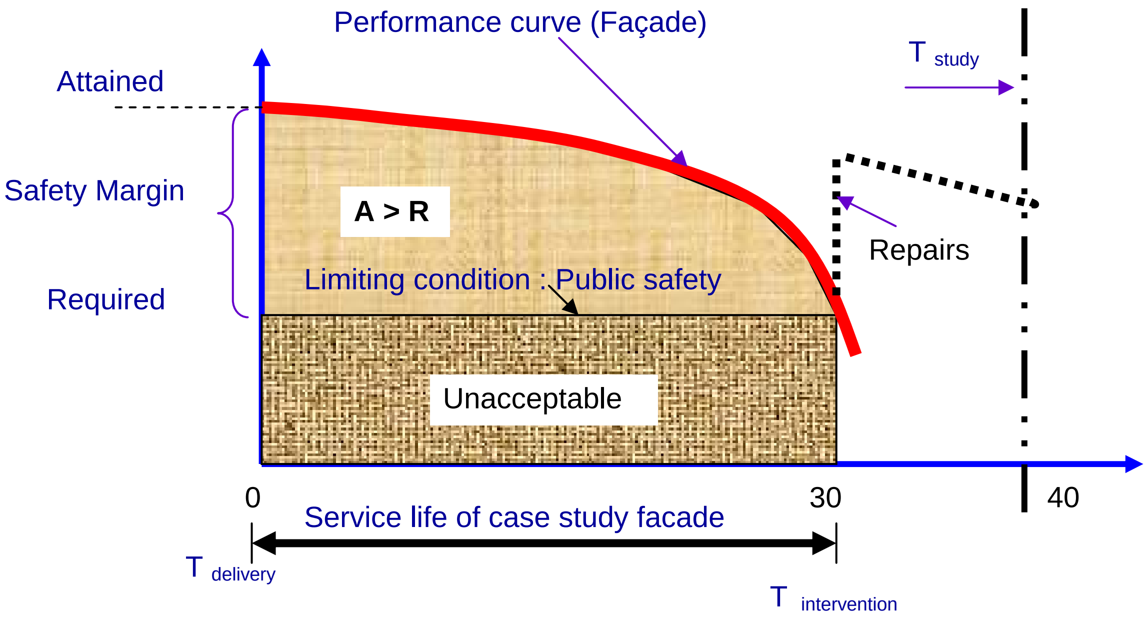


Figure 5.2: Bamforth's service life model for case study building facade

5.5.2.2.2 Preliminary estimates of RSL based on ISO factor method

Results from the previous section indicate that a reference service life of 30 years can be used as a basis for estimating the remaining service life. In particular, note that the repairs undertaken 10 years ago have improved the condition of the façade and walls, which are probably experiencing deterioration since then. This is denoted by the dotted line (Repairs) in Figure 6-2. Therefore the issue now is to investigate the time at which these elements would reach similar limit states in future. For this purpose, it is important to establish the factors that would affect the RSL of these elements. It was decided that the “Outdoor environment” (factor f_E) and “In-use conditions” (factor f_F) are the two most dominant factors that would influence the RSL. Note that the carbonation has been identified as the single most dominant factor that caused the disintegration of façade elements. The rationale behind the analysis was further subdivided for each of the wall faces and factors arrived based on discussion and consensus opinions. This is summarized in Table 6-2 below.

Factor	**Face**	**Relevant condition**	**Value**
f_A : Quality of component	All	Generally good	1
f_B : Design Level	All	Generally good	1
f_C : Work execution	All	Generally good	1
f_D : Indoor environment	All	Generally good	1
f_E : Outdoor environment	North South East West	Not at risk due to rain leaks At a higher risk due to rain leaks (more windows) Heats up in summer Cools up in winter	0.9 0.7 0.95 0.95
f_F: In use conditions	S N,E,W	Frequent use / repair Consistent	0.8 1
f_G: Maintenance	All	Consistent	1

Table 5.2: Evaluating factors for ISO method.

Thus plain application of the ISO factor method results in the following:

ESL (South) = 25 x 1 x 1 x 1 x 1 x 0.7 x 0.8 = 14 years

ESL (North) = 25 x 1 x 1 x 1 x 1 x 0.9 x 1 = 22.5 years

ESL (East) = 25 x 1 x 1 x 1 x 1 x 0.95 x 1 = 23.75 years

ESL (West) = 25 x 1 x 1 x 1 x 1 x 0.95 x 1 = 23.75 years
(Equation 6-2)

Note that a RFSL of 25 years has been used instead of 30 years. This is considered as a conservative option. Therefore, RSL based on (Equation 6-2) can be estimated as follows:

ESL (South) = 14 -10 = 4 years

ESL (North) = 22.5 – 10 = 12.5 years

ESL (East) = 23.75 – 10 = 13.75 years

ESL (West) = 23.75 – 10 = 13.75 years
(Equation 6-3)

The above results suggest that the given elements may have an estimated Residual Service Life of 4 years (on the lower side of the estimates) and 13.75 years (on the higher side of the estimates) with an average of 12.5 years.

5.5.2.2.3 Rigorous estimates of RSL based on probability distributions of factors in the ISO method

The above discussions were based on plain multiplication of some notional factors derived on judgmental basis. However, the factors influencing RSL are highly variable and therefore these factors should encompass a probability distribution as suggested by some researchers. (Hovde and Moser, 2004). Some of the factors obtained from the above reference were used in Table 5.3 to arrive at these results.

Factor	**Type of distribution**	**Face**			
		South	*North*	*East*	*West*
ERSL	Deterministic	25	25	25	25
f_A	Normal	1 /0.1	1/0.1	1/0.1	1/0.1
f_B	Deterministic	1	1	1	1
f_C	Lognormal	1.05/0.1	1.05/0.1	1.05/0.1	1.05/0.1
f_D	Lognormal	1.05/0.1	1.05/0.1	1.05/0.1	1.05/0.1
f_E	Gumbel	1.25 / 0.2	1.25 / 0.2	1.25/0.2	1.25/0.2
f_F	Lognormal	0.8/0.2	1.05/0.1	1.05/.1	1.05/.1
f_G	Normal	1.05/.1	1.05/.1	1.05/.1	1.05/.1
RSL (years)		28.9	37.8	37.8	37.8

Table 5.3: Factors for ISO method based on proababilistic distributions.

The RSL values estimated for the North, East and West side of walls appear less meaningful. Therefore the RSL value of 29 years is chosen to be representative of the existing situation. RSL estimated by the ISO factor methods need to be verified and for this purpose the RSL estimated based on the MEDIC method was chosen for comparative analysis.

5.5.2.2.4 RSL estimates of case study building façade and walls estimated based on the MEDIC method

As noted earlier, the MEDIC method requires a priori defined probability distribution curves for a given element based on experience and judgment. The Reference Service Life of 25 years adopted in the previous sections was chosen as the basis of defining the four degradation schemes of the façade element. At the present stage the façade and walls are in a “Fair” condition with less signs of deterioration. This can be confirmed by revisiting Photo 6-1. Since the present time of study is about 10 years since the major repairs, the element is hypothesized into the four following schemes:

Element in “Good” condition (A): 0 -7 years;
in “Fair” condition (B) 5 – 14 years;
in “Minor deterioration” condition (C) 10 – 22 years and
in “Needs replacement or serious deterioration” condition (D) somewhere between 15 – 25 years.

Note that there is a significant overlap of these conditions which is of practical significance. Building elements may not be characterized by exact transition from condition to another; rather the transition happens over time. The probability “space” of a given element is another significant point. For this purpose, the probability space was divided into two zones 1 & 2; 1 indicating favourable conditions of the element sustaining the estimated life and 2 indicating unfavourable conditions for sustenance of the element. Zone 1 seems appropriate since the asset is well maintained and monitored by the authorities. These results are presented in Figure 6-3.

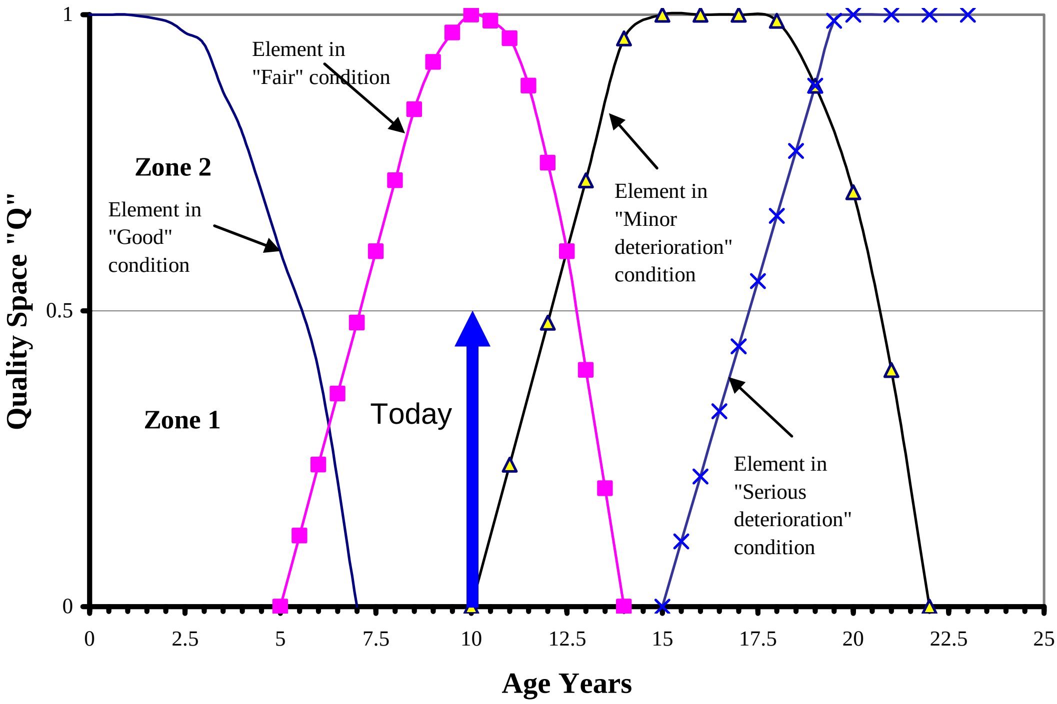


Figure 5.3: Typical conditional probablity curves for building façade based on a reference service life of 25 years

Following the deterioration curves defined in Figure 5.3 with the arrow representing the present time of study, it is possible to trace the future degradation stages of the elements. This is presented in Figure 5.4. The RSL in this case is defined as the time at which the elements reach condition state “D” (i.e., major deterioration or needs replacement).

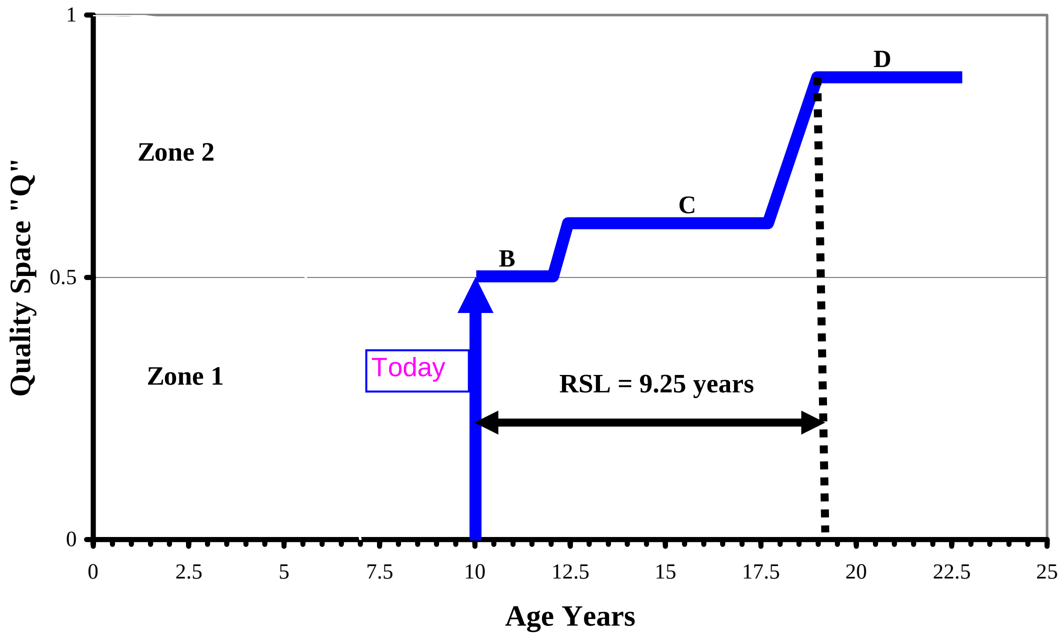


Figure 5.4: Future degradation pattern of the case study building façade and Residual Service Life estimation based on the MEDIC method

The above result shows that the Residual Service Life of the case study façade is 9.25 years. The RSL values estimated using the above methods has been verified with the experts, which is presented in the next section.

5.5.2.3 Comparison of residual service life estimates with expert opinions

Key results from the previous section can be summarised as follows:

RSL estimated by the ISO factor method using less rigorous techniques resulted in:

- 4 years on the lower side of the estimate
- 13.75 years on the higher side of the estimate
- 12.5 years on an average

RSL estimated by the ISO factor method using rigorous techniques resulted in:

- 19 years as the best possible estimate

RSL estimated by the MEDIC method resulted in:

- 9.25 years as the best possible estimate

Thus the above results can still be condensed into the following results of RSL estimated for the case study façade and wall elements:

- 5 years on the lower side of the estimate
- 20 years on the higher side of the estimate
- 10 to 15 years on an average

The above estimates of RSL were evaluated against expert opinions. For this purpose, persons who have worked in the case study building and involved in the maintenance regime were invited to provide their opinion on the case study facade. These experts on a collective basis believe that the façade and walls would require major repairs between 10 – 15 years. Thus the methodology adopted in estimating the RSL suggests that the models are capable of providing meaningful estimates which can then be compared with expert opinions to arrive at rationale decisions of refurbishing given elements.

5.5.3 Limitations of existing approaches and suggestions for a new methodology

Not withstanding the favourable comparisons described above, the state-of-the-art methods have the following limitation:

- Data required in the application of the models are not readily available.
- Significant assumptions are involved in the application.
- Interpretation of the procedures and results is subjective.
- Clear definition of RSL is lacking.
- Condition rating scales used for assessing the existing condition are not necessarily used for estimating RSL

Therefore the authors suggest the following procedure for estimating RSL as a generic approach.

- Adopt the condition assessment procedures specified earlier.
- Define a rating scale, KPI's for elements and analyse the present state of the elements according to the scale.
- Adopt discrete RSL intervals (i.e., 5 years or 7 year life spans). This can be used to determine whether the element in consideration would reach the given life span (and not the whole of life).
- Analyse the factors that would influence the RSL for the given element and span. Delphi studies, expert opinions or sample audit or detailed diagnostic investigations can be undertaken.
- Determine the expected scale of the element at the end of the life span.
- Determine the residuals of the scale differences.
- The element has the maximum chance of sustaining the life span provided the following equation is satisfied:
- $$\sum_{n=0}^{n} \mathrm{Re}\, siduals of \; \exp ected scale at end of life span - present scale = 0$$

  (Equation 6-4)

- However, the above equation may not always be satisfied. Therefore, categorise the residuals and relate it to the confidence of the estimate. (i.e residuals with 0.5 scale difference can be estimated as reaching a 90% chance of the given life span).

- Once it is ascertained that the element can reach the considered life span then further spans can be assessed in a similar manner until the residuals vary by a 3-4 scale difference.

5.6 Guidelines for Performance Monitoring and Security in Existing Building

Following risk checklist may be useful in monitoring the performance of refurbishment projects in the conception stage. This checklist is a sample only. Appropriate checklist should be prepared for the project under consideration. Similarly the “Project safety and Environmental management plan” Form IS-305 by ISIS (ABN 70 003 861 765) may be used during the refurbishment projects. There are number of checklists proposed by various organisations in maintaining the “security” issues and this can be acquired from web browsing.

CS Asia Pacific Project Risk Assessment Checklist

PROJECT TITLE:

______________________________DATE________

PROJECT OVERVIEW	DETAILS
CS STANDARDS COMPLIANCE	
Detail the EHS Standards / Procedures applicable to this project.	
Detail the Quality, Food Safety, GMP Standards/Procedures applicable to this project.	
Detail the Loss Prevention Standards applicable to this project.	
Comment on the Completed Project Risk Rating (specifically any problem areas)	
PURCHASING EQUIPMENT AND MATERIALS	
Have Environmental, Health & Safety and Food Safety Purchasing Considerations been followed? *(link)*	
ENVIRONMENTAL ASPECTS	
HAZARDOUS MATERIALS MANAGEMENT	
Detail the impact of this project on the level of hazardous materials (eg. flammables, asbestos, corrosives, essences)?	None /
What is the impact on the current handling and storage facilities and changes will be required?	
WASTE WATER MANAGEMENT	
Does the project increase or adversely change the effluent load?	No / Yes

PROJECT OVERVIEW	DETAILS
Is the effluent treatment plant adequate for the projected changes and will modifications be required? (Peak flow, pH..)	
Detail opportunities evaluated to prevent or reduce effluent	
Detail opportunities evaluated to prevent or reduce the use of water?	
SOLID AND HAZARDOUS WASTE CONTROL	
Does the project increase the quantity or the risk of solid or hazardous waste?	No / Yes
Detail the changes that impact on the level of solid or hazardous waste generated by the site. *(list)*	
Are the current facilities adequate or will changes be required for the storage of waste?	
Detail opportunities evaluated to reduce waste? (Refer Resource Protection Standard R2)	
SOIL AND GROUNDWATER POLLUTION	
Detail evaluation made of potential soil and groundwater contamination (for example, from spillage of materials)?	
EXTERNAL AND INTERNAL NOISE CONTROL	
Detail the impact of the project on internal noise levels and noise conservation initiatives incorporated?	
Detail the impact of the project on external noise levels and noise conservation initiatives incorporated?	
DISCHARGES TO ATMOSPHERE	
Detail the impact of the project on the level of air emissions (e.g. SO_2, CO_2, CO, NO, particulates, fumes)?	

RESOURCE PROTECTION STANDARDS	DETAILS
RESOURCE DEMAND AND CONSERVATION	
Detail the impact on current site energy usage resulting from this project.	
Detail energy conservation initiatives incorporated in this project (use relevant standards)	
Detail the impact on current site water usage resulting from this project	
Detail water conservation initiatives incorporated in this project	
Detail the impact on packaging usage resulting from this project	
Detail packaging conservation initiatives incorporated in this project	
FIRE PROTECTION	
Explain any impact on the fire risk?	None/
Is the current site fire suppression system adequate or what changes are required.	
What impact will this project have on the site emergency procedures?	
HEALTH AND SAFETY	
TRAINING	
Outline training aspects and any significant issues to be provided to CS Employees.	
Describe training aspects to be provided to contractors. (e.g. Food Safety, Permits to Work)	
SAFETY BEHAVIOURAL ASPECTS	
Comment on the safety issues considered in equipment selection and layout considerations	
Comment on any management issues considered with the implementation and ongoing operation of the project and its associated impacts on other equipment	
Comment on the manual handling and ergonomic issues considered in or resulting from the project	
QUALITY / FOOD SAFETY	
Comment if a HACCP plan is required to be developed or updated and/or a food safety risk assessment is to be conducted.	
Detail the monitoring equipment and procedures to be installed	
Describe the impact on quality and related issues affecting consumers	
Detail considerations to be taken to ease the cleaning of equipment, (e.g. allergen control, access, hose connections, chemical requirements)	

RESOURCE PROTECTION STANDARDS	DETAILS
BUSINESS CONTINUITY PLANNING	
Describe any impact on the Business Continuity Plans.	
CORPORATE SOCIAL RESPONSIBILITY	
Detail the reviews completed for any equipment sourced from specific “at risk” countries *(List)*	
LEGAL	
Detail legal issues notified to the General Counsel?	
Detail the impact on current licence/permits (eg. EPA Licence, Trade Waste Agreement, Dangerous Goods Regulations, Pressure Vessels)	
PROJECT ACCOUNTABLILTY	
Name of staff member to whom environmental responsibility has been designated?	
Name of staff member to whom health & safety responsibilities has been designated?	
Name of staff member accountable for notifying authorities of impairment to fire services (i.e. Fire, Insurance, Group Risk etc)?	
Name of Operations staff member responsible for participating in the implementation of the project ?	
Name of staff member responsible for the site induction and training of project specific contractors?	
Name of staff member responsible for the development or updating of the Food Safety Plan?	
OTHER	
Detail any other Environmental, Health, Safety, Quality, Food Safety, GMP, CSR, BCP and Loss Prevention or related issues	

PROJECT SIGN OFF

PERSON RESPONSIBLE	SIGNATURE	DATE	SITE RESPONSIBILITY	SIGNATURE	DATE
Project Manager			Health & Safety Manager		
Area Manager			Environment Manager		
Site / Operations Manager					
Qua;lity Manager			Divisional EH&S Manager		

5.7 References

Alkhrdaji, T. & Thomas, J., “Upgrading Parking Structures: Techniques and Design Considerations”,Available online, http://www.structural.net/News/Media_coverage/media_csi.html , (download: February 2005).

Bamforth, P., (2003) “Probabalistic approach for predictiong life cycle costs and performance of buildings and civil infrastructures”. *Proceedings of the 2nd International Symposium on Integrated Life-time Engineering of Buildings and Infrastructures*, Kuopio, Finland, pp.553-558

Chan, A. P. et al., 2001. “Application of Delphi method in selection of procurement systems for construction projects”, Construction Management and Economics, 19, pp:699-718.

CIB – Council for Research and Innovation in Building and Construction (1999): Agenda 1 for Sustainable Construction, CIB Report Publication 23, Rotterdam, The Netherlands.

Dascalaki, E., & Balaras, C. A., 2004. “XENIOS-a methodology for assessing refurbishment scenarios and potential of application of RES and RUE in hotels”, Energy and Buildings, 36, pp:1091-1105.

Flourentzou, F., Brandt, E., Wetzel, C. (2000), “MEDIC-a method for predicting residual service life and refurbishment investment budgets” *Journal of Energy and buildings*, 31, pp.167-170

Flourentzos, F., Droutsa, K., and Wittchen, K.B., (2000). “EPIQR software”, Energy and Buildings, Vol.31, pp. 129-136.

Flourentzos, F., Genre, J.L., and Roulet, C.A., (2002). “TOBUS software – an interactive decision aid tool for building retrofit studies”, Energy and Buildings, Vol.34, pp. 193-202.

Hovde, P.J., (1998). “Evaluation of the factor method to estimate the service life of building components”, Materials and technologies for sustainable construction, CIB world building congress, 1998, Gavle, Sweden, 7-12 June.

Hovde, P.J., and Moser, K., (2004). “Performance based methods for service life prediction” State of the art reports, CIB Report: Publication 294, ISBN: 90-6363-040-9,CIB, NTNU and EMPA, 2004.

Investimmo, (2001), “A decision-making tool for long-term efficient investment strategies in housing maintenance and refurbishment”, Newsletter No.1, September 2001.

ISO 15686 Part 1, (2000). “Building and constructed assets – Service Life Planning – Part -1: General principles”. International Organisation for Standardisation, Geneve, Switzerland.

ISO 15686 Part 2, (2001). “Building and construction assets – Service Life Planning – Part -2: Service Life prediction procedures”. International Organisation for Standardisation, Geneve, Switzerland.

Lam, K. P. et al, 2004. “ SEMPER- II: an internet-based multi-domain building performance simulation environment for early design support, Automation in Construction, 13, pp: 651-663.

Rey, E., (2004). “Office building retrofitting strategies: multi criteria approach of an architectural and technical issue”, Energy and Buildings, Vol 36, pp. 367-372.

Steelcase, Workplace Issues: One in a Series. “Reclaiming Buildings – Strategies”, Available online http://www.steelcase.com/Files/de9c9b911ac84b3bbdc25f352373316a.pdf (download: February 2005)

Venkatesan, S., Kumar, A. and Setunge, S. (2006). “Assessment and integration of Residual Service Life models”, in the Proc. of the Recent Advancements in

Engineering Mechanics (RAEM) conference, pp. 45-52, California State University, Fullerton, USA, Jan. 14-17, 2006.

6.0 RECYCLING AND WASTE MANAGEMENT

6.1 Introduction

As office buildings usually require a major refurbishment every 20 to 25 years, it can be expected that commercial refurbishment activity is likely to be a significant portion of overall construction activity for the foreseeable future and therefore a significant generator of waste. It was estimated by one of the waste management experts interviewed for this study that a 1000 square metre office refurbishment is likely to generate an average of 130 cubic metres of waste. Recycling and waste minimisation strategies for commercial refurbishment projects have the potential to contribute to significant benefits to the environment and to a more efficient delivery of commercial office space. Rising waste levies are currently providing an incentive to divert waste from landfill particularly in the more highly populated states. The NSW state government, in particular, appears to be using the price mechanism to drive increased reuse and recycling. This is despite evidence from the UK that Landfill Tax levies on waste sent to landfill have been largely ineffective in driving changes in waste management behaviour in construction (Martin and Scott, 2003). At the same time as the price of landfill is increasing, there has been a growth in the use of the various green rating schemes for commercial buildings. Increasingly companies are seeking to be listed on sustainable and ethical indexes and there is a consequent desire for 'green buildings'. This trend is also evidenced in the current federal Productivity Commission's Public Inquiry into Waste Generation and Resource Efficiency (Australian Government Productivity Commission 2006). While the inquiry is not specific to the construction industry a number of submissions have been made to the Inquiry from the construction sector reflecting the fact that the construction and demolition industry accounts for 42% of solid waste generation in Australia (Productivity Commission Draft Report, 2006 pg17). The issue of recycling and waste minimisation is therefore likely to become increasingly important to construction project managers due to the positive impact it can have on project costs as well as on company and industry image.

Despite current efforts, a significant proportion of the theoretically recoverable resources in refurbishment projects still ends up in landfill. There remains, therefore, considerable scope for waste minimisation in construction to make a significant contribution to reducing greenhouse gas emissions and enhancing the sustainability of the built environment. It is acknowledged that waste minimisation is more than just quantifying and sorting of waste, it involves promoting favourable attitudes and encouraging ownership of the process at all levels of the construction process (Lingard *et al.* 2001; Lingard *et al*. 2000). During the implementation process in particular, documented waste management plans have been widely shown to be both an incentive and a guide to waste management practice on building sites. Unfortunately however, it has been reported from several sectors of the industry that there is often no verification of these plans and little monitoring of the rates that are actually achieved. If overall industry performance is to be improved, then the question of responsibility for recycling and reuse rates has to be addressed. Industry will respond if it is required to raise rates, but it is unlikely to take the initiative while it remains unconvinced of the financial benefits. The publication of benchmark rates for reuse and recycling will make it easier to identify under-performance and to indicate those areas where regulators and environmental agencies should focus their attention.

Many of the priority actions for waste minimisation relate to environmental goals rather than to strictly commercial priorities. Nevertheless, it has been demonstrated that a marketable commercial advantage is available to contractors achieving best practice. An analysis of the options in relation to waste management at the outset of the project (including during the Design Stage) is fundamental for project planners to allow for methodologies required for waste minimisation. This should include a comparison of costs of no recycling with recycling options. It is possible to identify some strategies that are likely to produce a positive return, some that will probably be cost neutral and some that may result in future benefits but involve an initial cost. It is important to acknowledge the full cost of waste, both upstream and downstream of the project itself. In this regard it is helpful to engage as many stakeholders as possible in the refurbishment project. The building owner, for example, may see longer term financial benefits of designing for disassembly compared to structural changes. Similarly, commercial tenants may benefit from a modular design if, at the expiry of the lease, they are required to return the space as it was. General consciousness raising on the issues of recycling and waste management is likely to have considerable benefits both for the environment and for contractors.

6.2 Literature Review and Research Methodology

A literature review relating to the analysis of the options for minimising waste was carried out by researchers at the University of Western Sydney. Spreadsheets of relevant references to commercial building refurbishments were created for both the Australian and international context. This has been reviewed throughout the project and kept updated in a bibliographical database form. The literature review reveals a large range of approaches to waste management in the commercial construction sector internationally.

Peng et al. (1997) found that it will be necessary to put some effort into developing a secondary materials market in order to make construction recycling a self-perpetuating system. A high recovery rate and a high rate of throughput are necessary to make the operation profitable. Webster and Napier (2003) have reported on a deconstruction and salvage operation by the US Army of their excess buildings. The results have proved to be both economically viable as well as environmentally friendly. Of course, the labour resources available to the military are quite different from those of commercial sector. A recent study in Hong Kong (Wong and Yip 2004) has found that resistance still remains to the sorting and recycling of construction waste as it is not perceived to be cost effective. The diversity of outcomes from these reports indicates that the quality of the implementation process for waste minimisation is frequently crucial to a program's success. A systematic approach which is at the same time aware of the social and environmental aspects of the construction waste problem seems likely to be the most appropriate path to take. The authors suggest training programs are necessary to foster environmental awareness among construction workers and managers.

A number of administrative tools developed by industry groups or government bodies are in various stages of development with a range of degrees of success. SMARTwaste is a software tool developed in the UK to audit, reduce and target waste arisings on a construction site (McGrath 2001). The program involves an independent observer on site fulltime reporting observations to an environmental manager a few days a week. The environmental manager provides feedback to the construction manager, produces plans and makes recommendations. Because construction waste is generated a little at a time, the fulltime monitoring of the process is considered necessary to manage waste reduction. In addition, pre-demolition audits using SMARTwaste greatly aids the success of refurbishment projects (Hurley et al. 2002). SMARTWaste does not, however, address the issue of what becomes of the segregated waste, and does not distinguish between reuse and recycling. This presents a particular problem when dealing with refurbishment projects. An example of the way that this system differs from an ultimate destination approach can be illustrated by the manner that asbestos fibre waste removal from a refurbished building is recorded. Under SMARTWaste this would be considered 100% segregated but from a life cycle point of view it would have to be 0% reused or recycled. The SMARTWaste software is designed specifically for refurbishment projects therefore the distinction is not important for their purposes. For the purposes of the 'Relife' project a clear distinction needs to be made and the ultimate destination of the waste is an important issue.

Another concept which has achieved some success in the UK is that of Material Recovery Notes (MRN). These notes represent an attempt to extend the earlier recycling industry idea of attaching Packaging Recovery Notes to reclaimed materials. MRNs encourage closed loop management of materials rather than 'one life accounting' (Hurley and Hobbs, 2003). As such they emphasise the need for manufacturers to have a salvage and recovery system in place for all items which they introduce to the market. By placing the responsibility for the whole life cycle of a product on the product's producer MRNs encourage an eco-system approach to the built fabric of a city as envisaged by the proponents of construction ecology (Kibert 2000).

While considerable advances have been made in recent years there are still several common building materials for which there are very few end of life options available in Australia. A striking example is painted plasterboard from renovations and demolitions. In Europe and North America this material issue is receiving much attention (Malin 2006) but in Australia the only current option for used plasterboard is pulverising for use as gypsum in landscaping works but even this is not a widely used practice.

In the United States the emphasis is generally on encouraging the widespread use of products with recycled content and thereby creating a market which gives economic value to waste products and in turn encourages recycling. The California Integrated Waste Management Board website provides extensive lists of building product suppliers with the percentage of Post-consumer Content (PC) and Total Recycled Content (TRC). The TRC includes the PC, plus recycled material from within the manufacturing process itself - in other words, process efficiency gains. The PC percentage is an indirect measure of how much material has been diverted from landfill. It is not specified whether the percentages listed are by weight or by volume and the breadth of materials and components listed suggests that this is likely to be dependent on the particular case (California Integrated Waste Management Board 2005). Both the auditing of the waste stream and the preferential treatment for recycled content can improve waste management in construction refurbishment. However a combination of the two strategies is likely to be more effective than either strategy employed in isolation.

The literature review led to the identification of a number of recycling and waste management issues that could be presented to the Delphi Study experts for their consideration. These are discussed in the next section. It was also considered necessary to seek input from experts who were specifically identified as being involved in waste management in construction refurbishment projects. This process was undertaken separately from the Delphi process although there was some overlap in the experts consulted and both qualitative information on the process of waste minimisation in construction refurbishment as well as quantitative rates for different materials and components were collected.

Twenty one expert individuals associated with the commercial refurbishment sector of the construction industry in Australia were interviewed. The experts were based in NSW, Victoria, Queensland and the ACT. Most had interstate experience and one had national responsibility for waste management issues in a large construction/property corporation. Most of the experts had more than ten years experience in the construction industry with fifty percent having more than twenty years experience. Those with fewer than ten years experience tended to be in positions such as site manager where they had day to day contact with waste minimisation issues. The expert group included seven consultants from the professions including quantity surveying, architecture, engineering and environmental consultancy and fourteen practitioners whose positions ranged from senior project managers to site managers to environment and OH&S managers for large and medium construction companies. One third of the respondents had worked on more than twenty multi-storey commercial building refurbishments. In addition to the twenty one construction industry interviews, three expert waste contractors were surveyed specifically about their knowledge of waste from commercial construction and demolition. Sample charts of the rates results are presented below[1].

---

[1] Further information on rates of reuse and recycling is available from CRC CI Project 2003-028-B Regenerating Construction

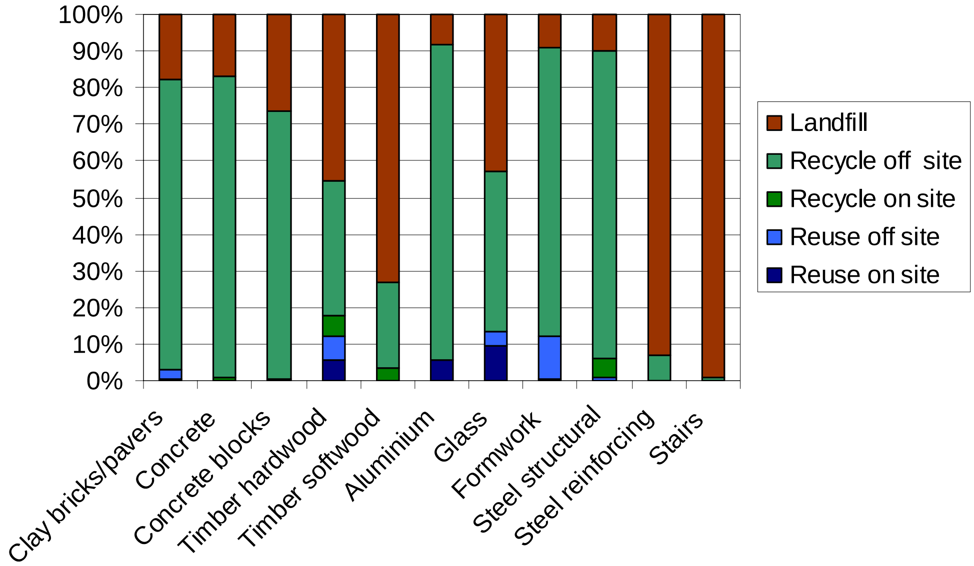


Fig. 6.1: Destination of building fabric components in commercial refurbishment projects

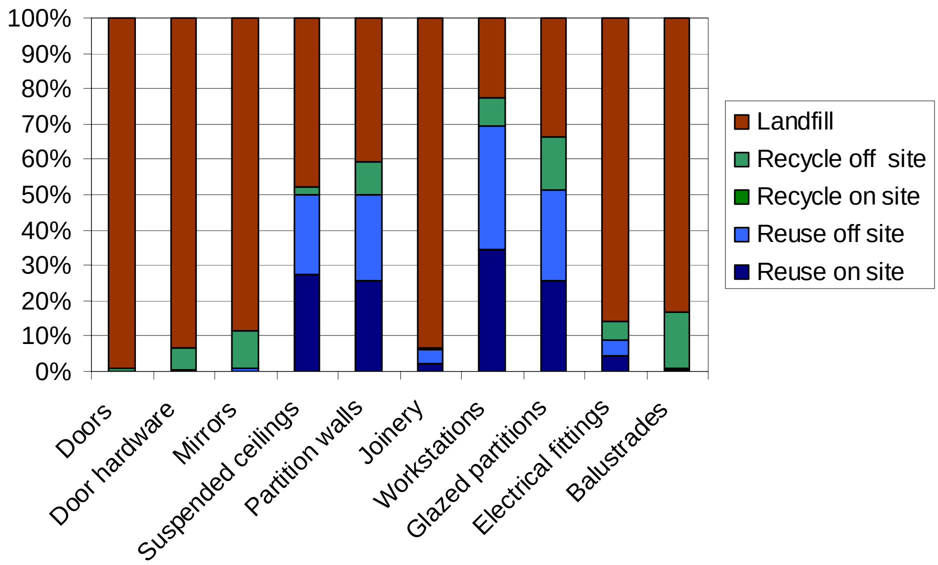


Fig. 6.2: Destination of fittings components in commercial refurbishment projects

6.3 Identification of Issues

The issues identified from the literature review as being significant in commercial refurbishment projects are:

- Recycling and recovery potential of waste
- Time taken for recycling
- Waste transportation costs
- Disposal of hazardous waste
- Negative public attitudes to recycled products
- Negative public attitudes to reused components

Three of these issues were removed from consideration as a result of the Delphi study. The Delphi experts did not rate the time taken for recycling or the last two issues about public attitudes as being significant. Hazardous waste was given the highest priority of the recycling and waste management issues and this was followed in order by waste transport costs and recycling potential of waste. The issue of incorporating the effects of Ecologically Sustainable Development was added to the list by the experts. The four issues considered significant will be discussed in detail in the following sections.

6.4 Hazardous Substances

Hazardous wastes in construction refurbishment are taken to include such things as asbestos fibres, PCBs, heavy metals, biological contaminants and some paints. The deleterious effect of the discovery of hazardous waste on a project site has been reported on in the literature review undertaken for this research (Cole 2000; Ihlanfeldt and Taylor 2004; Sterner 2001).

Asbestos was singled out as a major impediment to recycling in office refurbishments, both from the literature review and in the case study projects. In a case study of a major 1970s office building refurbishment undertaken at the University of Western Sydney it was found that the presence of asbestos associated with the air conditioning system totally constrained the renovation process. In fact, there was a tendency to ascribe all waste from the building works as possibly contaminated with asbestos so that even items such as metal ceiling hangers were included in asbestos contaminated waste. As a consequence virtually no recycling was allowed. One of the expert waste contractors interviewed by the research team confirmed that the merest trace of asbestos in a building can be enough to prevent a recycling effort. Best practice would seem to mandate that asbestos material should be removed by a licensed contractor with full protective gear before the general refurbishment activity commences. Otherwise potential recyclable materials are likely to be lost due to scheduling pressures. For this reason an initial hazardous waste survey needs to be incorporated in the feasibility stage of an office refurbishment project. Cost and scheduling for hazardous material removal also needs to be considered at this very early project stage. During the project design phase any possible hazardous material content should be recorded and flagged to all consultants, potential contractors and subcontractors. In the procurement phase contractors who use demolition techniques suitable for containing hazardous wastes should be sought out.

Only currently licensed and experienced contractors should be permitted to deal with hazardous wastes and comprehensive records should be kept of the eventual destinations of all material removed from the refurbishment site. Responsibility for the overseeing of the waste removal process should be clearly delineated before construction commences and a site coordinator appointed. A Risk Assessment needs to undertaken should hazardous materials be detected during the construction phase and on site practices revised to minimise contamination. Potentially hazardous materials should be kept in secure bunded areas. Unavoidable waste must be disposed of in a safe and timely manner. As an example the site manager should ensure that bagged hazardous materials are removed from the site before the bag is damaged due to surrounding construction activity.

Any refurbishment project should have a hazard response procedure in the event of accidents and spills. Suitable Spill Response Kits should be on site at all times. Staff trained in the use of the kits should be present on site for all site working hours. Specific hazards such as petroleum products or their associated containers should go to appropriate recovery centres and should not be sent to landfill.

Safety standards should not be compromised for any operational reason but the process needs to be understood so that the presence of hazardous waste is handled in a manner that still permits reuse and recycling of the inert and non-hazardous wastes from the building refurbishment. As a matter of good practice, no waste should leave the site without full details of content, weight or volume and destination being recorded in the Waste Information System. This practice aids in good housekeeping on site but also enables the setting up of a data base of waste practices for future projects.

Figure 6.3: Early scheduled removal of asbestos should enable recycling and reuse in subsequent refurbishments

6.5 Ecologically Sustainable Development

There is a growing trend for commercial office building owners, managers and tenants to seek 'green ratings' of various kinds for their buildings. This is partly due to the need to minimise ongoing costs of energy and water use. It also stems from a desire to be seen as a good corporate citizen who operates as a good steward of the environmental resources at their disposal. Environmental issues were singled out as important construction management drivers from the review of the literature on the subject (Cole 2000; Nystrom and Kehr 2000; Perry 2003; Poon *et al*. 2004). Their significance for recycling and waste management was identified by the Delphi Process experts.

The impact of business desire to be seen as environmentally friendly is likely to be a driver of a more comprehensive approach to the choices made during construction refurbishments. Increasingly green ratings are likely to include waste and recycling among their indices for building assessment. In turn this will make the collection of data and the comparative assessment of different options more feasible for building designers and constructors.

There are several schemes for environmental rating of buildings currently in use. NABERS (National Australian Built Environment Rating System) is a voluntary performance based rating system that can be used for the existing building stock. NABERS rates a building on the basis of its measured operational impacts which include energy, refrigerants (greenhouse and ozone depletion potential), water, stormwater runoff and pollution, sewage, landscape diversity, transport, indoor air quality, occupant satisfaction, waste and toxic materials. As it does not look at the building or renovation process it does not assess recycled content or construction waste minimisation. The Australian Building Greenhouse Rating Scheme (ABGR) provides market recognition and a competitive advantage for low greenhouse emitters and energy efficient buildings. The scheme encourages best practice in the design, operation and maintenance of commercial buildings to minimise greenhouse emissions. Administered nationally by the NSW Department of Energy, Utilities and Sustainability (DEUS) and locally by leading state greenhouse agencies, the ABGR scheme rates buildings from one to five stars with five stars representing exceptional greenhouse performance. Current market best practice in Australia is three stars. As ABGR applies to both existing and new buildings it is particularly useful for modelling the effect of a refurbishment project. The use of recycled materials and waste minimisation practices are not, however, specifically addressed. The Green Building Council of Australia's Green Star rating has eight environmental impact categories: management; indoor environment quality; energy; water; materials; land use and ecology; transport; and emissions. There is some allowance for the inclusion of recycled and recyclable materials. The LCADesign (Life Cycle Assessment) tool is currently being upgraded to include recycled content as a component layer in its decision making tool for designers. It is likely that this element of recycled and recyclable content in buildings will increasingly be included in green rating tools as more data becomes available about the potential energy and emission savings for building material recycling.

For current office refurbishment projects, information from the literature review as well as the expert consultations, indicates that careful auditing of the condition of the existing building during the feasibility phase of the project may make it possible to repair rather than remove components. For example existing ceiling tiles may only need to be painted rather than replaced depending on their condition.

Preconstruction phases

During the design phase of the project it is important to consider the merits of flexibility, prefabrication and deconstruction. Flexibility should be designed in to the interior fitout so that fewer operational refurbishments are needed. Prefabricated components should be used where possible as they save on both materials and work hours. All construction work should be designed to allow for future deconstruction at the end of its useful life. This means that high embodied energy materials may be used as they will pay back their environmental costs over many years and several life cycles. During the design phase it is also necessary to plan ahead for operational phase of the building's life. Waste management systems that will operate once the building is refurbished should be a design consideration. The designers should also consider the requirements of any green rating system to be applied to the refurbished building and maximise the rating that can be achieved.

During the procurement phase waste minimisation principles dictate that the project manager should endeavour to choose longer lasting products over those which quickly deteriorate. Where possible the project planners should specify a recycled content percentage in the new materials used, or they should specify materials that are recyclable at the end of their current period of use. Supplier claims on these matters should be independently verified. If site space or access is likely to preclude onsite sorting once construction commences, the project should commit to an offsite waste facility with sorting and verifiable reporting capabilities. Facilities in close location to the worksite are preferable.

Construction phase

Before the construction phase has begun training and management of onsite staff should be allowed for. Onsite induction and training in waste minimisation for all workers is an important component of this. As construction progresses, monthly reports should be compiled of total volume of waste removed from site, the percentage that is recycled and any initiatives or savings achieved. Documentation should be updated throughout the project and accurate drawings and specifications should be kept for future reference purposes. The ordering of materials in suppliers' preferred quantities is to be encouraged while overestimation to cover all contingencies is to be strongly discouraged. Once construction has commenced, all parties should seek to limit design variations to a minimum in order to avoid the need for rework and consequent waste.

6.6 Waste Transport Costs

As many construction waste materials are both heavy and bulky, the cost of ransporting them to their ultimate destination must be considered as part of the hidden costs of a refurbishment project. Systems are being developed which use Global Positioning Technology to monitor the bulk movement of construction inputs and outflows and this may ultimately lead to the actual transport costs involved in building being monitored on a detailed level rather than passed on to subcontractors (Li *et al*. 2005). In addition, studies are currently formulating the affordability of processes such as construction aggregate recycling according to the amount of construction activity that registers on satellite monitoring within a transportable region (Robinson and Kapo 2004). The essential issue for current refurbishment projects is a realisation that transport costs are a significant component of waste management. This should lead to a preference for local waste management facilities and a minimising of the number of trips taken to transport waste.

Several key points on waste transportation costs have been derived from both the available literature and the expert consultations that were undertaken.

Preconstruction phases

In the design phase of a refurbishment project it is good practice to list the likely waste streams stemming from the design and identify areas that can be targeted for reuse or recycling. In the procurement phase the project managers should endeavour to select credible waste contractors with appropriate experience, skills and licences. If space is likely to limit sorting on site, then the project should consider the use of a full service recycling contractor across the site. Waste contractors should be consulted in project planning before construction commences. If there are local waste exchanges interested in taking particular materials, these should be given priority as much as possible. Partnering with other nearby projects for reuse of materials and components may also prove a useful strategy. In addition, project managers should choose suppliers who will take back any excess materials and packaging so that waste transport costs are not increased by the cost of transporting packaging materials. Waste minimisation targets should be included in all relevant subcontract documents and material salvage and reuse should be encouraged at all levels. These matters all come under the general heading of 'Reduction of resource use'. As well as using less material resources the transportation cost will also result in a net saving.

Construction phase

In the construction phase of a refurbishment project management should appoint a waste coordinator on site. This person should ensure the project team are aware of the need to allow for accurate record keeping with respect of waste generated, waste movement and waste destinations. Project managers should plan to reduce the distances and frequency with which waste is transported from site. Recycling options should be communicated to contractors and subcontractors in order to reduce project waste transported from the site. Internal project reuse may be an option for many components such as ceiling panels, partitions and workstations (see Fig.2). External project reuse may also be a viable option. Site managers should consider publicising the sale (or donation to community groups) of unwanted materials and components. A comprehensive record of transactions involving waste transport should be maintained for post project analysis to assist in the planning of future refurbishment projects.

Generally

Finally, the question of waste levies for construction and demolition waste should be considered when assessing the 'whole of life cost' of decisions about reuse and recycling. In some circumstances such costs are borne by waste management contractors and so are disregarded by project managers. It is possibly for this reason that the expert's interviewed for this study did not report significant variation in reuse and recycling rates between states although as Table 6.1 shows the waste levies vary considerably.

State	NSW	Victoria	Queensland	Western Australia	South Australia
Metropolitan	$30.40/tonne	$13.00/tonne	$0	$3.00/tonne [1]	$10.80/tonne
Rural	$23.10/tonne	$11.00/tonne	$0	$0	$5.40/tonne

Table 6.1 – Waste levies for construction and demolition waste by state[2]

[1]The levy applies to putrescible waste

[2]As at July 2006

Source Productivity Commission Draft Report

Waste transportation can be a largely hidden cost of construction activity. It is nevertheless an area with considerable potential to reduce environmental impact of construction and improve the performance of the industry as well as its public image. Improved monitoring of the quantities and distances travelled by waste shipments may enable better targeting of areas where real gains are most likely to be made in both economic and environmental terms.

6.7 Recycling Potential of Waste

Many studies have shown that a considerable amount of the material currently sent to landfill from construction projects is potentially recyclable (Anderson and Mills 2002; Australian Bureau of Statistics 2003; Bossink and Brouwers 1996; BRE Centre for Resource Management 2003a; Faniran and Caban 1998; Fatta et al. 2003; Formoso et al. 2002; Hobbs and Kay 2000; Klang et al. 2003; Lawson et al. 2001; McGrath 2001; Nystrom and Kehr 2000; Peng et al. 1997; Poon et al. 2004; Wong and Yip 2004). This is more than just an economic problem, however, as current poor waste management practices have been suggested as a component of the environmental problems leading to climate change (Ackerman 2000). The construction sector's high usage of extracted materials (estimated at 40% of total) needs to be modified to accord with an understanding of "the metabolic behaviour of natural systems" (Kibert et al.

2000). Waste can be seen as a resource, and the consequences of waste generation need to be part of the evaluation process for any proposed construction works.

Furthermore it has been shown that increasing the percentage of material that is successfully recycled can reduce the production of greenhouse gases generated while at the same time improving the long-term profitability of commercial refurbishments (McDonald and Smithers 1998). This potential benefit to the bottom line of construction companies in the long-term, needs to be stressed if the industry as a whole is to lift its level of performance in terms of sustainability. Construction waste minimisation aims to reduce the production of methane and other gases generated in landfill, reduce the consumption of raw material resources and reduce the energy expenditures associated with transportation of bulk waste. Particularly the last of these is likely to result in cost benefits to the individual construction company. Several authors have reported that integration of the design and construction process is crucial to successful waste management and resource recovery (Bell 1998; Schultmann and Rentz 2002; te Dorsthorst and Kowalczyk 2002). The construction industry has largely tended to omit the phase after demolition from its consideration but this is likely to change and some studies claim that it is more important for the ultimate result to design a building for recycling than to use low energy materials (Thormark 2000). Schultmann and Rentz (2002) report that emphasis on the environmental aspects of maintaining and improving the building stock is likely to increase in the next decade. Consequently any gains that can be made through the process of waste minimisation can be expected to find a ready audience within the construction industry.

The construction industry can derive considerable economies from increased recycling rates. The most obvious of these are reduced cost for tipping fees and waste transportation as well as value recovered from the sale of reusable and recyclable items. Less obvious benefits have also been identified by this research. For example, maximising value and minimising waste are essential tenets of the drive towards ‘Lean Construction’, in other words a more efficient system of delivery of construction projects (Ballard and Howell 2003). Also careful sorting and management of waste leads to a cleaner, safer workplace and therefore has occupational health and safety benefits. The practice of ‘design for deconstruction’ allows for more efficient recycling and reuse at a future refurbishment or demolition but in addition it assists the concept of “buildability” and efficient construction planning. There are also definite public relations benefits for a construction contractor who can deliver a cleaner and ‘greener’ mode of operation. This aspect is likely to become increasingly important as the various ‘eco-rating’ schemes for buildings gain greater public recognition and feed into property marketing strategies and eventually rentals (Bon and Hutchinson 2000). Some public authorities in Australia are considering requiring certain ‘recycled content’ levels in their procurement strategies for buildings as has already happened in the USA. Increased recycling rates will then become an imperative for Australian refurbishment contractors. This will make the availability of valid statistical data on recycling rates in refurbishment all the more important.

Preconstruction phases

For current projects, during the feasibility phase, a complete site audit to itemise and quantify waste components with recycling or reuse potential should be undertaken. It may also be possible to consider allowing the necessary time for disassembly rather than destructive demolition. Sequence of demolition is often critical to the recycling potential of components. There may be a trade off between time and money in terms of recycling practice. It is helpful to investigate at the feasibility phase whether the refurbishment of fixtures, fittings and furniture (including work stations) is more cost effective than their replacement. Following on from this, designers should ensure that fittings, fixtures and furniture are targeted for reuse whenever possible. Some building components with low resale value may be suitable to be donated for reuse by community groups.

During the procurement process the project manager should include waste minimisation targets and preferred processes in all relevant subcontract documents, including support for material salvage and reuse. Manufacturers chosen to supply material components should have in place a strategy for 'end of life' for their product. Suppliers whose materials have a verifiable recycled content should also be favoured. Conversely the use of materials with no current reuse/recycling strategy should be actively discouraged.

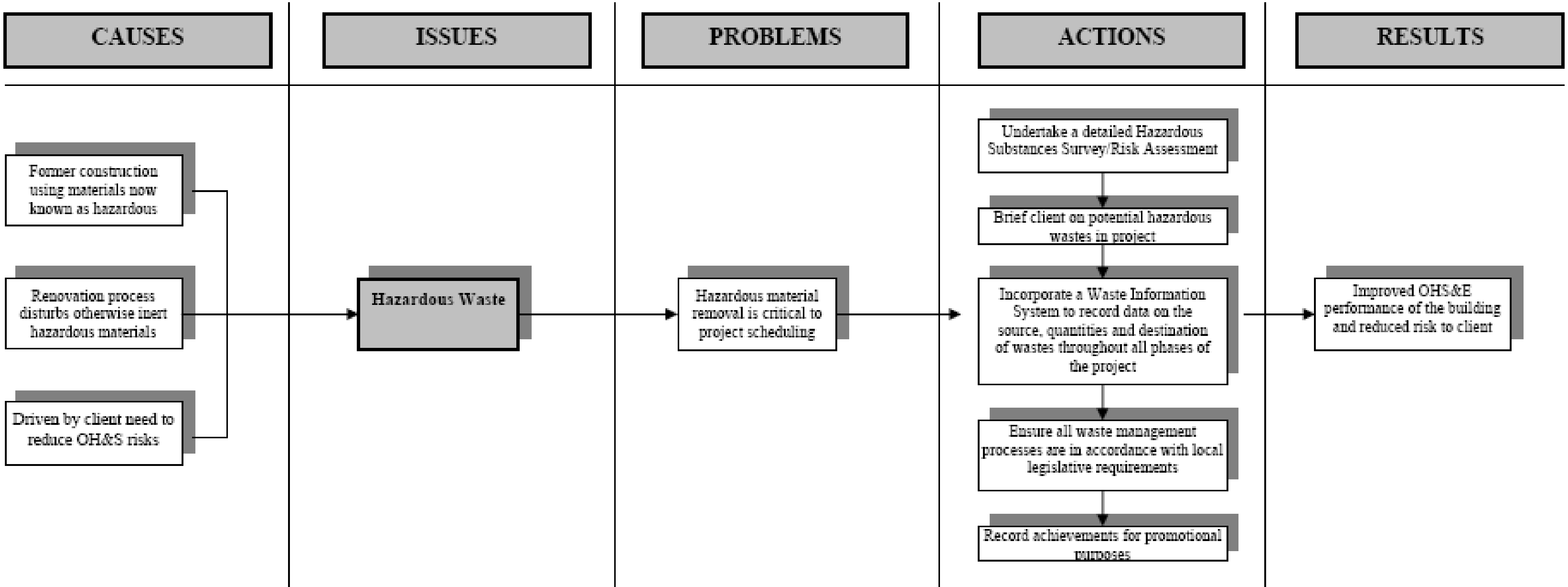
Construction phase

Once construction has commenced, record keeping of 'waste arising' during construction will help to identify areas of need and consequently aid future projects. Clearly labelled colour coded containers for recyclables on site at convenient locations and their use encouraged across the project. Due to their weight and bulk, all clean hard waste (bricks, concrete, fill etc) should be recycled either on or off site rather than sent to landfill. As far as possible all reinforcement and structural steelwork should be recycled and this is usually a positive cash flow item. Significant material off cuts should be retained for use elsewhere. A compost facility for food and other organic scraps should be provided on site if this is possible.

The recycling of building materials is a practice that has grown rapidly in recent years albeit from a very low base. As recycling becomes more common economies of scale are reached that increase the viability of the practice in monetary terms. An efficient recycling system for construction materials is an essential component of a sustainable industry.

6.8 Best Practice Guide

Sample Best Practice guides for Hazardous Substances and Ecologically Sustainable Development are included overleaf. These are intended as checklists for use when planning and carrying out a commercial refurbishment project. It is not intended that they comprehensibly cover all aspects of recycling and waste management but rather that they are a suitable *aide memoire* for the team that will conceive, plan, manage and operate a construction refurbishment project.



RECOMMENDATION ON KEY ACTIONS

FEASIBILITY PHASE

Estimates: Costs and scheduling time for hazardous material removal should be included in decision making about project feasibility.

DESIGN PHASE:

Problems flagged: Hazardous material content in waste should be identified and flagged to all potential contractors at the earliest possible stage.

PROCUREMENT PHASE:

Licenses: Determine demolition techniques best suited to contain hazardous materials in order to minimise contamination and ensure all contractors handling hazardous or controlled wastes are licensed to do so.

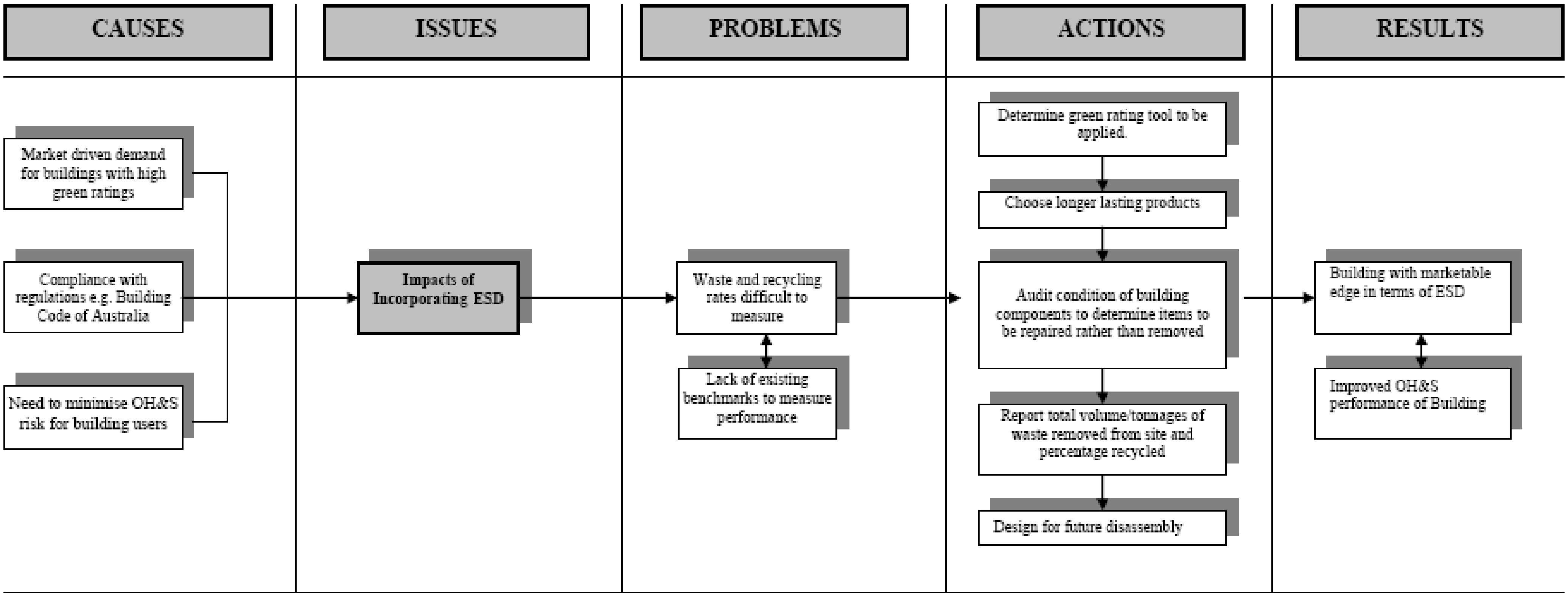
CONSTRUCTION PHASE:

Responsibility: Appoint a single point of contact (person) for all waste management issues on site and involve the site waste contractor before construction commences.

Risk Assessment: Undertake a Risk Assessment should hazardous materials be detected during the construction phase and revise onsite practices to minimise contamination. Keep potentially hazardous materials in secure bunded areas. Unavoidable waste must be disposed of in a safe and timely manner e.g. ensure bagged hazardous materials are removed from site before bag is damaged.

Hazard response: Ensure petroleum products or associated containers go to appropriate recovery centres (they should not be sent to landfill). Suitable Spill Response Kits should be on site at all times. Staff trained in the use of the kits should be present for all site working hours.

Records: No waste should leave the site without full details of content , weight or volume and destination recorded in the Waste Information System.



RECOMMENDATION ON KEY ACTIONS

FEASIBILITY PHASE

Condition audit: Careful auditing of the condition of the existing building may make it possible to repair rather than remove components e.g. existing ceiling tiles may be painted.

DESIGN PHASE

Flexibility, prefabrication and deconstruction: Build in flexibility of interior fitout. Prefabricated components should be used where possible. All construction work should be designed to allow for future deconstruction at the end of its useful life.

Plan ahead for operational phase: Plan for waste management systems which will be used during the operational phase of the building. Consider the requirements of any green rating system to be applied to the refurbished building.

PROCUREMENT PHASE

Waste minimisation: Choose longer lasting products. Where possible specify a recycled content percentage in new materials used, or specify materials that are recyclable. Verify supplier claims.

Project specifics: If site space or access is likely to preclude onsite sorting, commit to an offsite facility with sorting and reporting capabilities. Choose facilities in close location to the worksite.

CONSTRUCTION PHASE

Training and management: Provide onsite induction and training in waste minimisation for all workers.
Monthly reports should be compiled of total volume of waste removed from site, the percentage recycled and any initiatives or savings achieved. Keep comprehensive documentation updated including accurate drawings and specifications.

Site management: Encourage ordering of materials in suppliers' preferred quantities and discourage overestimation to cover contingencies.

Reduce rework: Limit design variations to a minimum once construction begins.

6.9 Conclusion

The experts interviewed for this study demonstrated a willingness to operate more sustainably if the processes and the information for doing so could be made more readily available. This willingness should be met with targeted guidelines for all stakeholders in refurbishment projects, such as building owner, facilities managers, tenants, designers, project managers, tradespeople and waste contractors. Appropriate dissemination of best practice ideas in recycling and waste management is likely to improve overall industry environmental performance. This in turn will increase the critical mass that can make some recycling practices viable through economies of scale. For some specific building materials where recycling rates are variable between states (eg. plasterboard, reinforcing steel) there is a need to clearly identify 'state of the art' recycling information and ensure it is dispersed to all contractors and industry associations and umbrella groups. In addition, secondary markets for reuse of components such as sinks, basins, cupboards and benches need to be encouraged by for example state government departments and major institutional clients. These bodies have a significant share of the commercial refurbishment market within their control and can establish a precedent for smaller businesses to follow. The question of recycling from refurbished buildings which formerly contained asbestos material needs to be addressed in detail to avoid the common current approach where all waste from such buildings, (whether contaminated or not), is automatically directed to landfill. Careful scheduling where asbestos removal happens prior to all refurbishment work including inspections is the most effective solution to this problem.

7.10 References

Ackerman, F. (2000). "Waste Management and Climate Change." *Local Environment*, 5(2), 223-229.

Andrews, S. (1998). "Waste Wise Construction Program Review: A report to ANZECC." Commonwealth Department of the Environment, Canberra.

Australian Bureau of Statistics. (2003). "The WasteWise construction program." ABS Yearbook 2003, 620-622.

Australian Government Productivity Commission. (2006). "Waste Management, Draft Report." Canberra.

Australian Building Greenhouse Rating (ABGR) Scheme. (2004). DEUS NSW Available from http://www.abgr.com.au/new/default.asp [Accessed 3 October 2006].

Aye, L., Bamford, N., Charters, B., and Robinson, J. (2000). "Environmentally sustainable development: a life-cycle costing approach for a commercial office building in Melbourne, Australia." *Construction Management & Economics*, 18(8), 927-934.

Ballard, G., and Howell, G. A. (2003). "Lean project management." *Building Research & Information*, 31(2), 119-133.

Bell, N. (1998). "Waste Minimisation & Resource Recovery: Some New Strategies." Royal Australian Institute of Architects, Red Hill ACT.

Bell, N., and McWhinney, S. (2000). "Waste Reduction Guidelines for the Construction and Demolition Industry." Commonwealth Department of the Environment and Heritage, Canberra.

Bossink, B. A. G., and Brouwers, H. J. H. (1996). "Construction Waste: Quantification and Source Evaluation." *Journal of Construction Engineering & Management*, 122(1), 55-60.

BRE Centre for Resource Management. (2003). "Construction and demolition waste: Part 1." BRE Good Building Guide 57, BRE, London.

Building Designers Association of Victoria. (1998). *Designing In Waste Minimisation*, Doncaster East, Melbourne, Victoria.

Building Research Establishment Ltd. (2005). "SMARTWaste." Available from http://www.smartwaste.co.uk/ [Accessed 4 October 2006].

California Integrated Waste Management Board. (2005). "Recycled Content Products Directory." Available from http://www.ciwmb.ca.gov/ [Accessed 3 October 2006].

Cole, R. J. (2000). "Building environmental assessment methods: assessing construction practices." *Construction Management & Economics*, 18(8), 949-957.

Council of the City of Sydney. (2005). "Policy for Waste Minimisation in new developments." Available from: http://www.cityofsydney.nsw.gov.au/Development/documents/PlansAndPolicies/Policies/WasteCodeForNewDevelopments.pdf [Accessed 4 October 2006].

Coventry, S., Shorter, B., and Kingsley, M. (2001). "Demonstrating waste minimisation benefits in construction (C536)." CIRIA, London.

CRC for Waste Management and Pollution Control Ltd. (1998). "Australian Waste Database: Solid Waste Management Performance Profile." Environment Australia, Canberra.

EcoRecycle Victoria. (2004). "Construction Waste Minimisation Plan." Melbourne. Available from: http://www.sustainability.vic.gov.au/resources/documents/Construction_Waste_Minimisation_Plan.pdf [Accessed 4 October 2006].

Environment Australia, and Bell, N. (2000). "Waste Reduction Guidelines for the Construction and Demolition Industry." Australian Government Department of the Environment and Heritage (DEH).

Ekanayake, L. L., and Ofori, G. (2004). "Building waste assessment score: design-based tool." *Building and Environment*, 39(7), 851-861.

Faniran, O. O., and Caban, G. (1998). "Minimizing waste on construction project sites." *Engineering, Construction and Architectural Management*, 5(2), 182-188.

Formoso, C. T., Soibelman, L., and De Cesare, C. (2002). "Material Waste in Building Industry: Main Causes and Prevention." *Journal of Construction Engineering and Management [H.W. Wilson - AST]*, 128(4), 316.

Forsythe, P., and Marsden, P. K. (1999). "A Model for Formulating a Project Waste Management Plan Based on Costing and Quantifying Construction Waste." *BDP Environment Design Guide*, General Issues Note No. 30.

Gertsakis, J., and Grant, T. (1999). "How to Approach Material Selection for Waste Minimisation - A Guide for Dealing with Material Suppliers." *BDP Environment Design Guide*, Product Note No. 22.

Graham, P. (2001). "Waste Management - Source Reduction." *BDP Environment Design Guide*, Technical Note No. 1.

Green Building Council of Australia. (2006) Available at http://www.gbcaus.org/ [Accessed 3 October 2006]

Hobbs, G., and Kay, T. (2000). "Reclamation and recycling of building materials: industry position report." BRE, London.

Ihlanfeldt, K. R., and Taylor, L. O. (2004). "Externality effects of small-scale hazardous waste sites: evidence from urban commercial property markets." *Journal of Environmental Economics & Management*, 47(1), 117-139.

Iranpour, R., Stenstrom, M., Tchobanoglous, G., Miller, D., Wright, J., and Vossoughi, M. (1999). "Environmental Engineering: Energy Value of Replacing Waste Disposal with Resource Recovery." *Science*, 285(5428), 706-711.

Kibert, C. J., Sendzimir, J., and Guy, B. (2000). "Construction ecology and metabolism: natural system analogues for a sustainable built environment." *Construction Management & Economics*, 18(8), 903-916.

Klang, A., Vikmana, P.-Å., and Brattebøb, H. (2003). "Sustainable management of demolition waste—an integrated model for the evaluation of environmental, economic and social aspects." *Resources, Conservation and Recycling*, 38(4), 317-334.

Lawson, N., Douglas, I., Garvin, S., McGrath, C., Manning, D., and Vetterlein, J. (2001). "Recycling construction and demolition wastes - a UK perspective." *Environmental Management and Health*, 12(2), 146 -157.

Li, H., Chen, Z., Yong, L., and Kong, S. C. W. (2005). "Application of integrated GPS and GIS technology for reducing construction waste and improving construction efficiency." *Automation in Construction*, 14(3), 323-331.

Lingard, H., Graham, P., and Smithers, G. (1998). "Waste Management - Civil & Civic Research Report." Dept. Building & Construction Economics, Royal Melbourne Institute of Technology, Melbourne.

Lingard, H., Gilbert, G., and Graham, P. (2001). "Improving solid waste reduction and recycling performance using goal setting and feedback." *Construction Management & Economics*, 19(8), 809-817.

Lingard, H., Graham, P., and Smithers, G. (2000). "Employee perceptions of the solid waste management system operating in a large Australian contracting organization: implications for company policy implementation." *Construction Management and Economics*, 18(4), 383-393.

Martin, A., and Scott, I. (2003). "The Effectiveness of the UK Landfill Tax." *Journal of Environmental Planning and Management*, 46(5), 673 - 689.

McDonald, B., and Smithers, M. (1998). "Implementing a waste management plan during the construction phase of a project: A case Study." *Construction Management and Economics*, 16(1), 71-78.

McGrath, C. (2001). "Waste minimisation in practice." *Resources, Conservation and Recycling*, 32(3-4), 227-238.

Mills, T. H., Showalter, E., and Jarman, D. (1999). "Cost-effective waste management plan." *Cost Engineering*, 41(3), 35-43.

National Australian Built Environment Rating System (NABERS). (2006) available at http://www.nabers.com.au/ [Accessed 3 October 2006].

Nystrom, H., and Kehr, W. "Analysis of intangible factors in waste minimization projects." *Engineering Management Society, 2000. Proceedings of the 2000 IEEE*, Albuquerque, New Mexico, USA, 552 - 557.

Perry, T. (2003). "Waste Not: The Greening of Construction Waste Management." *Environmental Design & Construction*, 6(7), 52-53.

Peng, C.-L., Scorpio, D. E., and Kibert, C. J. (1997). "Strategies for successful construction and demolition waste recycling operations." *Construction Management & Economics*, 15(1), 49-58.

Poon, C. S., Yu, A. T. W., and Jaillon, L. (2004). "Reducing building waste at construction sites in Hong Kong." *Construction Management & Economics*, 22(5), 461-470.

Robinson, G. R., and Kapo, K. E. (2004). "A GIS analysis of suitability for construction aggregate recycling sites using regional transportation network and population density features." *Resources, Conservation and Recycling*, 42(4), 351-365.

Seydel, A., Wilson, O. D., and Skitmore, R. M. (2002). "Financial Evaluation of Waste Management Methods: A Case Study." *Journal of Construction Research*, 3(1), 167-179.

Shen, L. Y., Tam, V. W. Y., Tam, C. M., and Drew, D. (2004). "Mapping Approach for Examining Waste Management on Construction Sites." *Construction Engineering and Management*, 130(4), 472-481.

Sterner , E. (2001). "'Green procurement' of buildings: a study of Swedish clients' considerations." *Construction Management and Economics*, 20(1), 21-30.

Thormark, C. (2000). "Including recycling potential in energy use into the life-cycle of buildings." *Building Research & Information*, 28(3), 176-183.

Webster, R., and Napier, N. (2003). "Deconstruction and reuse: Return to true resource conservation and sustainability." *Federal Facilities Environmental Journal*, 14(3), 127-143.

Wong, E. O. W., and Yip, R. C. P. (2004). "Promoting sustainable construction waste management in Hong Kong." *Construction Management and Economics*, 22(6), 563-566.

7. FLOOR SPACE OPTIMISATION

7.1 Introduction

In developing a strong business case for re-life rather than demolition and re-build, a major issue to be addressed is the maximising of the rentable floor space, which often puts a re-life project at a disadvantage. In increasing usable floor space, options available to the client include removal or adding floors and partitions, relocating services, cutting openings or extending floors and relocating lift wells etc.

In each case, innovative strengthening schemes have much to offer when considering upgrading the existing structure. Structural strengthening is the process of upgrading the structural system of an existing building to improve performance under existing loads or to increase the strength of the existing structural components to carry additional loads. The effect of strengthening or removing part (or all) of a structural element must be carefully assessed to determine its influence on the global behaviour of the structure. Failure to do so may overstress the structural elements surrounding the affected area, which can lead to a bigger problem and even localised failure (Concrete Monthly 2004).

Five major issues to be addressed in optimising floor space were identified through a survey of experts using the Delphi process. For each of these issues further research were conducted to ascertain the best appropriate practice in optimising the re-life decisions. This chapter presents the review of literature, research methodology and final outcomes in floor space optimisation and structural strengthening of re-life of buildings.

7.2 Review of Literature

A good retrofitting action plan will lead to the success of a re-life project. With the aid of decision-making tools, it is possible to select the most suitable retrofitting action (Steelcase, 2005, Concrete Monthly 2004, Flourentzou et al 2000). A number of such tools have been developed for office buildings with TOBUS, MEDIC, EPIQR and INVESTIMMO being the most commonly reported in the literature (Steelcase 2005, Concrete Monthly 2004, Flourentzou et al 2000). The decision-making software tools, EPIQR (for apartment buildings) and TOBUS (for office buildings) have been developed for the assessment of retrofitting needs of buildings in European countries. The use of these tools can facilitate a quick and accurate diagnosis of the condition of the existing building in terms of its major area including construction, energy performance, indoor environmental quality, and functional obsolescence. The main advantages of using these tools are the ability to evaluate various refurbishments and retrofit scenarios, and cost of induced works, in the preliminary stages of a project(Rey 2004, Chan et al 2001).

In EPIQR and TOBUS, deterioration of building materials and components are described by the use of a classification system with four classes. The prediction of the period of passing into the next deterioration state is of high interest as this is directly connected to higher refurbishment costs. The prediction of qualitative deterioration states are important and correspond to key moments in the element's life where some refurbishment action has to be taken (Rey 2004, Chan et al 2001).

European countries have used another software tool entitled MEDIC to predict the future degradation state of building. MEDIC is intended for use with EPIQR and is based on a subdividing of the building into 50 elements. MEDIC calculates the remaining life span of a building element not as a deterministic unique value but as a probability distribution. It can help the owner of a building to decide the most judicious moment to undertake refurbishment to achieve his short and long term financial needs (Steelcase 2005, Alkhrdaji& Thomas 2002). Following the footsteps of EPIQR an TOBUS, a decision-making tool for long term efficient investment strategies in housing maintenance and refurbishment – INVESTIMMO has been developed in European countries. It has been aimed at evaluating housing maintenance and refurbishment options, which covers expectations of tenants, housing market, and quality of building upgrading and environmental impacts in addition to the factors identified in TOBUS (Chan et al 2001).

From the review of literature, it was clear that these tools can be used to evaluate the general state of buildings with respect to some of the aspects of building re-life projects such as service life, functional obsolescence, energy consumption and environment impacts. However, no reported work presents a decision support tool, which can be used to compare and assess options available to the design team of a re-life project in optimizing rentable floor space.

7.3 Identification of issues to be considered in Optimising Floor Space

A review of published work was conducted to identify the issues, which requires to be considered in decision making in re-life projects (Rey 2004, Lam 2004, Dascalaki, E., & Balaras 2004). Based on the review and consultation with industry following issues were identified and were included in the DELPHI questionnaires:

- Change of use of floors
- Cutting openings or extending floors
- Relocate lift wells
- Remove/add doors
- Remove/add partitions
- Relocate/renew services
- Any of the above reasons for structural strengthening
- Other reasons for structural strengthening
- Structural appraisal prior to refurbishment
- Cost barriers to structural strengthening
- Safety/reliability issues for structural strengthening
- Expertise barriers to structural strengthening
- Use of innovative structural strengthening solutions

Out of these, five issues were identified by the experts as the most relevant in optimisation of floor space. These five issues are:

- Change of use of floors
- Relocate/renew services
- Structural appraisal
- Structural Safety
- Structural strength

Research tem then focussed on the identified five issues and developed best practice guidelines covering these issues as described below. Review of literature conducted for covering each issue is given in the following sections.

7.4 Structural Appraisal

A structural appraisal maybe deemed to be necessary due to any of the following reasons:

- Concern about the capacity of the existing building
- Structural constraints for the proposed refurbishment
- Change of loading conditions
- Change of load transfer mechanism
- Evidence of deterioration
- To aid a decision on whether to repair or demolish and rebuild

The case study building 1: CH1 building owned by the Melbourne City Council has a well documented structural appraisal conducted by Meinhardt Structural Engineers. A similar more concise appraisal has been conducted for the 63 George St. Building as well. Appendix D-1 gives the complete documents as typical examples of structural appraisal. Based on the major elements addressed in the report, the template given in table 8.1 has been developed by the research team for structural appraisal prior to refurbishment.

The template identifies the major structural elements to be covered and the parameters to be included in a complete appraisal. The template was presented to the industry experts and modified based on their comments.

Table 7.1 Template for structural appraisal

Building information

Building Name	
Building Number	
Building Address	
Year of Original Building	
Year of Last Renovation	
Number of Floors	
Gross. of Building	
Building type	
Construction type	
Occupancy classification	

Item	Type	Materials	Condition	Remaining Useful life	Designed load DL	LL	Compliance with current codes/standards	Current replacement value	Comments
Foundation									
Stumps									
Earthworks									
Columns									
Beams									
Joists									
Slabs									
Decks& balconies									
Roof (structural)									
Stairs(structural)									
Insulations									
Others									

7.5 Structural Strength

In situations where the use of the office floor requires changes to services such as lift wells air ducts, ventilation, lighting and the type of loads applied on it, load transfer mechanism of the building structure may require strengthening or re designing and re-building. Selection of an appropriate strengthening method is dependent on the materials of construction. Structural elements of existing buildings are commonly constructed of concrete, steel, timber and masonry. Concrete is the most commonly used building material and widely used in the forms of in-situ concrete, precast concrete and post-tensioned concrete.

The structural strengthening can be achieved by section enlargement, external post tensioning, external bonded steel elements, bonded advanced fiber reinforced polymer (FRP) composites, span shortening, or a combination of these techniques (Allehaux and Tessier 2002, Steelcase 2005, Gordon 1994, VSL Strengthening Systems, 2005, Brown 2005). No matter what strengthening technique is used, the ability to perform as an integrated system can be obtained only by providing an adequate bond between the existing member and the repair/reinforcement to ensure monolithic structural behaviour (Allehaux and Tessier 2002). Stress concentrations resulting from added material should be investigated as they may cause a localized failure.

Unfortunately, there is no specification or design that covers all repair/upgrade scenarios and engineers, architects, and contractors must be innovative and thorough, in their design details, specifications, and applications.

7.5.1 Structural strengthening methods and application examples

Structural elements of existing buildings are commonly constructed of concrete, steel, timber and masonry. Concrete is the most commonly used building material and widely used in the forms of in-situ concrete, precast concrete and post-tensioned concrete. Selection of an appropriate strengthening method is dependent on the materials of construction.

Except in cases where new structural members are installed (to share the load with existing members), most retrofits comprise a composite repair/retrofit system. The composite repair/retrofit can be achieved by section enlargement, external post tensioning, external bonded steel elements, bonded advanced fibre reinforced polymer (FRP) composites, span shortening, or a combination of these techniques (Concrete Monthly 2004, Alkhrdaji& Thomas 2002).

The following section gives a brief description of existing structural strengthening methods and several innovative techniques.

7.5.2 Section enlargement

This is a well established strengthening method in the construction industry. It involves the placement of additional concrete on an existing structural member in the form of an overlay or jacket (Alkhrdaji& Thomas 2002). The additional concrete may be:

- structural concrete, which is adequately bonded and reinforced with steel bars or wire mesh and designed to be a load-carrying element, or
- protective concrete, which is used to shield post tensioning steel, FRP cables, or bonded steel elements from fire, environmental or mechanical damage.

With this method, columns, beams, slabs and walls can be enlarged to increase their flexural, axial and shear capacity using reinforced concrete and steel systems (Concrete Monthly 2004, Alkhrdaji& Thomas 2002, VSL Strengthening Systems 2005). A typical enlargement is approximately 2 to 3 inches for slabs and 3 to 5 inches for beams and columns (Concrete Monthly 2004). The main disadvantage of this method is that the dead weight of the existing structure is increased due to the overlay or jacket. Designers are required to incorporate the weight of the additional material overlay or jacket in the design of the enlargened member. In the situations where concrete is used as an overlay material, lightweight concrete can be used to minimise the additional weight.

An overlaid existing slab can increase both the structural capacity of the slab as well as the supporting beams or joists by increasing the effective depth of reinforcement at the positive moment region. It can also increase the structural capacity at the negative moment region (typically at supports) with the addition of steel reinforcement in the overlay. Usually, a steel wire mesh is provided as reinforcement. The composite behaviour of the existing slab together with the added overlay can only be taken into account if monolithic structural action is assured. This requires a good bond or horizontal shear transfer capacity at the interface. In some occasions, the concrete at the surface of the member is weak and does not have adequate strength to ensure sufficient shear transfer. In this case, the weak concrete can be chipped away. Shear dowels can also be used to enhance the composite behaviour (Alkhrdaji& Thomas 2002).

The approach of enlarging the section is relatively easy to apply and economically effective, but it does not address the possible corrosion of embedded reinforcing steel, especially in a harsh environment and/or where there has been inadequate cover. When performing section enlargement, it is necessary to meet the current code requirements for reinforcement anchorage, development length, spacing, and concrete cover for new construction (Alkhrdaji& Thomas 2002).

Application Examples

Figure 7.1 shows details of a section enlargement used to increase the capacity of a main girder in a university car park. The girder was re-evaluated (because of a change in the required loading) and found to be deficient in flexure and shear. To correct the deficiency a 4-inch jacket of concrete was cast to enlarge the section and additional flexural and shear steel were added (Concrete Monthly 2004).

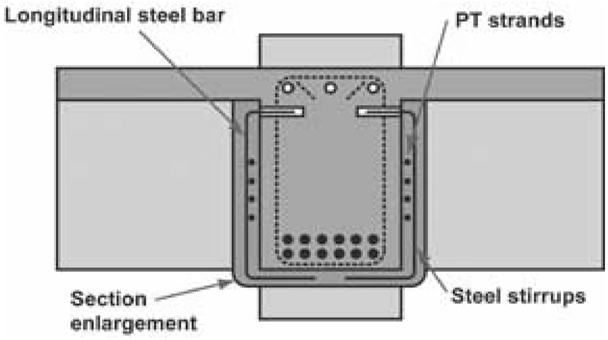


Figure 7.1: Beam Strengthening by Section Enlargement
(Concrete Monthly 2004)

In another car park (Alkhrdaji & Thomas 2002), analysis indicated that the beam was deficient in shear and flexure at the support. This deficiency was corrected by doweling additional steel stirrups to the sides of the beam. The beam was enlarged (Figure 7.2) and compression steel was included at the bottom of the beam.

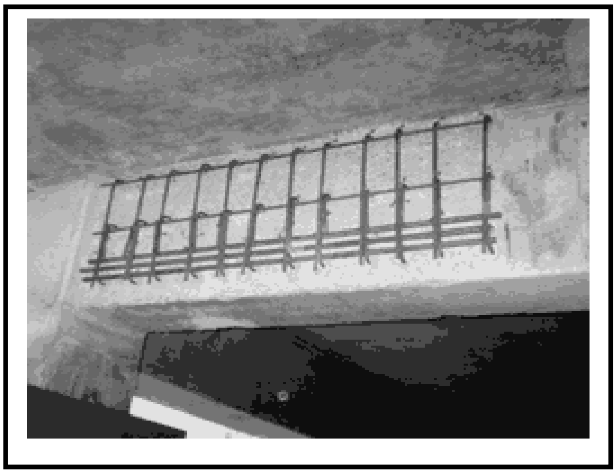


Figure 7.2: Beam enlargement - improved shear and flexural capacity
(Alkhrdaji & Thomas 2002)

7.5.3 External post tensioning

External post tensioning techniques have been effectively used to increase the flexural, axial and shear capacity of both reinforced and prestressed concrete as well as steel, timber, masonry and composite steel-concrete structures. The members are upgraded by applying external forces to the structural member using post-tensioned cables to counteract the effect of the additional loads. Due to the minimal additional weight of the repair system, this technique is particularly effective and economical to correct excessive and undesirable deflections and cracks in beams and slabs (Concrete Monthly 2004, Alkhrdaji & Thomas 2002 , VSL Strengthening Systems 2005, VSL Report series 1 2005).

External post tensioning is a construction method that can be produced efficiently on-site with few or no problems for grouting, and can be easily replaced/modified at a later date if needed. The disadvantage of this method is that it is located outside the structure, rendering it susceptible to corrosion, fire and acts of vandalism. However, these problems can be avoided by encasement in concrete or shotcrete.

The post-tensioning forces are delivered by means of standard prestressing tendons or high-strength steel rods, usually located outside the original section. The tendons are connected to the structure at the anchor points, typically located at the end of the member. Hence the approach requires accessibility to the sides and sometimes the ends of the member. The desired uplift force is provided by deviation blocks, fastened at the high and low points of the beams. Prior to stressing, all the existing cracks should be epoxy injected and spalls patched, to ensure that stressing forces are distributed uniformly across the section of the member. The designer of the external post tensioning system should consider the effect of the newly applied concentrated forces at the locations of deviators and anchorages (Alkhrdaji & Thomas 2002). Installing a new post tensioning system is not only economical, it requires less time to complete than section enlargement and hence is widely used in upgrading buildings.

Application Examples

Figure 7.3 shows an upgrading example of a car park in a shopping mall (Alkhrdaji& Thomas 2002). Assessment showed that a number of beams and the two-way slab were deficient in shear or flexure due to the inadequate detailing of the existing post tensioning systems. In addition, corrosion of the steel tendons in the slab forming the ramp was also observed. Both time and cost constraints were dominant in this project, as the ramp provided the only access to the back of the mall. The proposed solutions included a post tensioned solution, demolition of the existing ramp and construction of a new one, or the installation of a supporting steel frame underneath. Both the latter two options would render the ramp out of service for a significant period of time and hence the (first) option to install a new post tensioning system was selected as most desirable. The system was installed in grooves made in the existing ramp, with the groove depth varying to accommodate the required profile of the steel tendons. The tendon anchors were embedded within the slab. The interior beams were upgraded using an external post tensioning system to address the flexural deficiency, and external steel stirrups to address shear deficiency.

Figure 7.3: External post tensioning of beams (Alkhrdaji & Thomas 2002)

Upgrading of a parking structure in San Francisco was carried out in 1986. It has five parking levels including the roof comprising a system of post-tensioned beams and slabs. At the roof level, severe slab cracking and substantial water leakage was observed and, subsequently a detailed inspection was carried out. Extensive cracking in the top of the slab parallel to the beams was discovered, and excessive beam deflections of up to 38 mm in many instances were recorded. External post-tensioning tendons were used for the rehabilitation of the beams (Figure 7.4) and deteriorated tendons in the slab were replaced with new tendons.

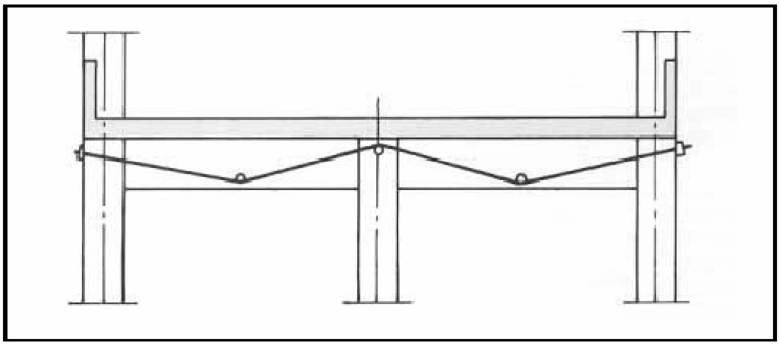


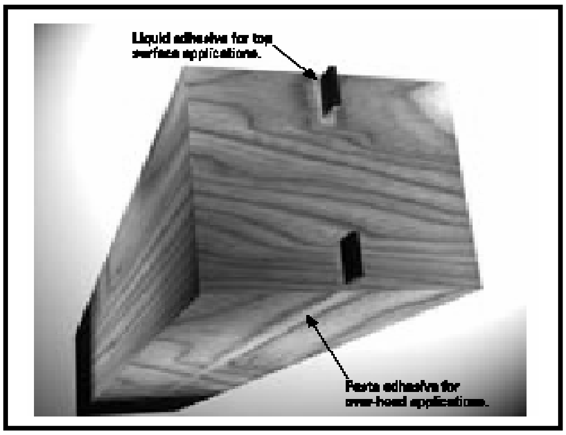
Figure 7.4: Scheme of added beam tendons

7.5.4 Composite strengthening systems

Fibre reinforced polymer (FRP) composites have been used for nearly thirty years in aerospace and manufacturing applications where low weight, high tensile strength, and non-corrosive structural properties are required. In civil engineering applications, FRP has proven itself for years in fabric roof structures, internal concrete reinforcement, deck gratings, and most impressively as externally bonded reinforcement. FRP materials are successful in all of these applications because they exhibit low creep, and compared with steel, are thinner, lighter (having ten times the tensile strength) (Setunge et al, 2005) Other advantageous characteristic of FRPs for structural strengthening applications include their high durability, non-corrosive properties, , lower cost, aesthetic appeal, speed and ease of installation (Concrete Monthly 2004, Setunge et al, 2005, ACI, 2004, FIB, 2004).

FRP composites are being widely applied to the retrofitting and strengthening of concrete, masonry and wooden structures (Figure 7.5) (Lindman, 2005)

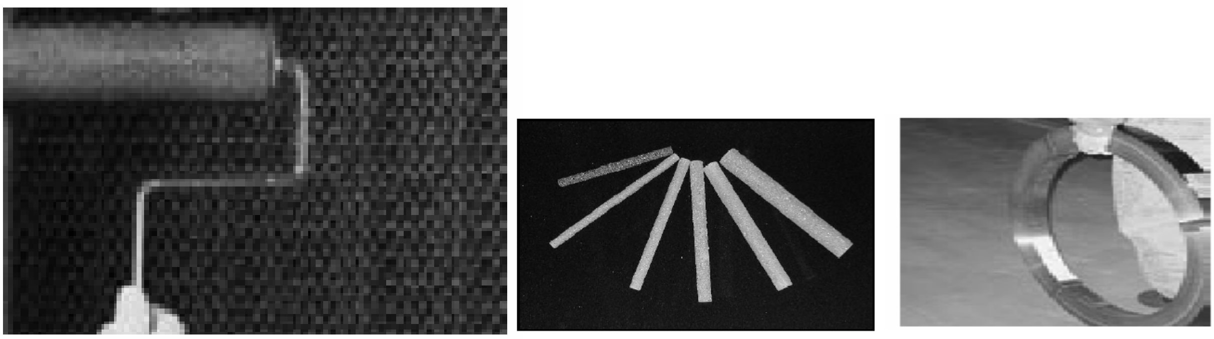
(a) Application on concrete column (b) Application on masonry wall



(c) Application on timber joist

Figure 7.5: Application of FRP composite material (Lindman, 2005)

The FRP composite material comprises reinforcing fibres embedded in a polymer matrix that protects them against mechanical damage, transfers stress between them, and maintains the shape of the composite. Typical fibres used to create the FRP are glass, aramid and carbon, but studies in Switzerland demonstrate that aramid fibers possess inadequate compressive strength, and glass fibres do not resist alkalis. Consequently, the most common fibre employed in concrete strengthening applications is carbon FRP (CFRP) due to its superior properties and durability. The most common types of CFRP are fabrics, plates, and rods (Alkhrdaji& Thomas 2002).



(a) FRP fabric (b) FRP rod (c) FRP plate

Figure 7.6: Common types of CFRP

As with any other composite systems, the bond between the strengthening plates and the existing concrete is critical, and surface preparation of both phases of the system (concrete and CFRP) is very important. If CFRP plates are used, they should be ground on the bonding side, and immediately prior to bonding, the surface cleaned. The epoxy glue components should then be applied to the plate immediately after mixing. After positioning the plate in the designated position, a slight pressure should be applied to squeeze out excessive adhesive. CFRP plates are currently limited to flat plates (Alkhrdaji& Thomas 2002).

FRP composites are ideal for enhancing flexural capacity of existing beams, walls and slabs. Typically the flexural capacity of concrete members can be increased by as much as 60%. The flexibility and high strength characteristics also allow FRP to be used as supplemental shear reinforcement and the ductile behaviour of a member can be increased with sufficient composite shear reinforcement. FRP composites can upgrade the shear capacity of an existing member by 100%. FRP application to improve confinement is a powerful strengthening technique offering almost double the normal compressive load carrying capacity of concrete. Confinement also increases concrete ductility (Brown 2005, Setunge et al, 2005)

CFRP fabric sheets for curved surface application come in continuous rolls. These sheets can be easily and quickly tailored and wrapped around almost any profile. CFRP fabrics may be adhered to the tension side of structural members to provide additional flexural strength; adhered to the web sides of joists and beams; or wrapped around columns to provide additional shear strength. Wrapping CFRP around columns also increases concrete confinement, thereby boosting the strength and ductility. Prior to applying the fabric, the concrete surface should be blasted with sand or water to remove loose material. In addition, all existing cracks should be injected with epoxy. To apply the fabric, epoxy-based primer should be rolled or brushed onto the prepared concrete surface followed by the first epoxy coat - applied by roller whilst the primer is tacky. CFRP fabric sheets are then applied to the fresh epoxy using a ribbed roller to remove air bubbles and ensure impregnation of the fibres with resin. After the sheet is installed, the second and final epoxy coat is applied and allowed to cure (Alkhrdaji& Thomas 2002).

Usually, FRP bars are epoxy bonded into grooves cut into the existing concrete surface. The bars provide additional reinforcement, strength and stiffness to the structure - similar to adding steel reinforcement. However, unlike steel reinforcement, FRP bars are non-corrosive. This allows the bars to be installed in much shallower grooves since minimal cover is needed (Concrete Monthly 2004, Watson Bowman Acme 2005). This technique has not been used in Australia.

Strengthening using externally bonded FRP is more complicated than with conventional materials, as the linear/elastic behaviour of FRP can result in different failure modes (i.e. concrete crushing or FRP rupture). In fact, the contribution of FRP reinforcement to the strength of the member depends on many variables. Many agencies have developed material standards and design guides for practitioners. In the United Kingdom, the Concrete Society released Technical Report No. 55 for design guidance in strengthening concrete structures using fibre composite materials. The American Concrete Institute (ACI) is in the final stages of releasing a similar document (ACI Committee 440), and the Federal Highway Administration (FHWA) is sponsoring research programs to develop model specifications for the repair and strengthening of existing bridges using FRP composites that ensure quality and performance [(Alkhrdaji& Thomas 2002)]. A research project funded by the CRC for CI has developed a guide for use of FRP systems for structural refurbishment in Australia (Setunge et al, 2005).

Application Examples

Figure 7.7 shows a schematic for the structural strengthening of a utility tunnel at a university in South Florida. The utility tunnel roof originally functioned as a pedestrian walkway. A new dormitory structure required the walkway to be the primary access for emergency vehicles and an analysis of the tunnel's top slab revealed it did not have adequate strength to carry loads from the fire trucks and other emergency vehicles. The school needed an innovative approach to strengthen the tunnel slab to bring it up to the required strength. A structurally efficient, easy to install and cost-effective strengthening option was achieved by using externally bonded FRP sheets.

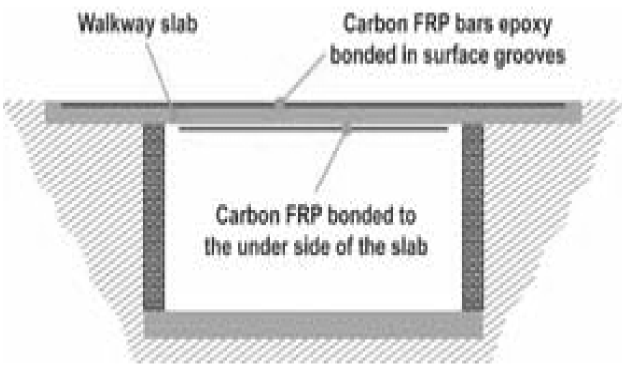


Figure 7.7: Tunnel slab FRP strengthening method

The strengthening solution consisted of CFRP sheets bonded to the bottom of the slab, serving as additional bottom tension reinforcement, as shown in Figure 7.8. In addition, the overhanging portions of the slab were strengthened using CFRP bars epoxy-bonded in grooves made on the slab's top surface. This technique of placement in grooves is more appropriate for the top surface because the bars were bonded below the surface, thereby avoiding traffic damage to the externally bonded reinforcement.

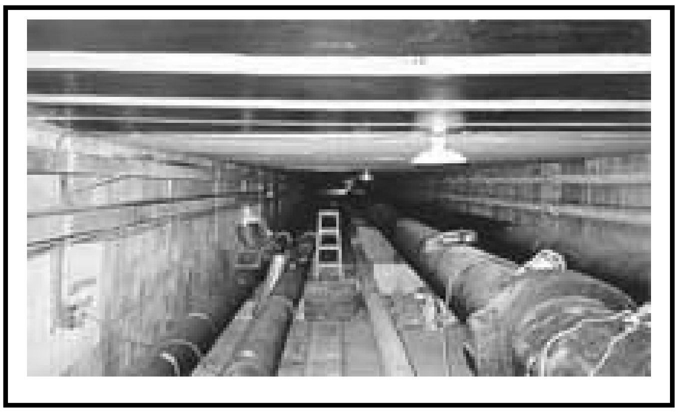


Figure 7.8: CFRP fabric on slab underside

In another project some of the confining stirrups were inadvertently left out of several of the ground floor columns in a multi story office building (Edge Structural Composites, 2005). CFRP was selected for the rectification work. Only one layer of carbon fibre was applied in the plastic hinge regions in order to bring the columns back to the designed capacity. The carbon fibre was applied in either a single 24” wide bands or as three 12” wide bands depending on the particular column configuration (Figure 7.9).

Figure 7.9: Application of carbon fiber sheets on column

7.5.5 Bonded steel elements

Bonded steel elements are commonly used to strengthen steel, timber, and concrete members. Steel elements can be steel plates, channels, angles or built up members. Steel elements (typically plates) bonded to the tension face of beams can increase flexural capacity; contribute to an increase in flexural stiffness; and consequently decrease the deflection and cracking. Steel elements bonded to the sides of the members can improve the shear strength of the member. The bonded steel element act both as a supplement to the existing embedded reinforcing steel and as a secondary reinforcement that shares the applied forces, thereby reducing the stresses in the existing concrete and steel bar (Alkhrdaji & Thomas 2002).

The method can be applied to existing steel structures by welding, gluing or bolting in place additional steel elements. In the case of concrete or timber members the steel elements can be glued in place using epoxy adhesive to create a composite system. The preparation of all component surfaces, the application of adhesive and the placement of components must be executed with great care to achieve a reliable composite action of the system, and the capability to transfer shear stresses across the adhesive interface. The surfaces to be bonded must be clean (abrasive blasting for the steel and concrete surfaces is preferred). In addition, as with any gluing operation, the bonding of steel plates to concrete or timber requires the application of an even pressure to fix the components in position - this is achieved by using adhesive anchors. It is strongly recommended to provide supplement anchors, especially at the ends of the plate to ensure the bonded steel element will still carry load in the event of adhesive failure. Considerable site work is required to accurately locate the existing reinforcement in concrete members so as to avoid causing damaging while placing the anchors. In addition, elaborate and costly false-work is required to maintain the steelwork's position during bonding (Concrete Monthly 2004, Alkhrdaji& Thomas 2002).

Exposed steel elements must be protected with a suitable system immediately following installation. Regardless of the specified corrosion protection, its compatibility with the other materials and its long-term durability properties and maintenance requirements must be fully considered. Externally bonded steel elements should not be used as a long-term solution for structures subjected to aggressive environments. Fire protection is also an important consideration when using bonded steel elements (Concrete Monthly 2004, Alkhrdaji & Thomas 2002).

In the ultimate strength design philosophy both the existing element and the additional new steel component will yield, and the composite section may be assumed to resist the total load. Adequate design, specification, and execution of the job are necessary to ensure the composite action of the upgraded system (Alkhrdaji & Thomas 2002).

Due to their weight and the restrictive length, steel plates can be unwieldy on-site. The steel elements may also need to be spliced, thus complicating the design and construction operation (Alkhrdaji & Thomas 2002). Adding steel elements under an existing slab or beam may reduce the headroom substantially.

Application Examples:

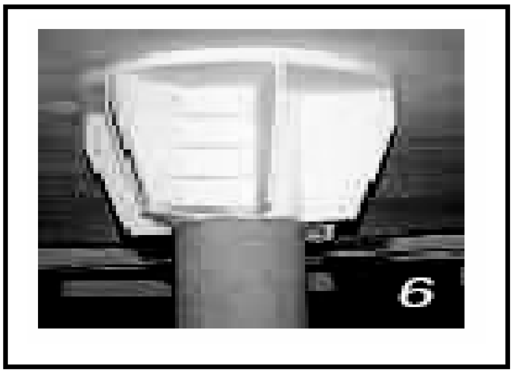


Figure 7.10 Steel punching shear assembly

The requirement for strengthening of concrete decks is common during Plaza renovation projects in the USA as the addition of planters and structures increases the dead load on the existing structure. Figure 7.11 shows an installed structural steel beam with an additional steel bracket at the column head on the underside of such a structure.

Figure 7.11: Steel beam and bracket on underside of the structure

7.5.6 Span shortening

This is a strengthening technique that reduces the stress in beams by reducing the unsupported length of the member. Materials used for span-shortening applications include structural steel members and cast-in-place reinforced concrete members. Connections can be made by using bolts or adhesive anchors (Concrete Monthly 2004).

Span shortening may result in a loss of space and reduced headroom**.** Therefore, span shortening is not always a desirable method for strengthening existing structures where optimization of floor space is needed. However, if there is any possibility to use nibs or corbles as additional supports, the loss of space due to extra structural members can be overcome.

7.5.7 Hybrid strengthening system

The strengthening of concrete with externally bonded reinforcement is generally achieved by using either steel plates or CFRP sheets. Each material has its specific advantages and disadvantages. To combine the features of the two materials, a hybrid steel/CFRP strengthening method has been developed (Brosens 2001). The additional longitudinal reinforcement consists of externally bonded steel plates, whereas the shear reinforcement consists of externally bonded CFRP sheets.

Application Examples:

Figure 7.12a illustrates a schematic for the strengthening of a roof system of an elementary school in New Jersey. The school administration wanted to install skylights on the existing roof. The roof consisted of prestressed concrete hollow planks. Installation of the skylights required cutting openings in the planks that would reduce their load-carrying capacity. This issue was resolved by designing a hybrid strengthening system composed of FRP fabric and steel elements. The FRP strengthened the planks adjacent to the one to be cut, while the steel elements tied the plank to the adjacent ones, thus creating a new unit consisting of three planks with adequate capacity. In addition to the application being quick to complete, this was also a cost effective and aesthetically pleasing solution (Concrete Monthly 2004) (Figure 7.12b).

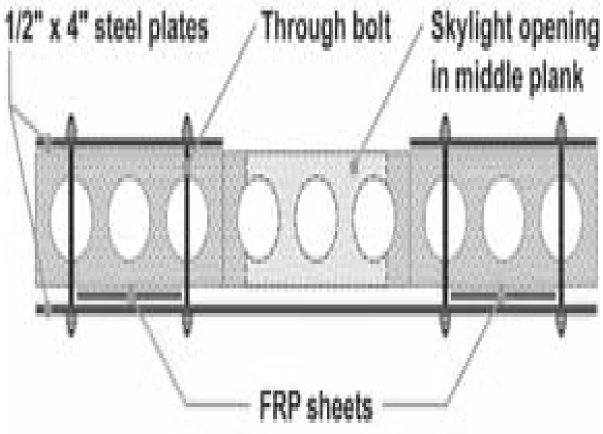


Figure 7.12a: Schematic strengthening system

Figure 7.12b: Strengthening roof planks in a school

In 1998, a former school building in Belgium was transformed into a city library with a considerable increase of load as a consequence. The floor slab had to be strengthened to double the bearing capacity from $3kN/m^2$ to $6kN/m^2$. These floor comprised 50mm thick slabs with ribs spaced every 55cm. An extensive investigation was done and it was found that there were no internal steel stirrups in the ribs (Brosens 2001).

An experimental program revealed that externally bonded CFRP sheets applied to one side of a rib as shear reinforcement was almost as effective as CFRP sheets on both sides. For that reason, two layers of CFRP sheets were applied on one side of the ribs in order to increase the shear capacity of the floor slab. In the first layer, CFRP was oriented vertically while in the second layer, the CFRP was oriented horizontally. In addition the flexural rigidity of the ribs had to be increased in order to carry the higher bending moments. Consequently an externally bonded steel plate was applied to the bottom of the rib. The anchorage of the steel plate was achieved by two bolts at each end (Brosens 2001) (Figure 7.13).

Figure 7.13: Strengthening of ribbed floor slab

In 2002, the supporting beams of a roof structure of a stockroom in Brussels (Belgium) were strengthened using a hybrid strengthening technique. Due to original design calculation errors, the bearing capacity of the main supporting beams was only half of that required. The internal steel tensile reinforcement was not adequate. The beams had a span of 14 m with a rectangular cross section of 400 mm x 800 mm. The roof structure consisted of two adjacent spans of these simply supported beams. The concrete beams were fabricated and already positioned on site. To prevent a delay of the construction works, the option of strengthening was chosen rather than replacement of the beams. Above the mid support, the two beams were connected to each other in order to obtain a statically indeterminate structure and thus reduce the mid-span moments of the beams.

To obtain the required bearing capacity and stiffness of the structure, a steel plate with a cross section of 15 x 8 mm was applied to the bottom surface at the mid span of the beams. At the mid support, the two beams were connected by providing a steel plate at the top surface of the beams. This steel plate transfers the tensile stresses, originating from the negative bending moment at the support. Both ends of the steel plate were anchored to the concrete beam by bolts. To enable the transfer of compressive stresses, the opening between the two beams was filled with an epoxy repair mortar. To prevent additional cracking due to thermal forces in the lower part of the beam above the support, additional tensile reinforcement was added in this area using flexible CFRP sheets. At each side of the beam, three layers of CFRP were applied. Finally, two stirrups made of CFRP sheets were provided to take the increased shear forces caused by the connection of the two beams. Figure 7.14a and 7.14b give the overview of hybrid strengthening of the supporting beams of the roof structure.

Figure 7.14a: Overview of hybrid strengthening work

Figure 7.14b: Detail of connection of two beams

Table 7.2 Summary of structural strengthening techniques

Strengthening Method	**Design Action**	**Applications**	**Issues associated**
Section Enlargement	Flexural, shear, confinement	Concrete elements	• Not good in harsh environment. • Possible corrosion of embedded reinforcing steel. • Increase the weight of existing structure
External post tensioning	Flexural, shear, confinement	Steel, timber, concrete and masonry elements	• Vulnerable to corrosion, fire and vandalism. • Protection can be achieved by encasing thepost tensioning system in concrete or by using shotcrete.
Composite strengthening system	Flexural, shear, confinement	Timber, concrete, and masonry elements	• Can damage the externally bonded composite
Bonded steel elements	Flexural, shear	Steel, timber, and concrete	• Influence to corrosion and fire. Suitable protection system should be used. • Adding strengthening material under existing structure may reduce the usable headroom
Span shortening	Flexural, shear	Steel, timber, and concrete	• Result in loss of space and reduced headroom.
Hybrid strengthening system (Steel/CFRP)	Flexural, shear	Steel, timber, and concrete	• Since the plate end is a discontinuity, high shear stress concentrations might cause premature peeling failure in the end zones of the external reinforcement.

7.5.8 Matrix of structural strengthening solutions and needs

Research team have compiled a detailed matrix which allows a re-life project team to map a strengthening need to a potential solution. The matrix covers typical methods, potential applications, examples and availability of expertise. Appendix D-2 gives the matrix.

7.5.9 Typical design examples

Typical design examples have been developed for most of the identified structural strengthening schemes by the research team after a review of state-of-the-art review of strengthening techniques. These are given in Appendix D-3. Approximate costs established through industry consultation are also provided to facilitate initial decision making by the re-life project team.

7.6 Relocate Renew Services

Relocating renewing services may be a major issue considered in re-life of buildings. The need may arise due to a number of reasons as identified through detailed analysis of case study reports and published work (Billington 2003, Queensland Government Department of Public Works, 2005)

:

- Relocating of services may be considered to maximise usable office space
- Reduction of energy consumption to meet current energy rating requirements
- Promoting green buildings for sustainability outcomes
- Improve user comfort which will improve productivity
- Availability of new technologies which improve energy consumption
- Increase in use of technology which increases the need for energy usage
- Outdated or poorly operating building services

The project manager for the re-life initiative will need to be aware of the decision issues in relocating/renewing of services to arrive at an optimised floor space. Research team have analysed the appraisals conducted for the two case-study buildings and have developed a list of possible options to be considered in re-life projects, a template for services appraisal and list of some new technology options to be considered.

7.6.1 Services appraisal

Consultation with the industry partners revealed that in many occasions the decisions to refurbish are taken to improve user comfort and functional issues. Therefore a comprehensive services appraisal is essential during the conception stage of the re-life project. A typical template developed for services appraisal is given in Table 7.3. Major elements to be covered in a services appraisal are: types of services, materials, condition, remaining useful life and compliance with current energy rating requirements. Whilst the minimum energy rating required is rating 4 for office buildings, the project manager may explore possibilities of achieving a higher rating to promote sustainability outcomes.

7.6.2 Challenges in relocating/renewing services

Some major challenges in relocating services are:

- Cost
- Compliance with current regulations
- Identifying the best available technology
- Construction feasibility
- Structural implications – feasibility of drilling through structural elements
- Flexibility for long-term use

In addressing these, research team has identified decision parameters to be considered in relocating/renewing services and included in the decision modules presented in the Best practice Guide.

Table 7.3: Building services appraisal

Reticulated Services	**Type**	**Materials**	**Finish**	**Condition**	**Remaining Useful life**	**Compliance with current codes/standards**	**Current replacement value**	**Comments**
Gas								
Water supply								
Sanitary plumbing								
Sanitary fixtures								
Plumbing Piping								
Plumbing Fixtures								
Electrical Service								
Electrical Generation								
Electrical Distribution								
Electrical Lighting								
Special Electrical Systems								
Ventilation								
Space heating								
Evaporative cooling								
HVAC Distribution								
HVAC Equipment								
HVAC Controls								
Others								
Telephone								
Computer links								
Monitoring systems								
Others								
lifts								
escalators								
walk ways								
hoists, conveyors								
Others								
Fire Protection								
Security								

7.6.3 Expected standard of technical services

Typical standards for premium grade office space services identified by the property council of Australia (these are currently been re-developed) are given in Table 7.4 (CH1 Engineering Report, 2004).

Table 7.4: Classification of office space

Size	Floor Plate	Finish	Technical Services
Premium Grade			
Sydney and Melbourne CBDs Generally > 30000 sqm Other CBDs Generally > 20000 sqm	>1000 sqm Largely column free	A landmark office building located in major CBD office markets which is apace setter in establishing rents and includes: • Natural lighting • Good views outlook • Prestige Lobby finish • On-site undercover parking • Quality access to/from an attractive street setting • Premium presentation and maintenance	State of the art technical services will typically include the following: • HVAC systems: Multiple zones of approximately 70 sqm with around 25 watts per sqm for tenant equipment, supplementary fresh air system, auxiliary condenser water loop for tenant use and capacity for tenant exhaust risers • Lifts Waiting interval not to exceed 25 secs, handling capacity in excess of 15% and a high quality ride with low noise, at least one dedicated goods lift • Power Minimum of 25 watts per sqm load capacity, Dedicated data risers should be available • Lighting High quality ultra low brightness fittings • Building Intelligence High quality building automation system, 24 hr access (card key), after hours air conditioning dial up, energy and stand by power management, manned control room, perimeter security, Closed circuit TV Standby power: Full power to all essential services, at least 50% lighting and lifts

7.7 Change of Use of floor

Change of use of floors may be a result of functional obsolescence, change of business, change of major occupancy, correcting a poor initial design or simply maximising the rentable floor space. Issues to be considered in changing the use of floors can be summarised as (Building and commission, 2005):

- Changing the classification of building (eg. from a lower grade to a premium grade)
- Additional permits, regulations
- General structural condition
- Tenant contract/agreement
- Impact on other buildings in the neighbourhood/ other tenants
- Adequacy of parking

Change of use of floor will affect decisions on other areas such as Services, Structural strengthening and Structural appraisal. Structural issues have been already captured in section 8.5: Impact of other issues on structural strength. Typical floor loadings extracted from AS1170, 2004 for office buildings are given in table D1 of appendix D-4.

7.8 Structural Safety

Whilst structural safety is a subset of impact of other issues on structural strength covered in detail in Section 7.5, there are some additional issues to be considered during construction stages. These may arise due to:

- Removal/demolition of walls, ceilings, roofs or floors
- Concrete cutting, drilling and opening
- New construction within existing building
- Consideration of health and safety related issues of occupiers and/or construction staff

According to Victorian workcover Safety (1999) Industry Standard for Concrete Cutting and Drilling" Typical hazards during construction may be summarised as:

- Toxic fumes
- Working in confined spaces
- Noise,
- Equipment hazards
- Risk of structural damage,
- Risk of damages to services
- Exposure to Asbestos

These can be addressed by performing a risk assessment of potential hazards using an accepted risk assessment checklist. Appendix D-5 gives a list of OH&S code of practices for all states of Australia and Appendix D-6 gives a sample safety checklist published by the Victorian Work Cover Authority.

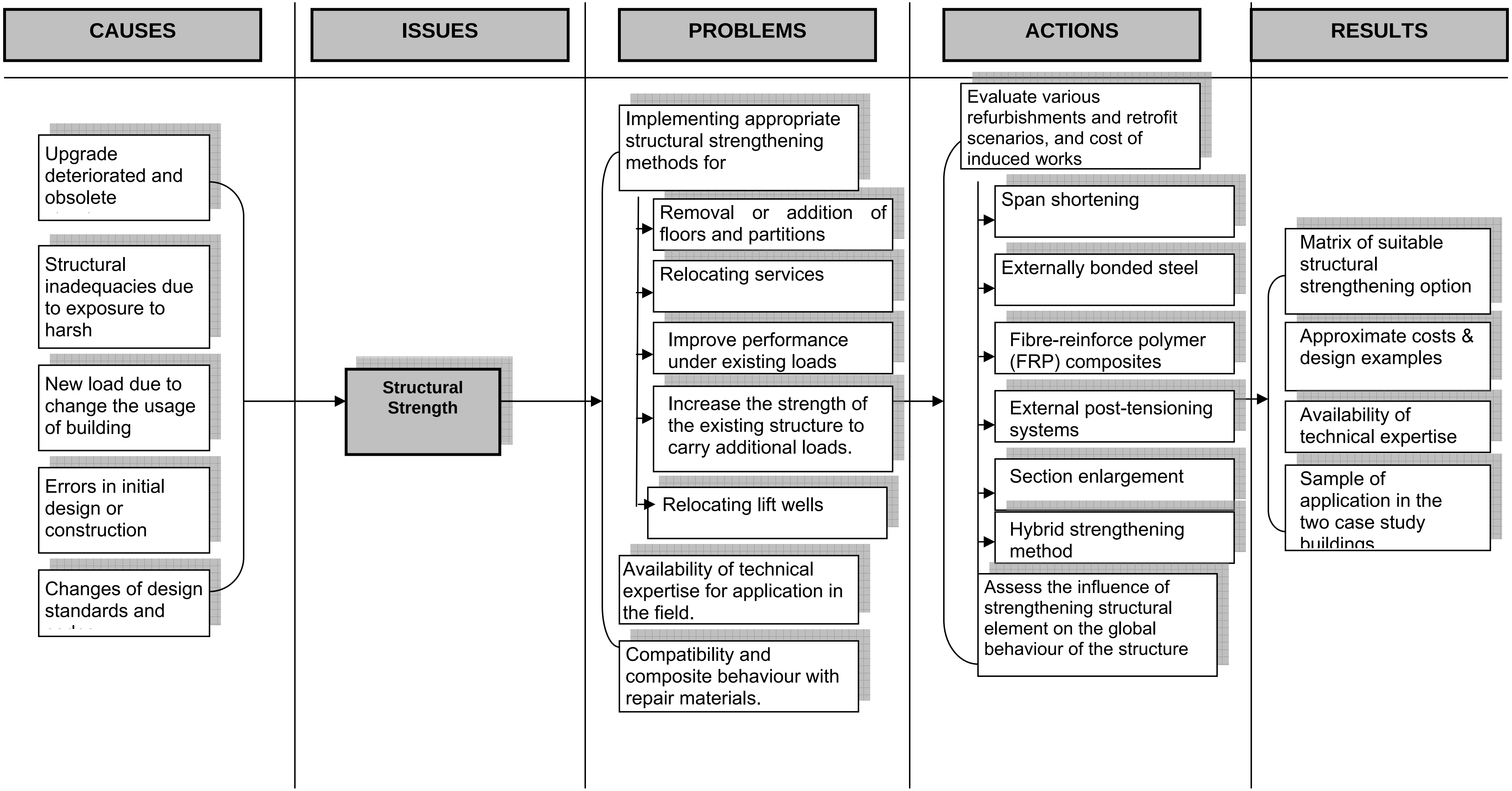
7.9 Actions needed at different stages of the project life cycle

Issues considered in optimising floor space have been mapped into the project development life cycle as shown in Table 7.5. These were then condensed into decision modules. A typical module for Structural Strength is given in Figure 7.15.

Table 7.5

ISSUES IN FLOOR SPACE OPTIMISATION AND STRUCTURAL STRENGTHENING AGAINST DEVELOPMENT PHASES

Re-life Project Development Phases						
Issues in Floor space optimisation and structural strengthening	**Conception**	**Feasibility**	**Design**	**Procurement**	**Construction**	**Operation**
● Structural Appraisal	□	□	□			
● Change of use of floors	□	□	□			
● Relocate/renew services	□	□	□	□	□	
● Structural Strength		□	□			
● Structural Safety		□	□	□	□	


CAUSES
ISSUES
PROBLEMS
ACTIONS
RESULTS
Upgrade deteriorated and obsolete
Structural inadequacies due to exposure to harsh
New load due to change the usage of building
Errors in initial design or construction
Changes of design standards and
Structural Strength
Implementing appropriate structural strengthening methods for
Removal or addition of floors and partitions
Relocating services
Improve performance under existing loads
Increase the strength of the existing structure to carry additional loads.
Relocating lift wells
Availability of technical expertise for application in the field.
Compatibility and composite behaviour with repair materials.
Evaluate various refurbishments and retrofit scenarios, and cost of induced works
Span shortening
Externally bonded steel
Fibre-reinforce polymer (FRP) composites
External post-tensioning systems
Section enlargement
Hybrid strengthening method
Assess the influence of strengthening structural element on the global behaviour of the structure
Matrix of suitable structural strengthening option
Approximate costs & design examples
Availability of technical expertise
Sample of application in the two case study buildings

RECOMMENDED ACTIONS		
	FEASIBILITY PHASE • Identify structural issues covering the causes listed • Identify the clients’ requirements and problems associated with structural strengthening. • Use the matrix to assess the feasibility of any potential solution. **DESIGN PHASE:** • Evaluate the selected solutions using the sample calculations • Establish availability of expertise for application on the field. • Detailed design to be undertaken by a qualified structural engineer.	

7.10 References

1. AS1170.1, Design Loads on Structures, Standards Australia 2004.
2. Alkhrdaji, T. & Thomas, J., “Upgrading Parking Structures: Techniques and Design Considerations”,Available online, http://www.structural.net/News/Media_coverage/media_csi.html , (download: February 2005).
3. Allehaux, D. and Tessier, P., 2002. “Evaluation of the functional obsolescence of building services in European office buildings”, Energy and Buildings, 34, pp:127-133.
4. Australian Safety and Compensation Council website http://www.ascc.gov.au/ascc/(download: February 2005)
5. Billington, S.,2003. “Impact of New Structural Systems and Materials on Construction Practice for Reduced Life-cycle Costs, CEE ,Available online http://blume.stanford.edu/Projects/Zhang/Research/Docs/CIFE-Proposal-for-webpage.pdf (download: February 2005)
6. Brosens, K. et al., 2001, "Strengthening of concrete structures with externally bonded reinforcement - Design philosophy and practical applications", 10th International Congress on Polymers in Concrete, Honolulu, Hawaii, USA.
7. Building and commission 2006 Brochure “What you need to know about Essential Safety Measures Maintenance” Available online, http://www.buildingcommission.com.au/resources/documents/Maintaining_Essential_Safety_Measures_FINAL1.pdf (download: February 2005)
8. Building and commission 2005 Brochure “A Consumer’s Guide Building in Victoria” Available online http://www.buildingcommission.com.au/resources/documents/Loc_Gov_Con_Guide.pdf(download: February 2005)
9. C.A. Lindman Brochure : Exterior Restoration and Structural repair, Available online http://www.calindman.com/htmlfiles/services1.htm1, (download: February 2005)
10. Chan, A. P. et al., 2001. “Application of Delphi method in selection of procurement systems for construction projects”, Construction Management and Economics, 19, pp:699-718.
11. Dascalaki, E., & Balaras, C. A., 2004. “XENIOS-a methodology for assessing refurbishment scenarios and potential of application of RES and RUE in hotels”, Energy and Buildings, 36, pp:1091-1105.
12. D. S. Brown Brochure, “Fiberbond FRP Structural Strengthening System”, Available online http://www.dsbrown.com/downloads/pdfs/Brochures/FRP/FRPbrochure.pdf, (download: February 2005)
13. Edge Structural Composites Brochure: Strength through technology, Available online http://www.edgest.com, (download: February 2005).
14. Einde et al., 2003. “Use of composites in civil structural applications”, Construction and Building Materials, 17, pp:389-403.
15. Environment Protection Authority,2004 Handbook for Pollution Avoidance on Building Sites - Second Edition”, Available online http://www.epa.sa.gov.au/pdfs/building_sites.pdf
16. Flourentzou, F. et al., 2000. “MEDIC-a method for predicting residual service life and refurbishment investment budgets”, Energy and Buildings, 31, pp:167-170.
17. Gordon, T.J., 1994. “The Delphi Method”, AC/UNU Milliennium Project.

18. Grace, N. F., 2004. “Concrete Repair with CFRP- Evaluating the durability of externally bonded fiber-reinforce polymer plates and fabric exposed to the environment”, Concrete International, pp:45-52.
19. Karbhari, V. M. & Zhao, L., 2000. “Use of composites for 21st century civil infrastructure”, Computer methods in applied mechanics and engineering, pp:433-454.
20. Lam, K. P. et al, 2004. “ SEMPER- II: an internet-based multi-domain building performance simulation environment for early design support, Automation in Construction, 13, pp: 651-663.
21. Linstone, H. A. & Turoff, M., 1975. “The Delphi Method Techniques & Applications”, Reading, Mass : Addison-Wesley Pub. Co., Advanced Book Program.
22. Morgan, D. R., 1996. “Compatibility of concrete repair materials and systems”, Construction and building materials, 10, 1:pp57-67.
23. News from the Cement and Concrete Industries, Concrete Monthly. “Design, application techniques key to successful structural repair, strengthening of aging concrete facilities”, Available online http://www.concretemonthly.com/monthly/art.php/516 , February 2004 Issue.
24. Rey, E., 2004. “Office Building Retrofitting Strategies: Multicriteria Approach of an Architectutal and Technical Issue”, Energy and Buildings, 36, pp:367-372.
25. Steelcase, Workplace Issues: One in a Series. “Reclaiming Buildings – Strategies”, Available online http://www.steelcase.com/Files/de9c9b911ac84b3bbdc25f352373316a.pdf (download: February 2005)
26. Toutanji, H. A. & Gomez, W., 1997. “Durability Charateristics of concrete beams externally bonded with FRP composite sheets”, Cement and Concrete Composites, 19, pp:351-358.
27. Van Gemert et al., 2004, "Strengthening of concrete constructions with externally bonded reinforcement: design concept and case studies", IMTCR 2004 innovative materials and technologies for construction and restoration, University of lecce, Italy.
28. Victorian work cover Safety1999 Industry Standard for Concrete Cutting. and Drilling”, Available online
29. http://www.workcover.vic.gov.au/vwa/publica.nsf/docsbyUNID/25C33AA05AD3BB38CA256FD3000892E9/$file/concrete.pdf(download: February 2005)
30. VSL Report series 1, “External Post-tensioning-Design Considerations, VSL External Tendons, Examples from Practice”, Available online http://www.vsl.net/downloads/VSL_technical_reports_PT_External.pdf , (download: February 2005)
31. VSL Strengthening Systems Brochure, Available online http://www.vsl.net/downloads/VSL_Construction_Systems/Sections/Strengthening.pdf, (download: February 2005)
32. Watson Bowman Acme Brochure, “Composite Strengthening Systems”, Available online http://www.wbacorp.com, (download: February 2005)
33. WorkCover NSW Health and Safety Code of Practice,2001 Risk assessment ”, Available online http://www.workcover.nsw.gov.au/NR/rdonlyres/EBAEAF8D-8F25-47F5-9CDE-F65FE7B1D712/0/cop_riskassessment_963.pdf(download: February 2005)
34. Queensland Government Department of Public Works, 2005 “Developed Design Report Appendix B1: Façade Condition Assessment 63 George Street: Integration of Office Buildings ”
35. Meinhardt (Vic) pty Ltd,2002 “REPORT BUILDINGS STRUCTURE AND BUILDING FAÇADE CH1 Building Melbourne City Council

36. Setunge, S., Nezamian, A. “A User friendly Guide for Rehabilitation or Strengthening of Bridge Structures using Fibre Reinforced Polymer Composites”, Accepted for publication by Standards Australia as a technical guideline.
37. Setunge, S., Nezamian, A., et al “ Case study: strengthening of Tenthill Creek Bridge”, Report 2002-005-C-2, 2004.
38. Dascalaki, E., & Balaras, C. A., 2004. “XENIOS-a methodology for assessing refurbishment scenarios and potential of application of RES and RUE in hotels”, Energy and Buildings, 36, pp:1091-1105.
39. Linstone, H. A. & Turoff, M., 1975. “The Delphi Method Techniques & Applications”, Reading, Mass : Addison-Wesley Pub. Co., Advanced Book Program.

Appendix D-1

CH1 Building Appraisal

(Source : REPORT BUILDINGS STRUCTURE AND BUILDING FAÇADE, Meinhardt (Vie) pty Ltd,2002)

REPORT 29/4/2002	The report was prepared by Meinhardt (Vie) pty Ltd for: CITY OF MELBOURNE (CH1 Building) 200 LITTLE COLLINS STREET MELBOURNE VICTORIA 3000
BUILDING DESCRIPTION	The building comprises of seven office levels, main roof, plantroom level and roof above four carpark levels including two underground basement levels. The building is a rectangular structure oriented in a North-South direction and its footprint reduces from level one up to the roof level. A small extension forms an open deck to the ground floor level at the Northeast corner. The building was linked to 225 Bourke Street building at the north elevation via suspended steel bridge structure at level 6. The link bridge system was built during 1990. The carpark structure was built approximately 60 years ago and the office structure was built approximately 35 years ago. The **office floors** of the building were designed for **1.7 kPa superimposed dead load and 2.4 kPa live load**. The **roof level** was designed for **0.8 kPa dead load and 2.87 kPa live load**. The **service area** was designed for **1.2 kPa dead load and 4.8 kPa live load.**
Carpark	The carpark structure primarily comprises of a reinforced concrete slab supported by secondary and primary beams and steel columns. The basement retaining walls were constructed of reinforced concrete. There are four accesses to the carpark. Each carpark level has it own access via the street level. There is no access from one carpark level to the others except the fire escape stairs.
Office levels	The office structure comprises **235mm thick** reinforced concrete flat slabs typically supported by the concrete encased steel columns and steel edge beams on the perimeter. The edge beams around the perimeter are part of the sway frame of the building resisting lateral loads. The services core is located centrally at the south end in the second last bay of the building. The reinforced concrete slab is **150 thick** in this area and is supported on the concrete encased steel beams with an infill masonry wall between floors.
Roof	The main roof structure is similar to the typical office level except the slab is **254 mm thick** and there is a double storey masonry clad building with a concrete slab supported by a steel frame located in the centra! area for the plant room and service quarters. The main roof and the plant platform roof are trafficable with a waterproof membrane and surface protection. Other mechanical equipment is also located on the main roof area.
BUILDING CONDITION **Carpark**	The inspection *was restricted to a visual examination of accessible areas* within the building and the exterior of the building from the ground level. **Visually the structure was found to be generally sound and in serviceable condition for its age. The floors typically appeared to be reasonably flat.** • Efflorescence and water stains were visible to the slab soffit at the downpipe, ductwork and conduit locations typically. • There were signs of moisture transfer through the slabs and corrosion to the downpipes and support angles. • Spalling of concrete to the slab soffit was also observed.

	• There is evidence of previous patching over some cracks and areas displaying concrete spalling. • There were signs of moisture penetration from behind in the basement walls along the East, West, and South elevations in the lower basement level. • It appears that the reinforcement has been corroded and the slab has deteriorated locally in the leakage areas. **Local repairs will be required to prevent further damage.** • Exposed steel connection plates at various column locations were evident. **Firespray to all exposed steelwork should be carried out to provide adequate fire rating level.** • Spalling of concrete was evident on the upstand parapets, walls and columns at various locations. This is likely to be due to car impact loads. **Minor repair is required.** • Minor sTab cracking was noted in the carpark mezzanine level. It appears that the cracks are in the screed layer only. • Minor shrinkage cracking to the masonry wall was evident in the plant room area. **It is not structurally significant.** • The asphalt topping over the ground floor carpark on the South side was damaged possibly due to spilled oil. **Minor repair is required**. • Previous records indicate that cracks to the underside of the carpark slab **<u>were surveyed and repaired</u>** in mid 1990.
Office levels	**The floors have been occupied as an office area. The structural elements such as the slabs, walls and columns were generally concealed. Some minor floor deflection was noticed. No significant structural defects were evident.** • There is evidence of previous patching over some cracks on level one soffit. • Existing cracks generally happened in the **<u>tension zone at the midspan of the slabs</u>**. We expect that cracks would also happened with similar pattern in other office floor slabs. • Previous records indicated that slab cracks have been repaired in late 1980's and early 1990's for level 1, 5, 6 and 7 and level 2 cracks have been repaired in late 1990's. • The expecting floor deflection is about **50mm plus** under the current toad condition, however there is only a minor floor deflection noticed, we expect that levelling screed has been applied to the floor at some stage. There was no record found in regard to the levelling screed. • It was noticed that the **<u>existing level one slab has been strengthened,</u>** at the north end of the building adjacent to the fire escape stair, for heavy loads **<u>by using steel beams connected to the existing steel columns</u>**.
Main Roof and Upper Roof	**Generally the roof is in a good condition.** • The previous record shows that the concrete roof slab has been repaired in early 1990's with two coats of mastic asphalt on isolating membrane installed on top of the existing concrete paving and membrane to prevent moisture transfer through the roof slab. • No water ponding was noticed at the time of the inspection. • The current waterproof membrane system appears to be in a good serviceability condition. Such roof membranes have a 15 - 25 year life, so **replacement can be anticipated in 10 years time.**
Plant Room	**Plant room floor slab and masonry walls appeared to be in good condition with no significant structural defects.** • Exposed shelf angle at lift motor room level was corroded on the west elevation. • Cracking in joint sealant was evident at the masonry control joint typically. • Capping to parapet walls in the upper roof was out of place on the

	west side. **Some minor repair is required**.
Stair Well	Minor cracking to stair landing was evident typically. **Repair is not required**
Shear wall	**Extensive cracking was evident** on the shear wall on the North elevation. Previous patching to cracks was observed also. **All cracks should be repaired with approved epoxy grout.**
TYPICAL FLOOR ANALYSIS AND AVAILABLE FLOOR LOADINGS	The original documentation indicates that the **concrete strength used was 28 MPa at 28days**. With the apparent age of the building, concrete strength would have **increased to around 1.4 times the 28days strength required** to be used for the design, and the long-term deflection would also have taken place. The **steel reinforcement** used in the slab has the yield strength of **410 MPa for top reinforcement** with deformed bars and **250 MPa for bottom reinforcement** with round bars.
Current Office Loading	The slab has been analysed with the **office loading of 3kPa live load**, as suggested by the Australian Standard for general office loading, and **1.2 kPa dead load** for screed and ceiling loads. The analysis indicates the slab has an **adequate capacity** for bending and shear under these loads. The maximum long-term deflection of the slabs was expected to be about **60mm** under the full load.
Available Structural Capacity	The analysis of the slab indicates an allowable **live load of 3.5 kPa -in the perimeter zone and 6.0 kPa in the central zone**. These loads make an allowance for permissible live load reductions and moment redistribution in accordance to the current codes. The slab in the central zone has more capacity than the perimeter, allowing the central zone to be used for relatively modest storage areas. It is expected that the long.term deflection of the slabs has taken place being due to permanent loadings over a 30 year period. The additional deflection under the available loading will be about 5mm. In order to bring the building typical floor to a quality office standard, the existing floor deflections, where evident, should be treated with levelling lightweight screed. Hence the **available floor loading for superimposed live loads would be 3.0 kPa in the perimeter zone and 5.5 kPa in the central zone.** These loads **still conform** to the requirements of the Australia Code but would **not meet the current requirements** of the Commonwealth Government for general floor loadings **being 4 kPa live load plus 1 kPa allowance for partitions**.
Existing column and footing	The analysis indicates that the existing columns and footings have an adequate capacity to accommodate the proposed new loads.
Design Consideration and Discussion	**Since the original design was undertaken, the current design code has been modified and become more stringent in the design of the reinforced concrete flat slabs**. The new analysis provides a more accurate result than the original design. It indicates the slab to have an allowable capacity of **3.0 kPa in the perimeter zone** and **5.5 kPa in the central zone**, assuming the allowance for lightweight leveling screed is 0.5kPa maximum. The new analysis also indicates that the maximum total long term deflection of the slab is expected to be **about 50-60mm in the perimeter zone**, which is about Span/173 to Span/144, and to be about **9mm in the central zone** which is about Span/833, under the full-applied loads. Documentation indicates the slab to have had a concrete screed applied to the structural surface to provide a level finish during construction. Therefore the above deflections would not be evident as the levelling screed was applied following the initial deflection of the slab under its self-weight. The initial deflection was about 17mm under the self-weight. Hence the long-term deflection of the slab surface would be expected to be **around 33-43mm**, which is about Span/263 to Span/201 in the perimeter zone.

	Under the fully-applied loads, the **maximum deflection does exceed the allowable deflection according to the current code**. As mentioned above the central zone has more capacity than the perimeter zone to support these heavy loads. The floor appears to be structurally adequate under the current floor-loading arrangement. **It is recommended that a structural assessment should be carried out for any future heavy floor loads.** Cracking of the slab in the tension zone has been recorded previously and remedial work has been carried out in early 1990's. Cracking in the tension zone is structurally acceptable, since the reinforcement in the cracked zone carries the tensile force induced by the applied loads.
Services Penetration	The structural review and inspections did not reveal deficiencies in the installation and reticulation of building services that may have an effect on the structure. It has, however, been reported that penetrations through floor and beams, particularly in the region of the service core, have not been properly treated to achieve or maintain the requisite fire-rating. This is a matter of good house-keeping and should be controlled by the building owner/manager. With total review of the services and, we believe, general renewal, the matter would be upgraded to satisfy the current regulations. We are not aware of significant services penetrations through the slab and close to columns that may have cut major reinforcing steel and have possibly been detrimental to the structural capacity of the floor system. Apart from maintaining the fire-rating of members by provision of adequate protection, the penetrations and their effects are not structurally significant.

Health& Welfare Building at 63 George St, Brisbane Appraisal

(Source: Developed Design Report Appendix B1: Façade Condition Assessment, Queensland Government Department of Public Works, 2005)

Location	Element	Hazard	Risk	Estimated Durability	Repair Maintenance
Facades					
SW (George Street) Elevation	Windows	Water penetration	High	Not serviceable	Replacement required (ST)
	Reinforced Concrete	Spalling concrete	Low	In excess of 15 years	No anticipated maintenance
	FC cladding	Fixings corrosion	Low	In excess of 15 years	Repair corroded screws (MT)
	Pebble aggregate	Delamination	Low	10 - 15 years	Repair minor defects (ST) Re apply clear sealer (MT)
	Jointing	Water penetration	High	Less than 5 years	Replacement required (ST)
	Not determined	Specific observed water penetration	High	current	Investigate and rectify (ST)
SE (Mineral House) Elevation	Windows	Water penetration	High	Not serviceable	Replacement required{ST)
	Brickwork	Instability	Medium	5-10 years	Brick tie replacement (MT)
	Cavity walls	Water penetration	Medium	Less than 5 years	Repair or encapsulate (81)
	Slab edges	Spalling concrete	Medium	5-10 years	Spalling concrete repairs (MT)
	Travertine	Delaminatiol1	Low	5-10 years	Crack repairs (MT)
	Pebble aggregate	Delamination	Low	10 - 15 years	Repair minor defects (ST) Re apply clear sealer (MT)
	Not determined	Specific observed water penetration	High.	Current	Investigate and rectify (ST)
SE (Rear) Elevation	Windows	Water penetration	Hillh	Not serviceable	Replacement required (ST)
	Window lintels	Instability	High	Current	Replacement required (ST)
	Brickwork	Instability	Medium	5-10 years	Crack repairs (ST) Brick tie replacement (MT)
	Cavity walls	Water penetration	Medium	Less than 5 years	Repair or encapsulate(ST)
	Concrete sills	Spalling concrete	High	Less than 5 years	Spalling concrete repairs (ST) Encapsulation (ST)
	Concrete ledges	Spalling concrete	Medium	5-10 years	Spalling concrete repairs (MT)
	Concrete ledges	Render delamination	Low	5- IO years	No anticipated maintenance

	Copper cappings	Water penetration	Medium	Less than 5 years	Encapsulation (ST)
	Mosaic tiles	Delamination	Medium	Less than 5 years	Repair drummy tiles (ST/ MT) Replace tiles (L T)
	Not determined	Specific observed water Denaturation	High	Current	Investigate and rectify (ST)
NE (Rear) Elevation	Brickwork	Instability	Medium	5-10 years	Brick tie replacement (MT)
	Cavity walls	Water penetration	Medium	Less than 5 years	Repair or encapsulate (ST)
	Slab edges	Spalling concrete	Low	10 - 15 years	Spalling concrete repairs (MT)
	Not determined	Specific observed water penetration	High	Current	Investigate and rectify (ST)
NW (Mary Street) Elevation	Windows	Water penetration	High	Not serviceable	Replacement required (ST)
	Brickwork	Instability	Medium	5-10 years	Crack repairs (ST) Brick tie replacement (MT)
	Cavity walls	Water penetration	Medium	Less than 5 years	Repair or encapsulate (ST)
	Mosaic tiles	Delamination	Medium	Less than 5 years	Repair drummy tiles (ST/J MT) Replace tiles (LT)
NW (David Longland Bid) Elevation	Roof flashings	Water penetration	High	0-5 years	Repair or replace (ST)
			Roofs		
Ground Floor Courtyard	Waterproof membrane	Water,. penetrations	High	Current	Replacement required (ST)
Level 8 Balcony	Waterproof membrane	Water penetration	High	Current	Replacement required (ST)
	Waterproof membrane	Note Asbestos removal hazard	Low	Current	Removal required (ST)
	Parapet flashings and cappings	Water penetration	High	Current	Repair or encapsulate (ST)
Level 9 Kliplok	Penetrations	Water Penetration	High	Current	Repair or replace (ST)

	Roof deck	Water penetration	Med	Current	Repair (ST)
Level 9 Plant	Penetrations	Water Penetration	High	Current	Repair or replace (ST)
	Waterproof Membrane	Water penetration	High	Current	Replacement required (8T)
	Wall finishing	Water penetration	High	Current	Repair or encapsulate (ST)
Level 9 Coper Pan	Penetrations	Water penetration	High	Current	Repair or replace (ST)
	Roof deck	Water penetration	High	Current	Replace or encapsulate (ST)
	Box Gutter	Water penetration	High	Current	Replace or encapsulate (ST)
	Parapet capping	Water penetration	High	Current	" Replace Of encapsulate (ST)
	Parapet flashings	Water penetration	High	Current	Repair or encapsulate (ST)

Appendix D-2 **Matrix of suitable structural strengthening options**

Structural Strengthening Solutions	Application Projects	Characteristic	Possible Applications	Issues Associated with the solutions	Companies/Contractors
1. **Externally bonded composite system** - **Fiber Reinforced Polymer (FRP)** - **Hardwire® Steel Reinforced Polymer (SRP)**	• Utility tunnel at a University in South Florida • Restoration of swimming pool roof structure, Kalmthout, Belgium	• speed and ease of installation • lower cost • aesthetic appeal • light weight • non-corrosive • excellent fatigue behaviour • non-conductive • can be used for flexural, shear, and axial (confinement) upgrading and crack control • due to thin profile, r/f can be easily run in two directions for two way slabs • allow for carpet, tile, and other flooring finishes to be installed over the system without any significant change in floor elevation	• concrete slab, beam, column and wall • wooden beam, column • masonry	• can damage the externally bonded composite • problematic in flooring applications when used on cracked concrete slabs as these cracks may allow reflective cracking throu' polymer topping.	• VSL International Ltd • Structural Preservation System (USA) • Edge Structural Composites (USA) • C.A. Lindam Companies (USA) • Watson Bowman Acme Corp. (USA)
2. **Section Enlargement**		• relatively easy method • not good in harsh environment. Possible corrosion of embedded reinforcing steel. • can increase load carrying capacity or stiffness • additional concrete can be placed in the form of an overlay or jacket	• concrete columns, beams, slabs	• Increase the weight of existing structure. weight can be minimised	• VSL International Ltd • Structural Preservation System (USA)
3. **External Post-tensioning**	• Two-span steel truss bridge (48-48m) over River Aare at Aarwangen, Switzerland • Pier 39, Parking Structure San Francisco, USA • Double-tee stems on an overpass located on the premises of a University in Washington. Damaged due to overheight truck.	• Possibility of controlling and adjusting the tendon forces, inspecting corrosion protection and replacing tendons. • can be used for both reinforced and prestressed concrete • minimal additional weight to the repair system • economical • requied less time to complete • can be used for flexural , shear and axial (confinement) upgrading	• Applicable for structural steel, composite steel-concrete, timber and masonry structures. e.g. building with masonry walls, girders in buildings, roof structures, circular structures such as silos, reservoirs and large masonry chimneys. • great success to correct excessive deflections and cracking in beams and slabs, parking structure and cantilever members. • due to minimal additional weight of repair system, this is effective and ecconomical for long span beams • existing concrete structures against fatigue and cracking	• vulnerable to corrosion, fire and vandalism. However, improved ductility & fire proofing can be achieved by placing reinforcement in ducts that can grouted after stressing of tendon. Protection can also be achieved by encasing the post tensioning system in concrete or by using shotcrete. • Externally bonded bars can be damaged by traffic. However, that can be prevented by installing the system in grooves made in existing member. • requies access to sides and sometimes ends of member	• VSL International Ltd • Structural Preservation System (USA) • C.A. Lindam Companies (USA)
4. **Bonded steel element**	• Quatier des Celestines, a 19th century building in Namur	• Steel element can be steel plates, channels, angles or built-up members • steel elements can be bonded with epoxy adhesive. In addition to epoxy, mechanical anchors can be used to ensure steel element will share loads in case of adhesive failure. • can improve shear and flexural strength	• Steel plate bonded to tension face of concrete beam can increase flexural capacity, flexural stiffness and in deflection and cracking decreases • Steel plate bonded to side of the member can improve shear strength of concrete beam. • install structural steel beams on the underside of structures and steel brackets at column heads. • long-term solution for structures subjected to aggressive environment	• influence to corrosion and fire.Suitable corrosion protection system and fire protection system can be used. • due to their restrictive length, steel elements need to be spliced which complicate the design and construction operation • existing reinforcement can be damaged while placing the anchors. Considerable site work is required to accurately locate existing reinforcement. • Expensive false work is required to maintain the steel work's possition during bonding. • Adding strengthening material under existing structure may redue the usable headroom	• VSL International Ltd • Structural Preservation System (USA) • C.A. Lindam Companies (USA)

Structural Strengthening Solutions	Application Projects	Characteristic	Possible Applications	Issues Associated with the solutions	Companies/Contractors
5. **Span Shortening**	• Shortened span in Parking Garage	• reduce the force in overstressed beam • increase the load carrying capacity • best material for this application is steel, which is quick to install.		• result in loss of space and reduced headroom. • New footing for new column is expensive less expensive approach is to install diagonal braces that extend from the bases of existing columns	
6. **Hybrid strengthening method** eg. steel/CFRP	• Strengthening of a roof system of an elementary school in New Jersey. They wanted to install skylight on existing roof slab. • Transformation of former school building to library • Roof structure of warehouse at Brussels in Belgium (due to calculation error,capacity of main supporting beams are not suticient)	• less expensive • aesthetically pleasing • fast application	• slab with opening • rib slabs		• Structural Preservation System (USA)
7. **Removing existing concrete and casting with lightweight concrete overlay (with steel wire mesh or steel bar)**	• Baltimore's historic Hippodrome Theater renovation -France	• increase bending capacity by increasing effective depth of existing bottom r/f • at support, embedded steel steel r/f in overlay increase the bending capacity • r/f in overlay limits cracking of overlay	• concrete slab and beam	• adequate surface preparation is required to ensure the bond between overlay and existing structure • overlay replace existing topping and therefore small increase in dead load, which offset by using lightweight concrete.	• Structural Preservation System (USA)
8. **Hardwire**	• Baltimore's historic Hippodrome Theater renovation -France	• hardwire made of ultrahigh strength steel wires twisted together to form reinforcing steel cords wires bonded to existing structures with epoxy adhesive • hardwire works as additional r/f to provide tensile strength	• reinforced and prestressed beams, girders, and slabs to provide additional flexural strength. • can be used on sides of beams and girders to provide additional shear strength. • can be used on structural elements to increase their capacity.		• Structural Preservation System (USA)
9. **Hardwire steel belt with polymer flooring system**	• Leading national home improvement warehouse • multi-story warehoue/ distribution facility for a large automative parts distributor in illionis	• hardwire does not replace today's polymer flooring system. However, additon of hardwire dramatically strengthens retrofitflooring design capabilities. • combination of polymer flooring with these thin steel belts creates a system with the ability to increase structural capacity, blast resistance and general toughness of concrete • ability to integrate with multiple polymer and cementitious materials	• heavy trafficked warehouses, manufacturing slabs, elevated slabs, slabs on pile construction, and slabs that are structurally deficient from improper design or construction • viable solution where emission and odors are an issue.		• Structural Preservation System (USA)
10. **Replacing existing wire system with encapsulated monostrand post tensioning system**	• Parking Garage in New York	• existing structure to be post tensionned system • time and cost effective			• Structural Preservation System (USA)
11. **Epoxy mortar**	• Timber floor in a castle	• can be used to strengthen old timber structures. excellent material to repair wood because it has strong bond to wood and MOE is nearly equal to wood.	• Timber - A large groove was sawed on top side of the beam. Steel r/f has been placed in these groove. Then grooves are filled wth epoxy mortar.		

Appendix D-3 Typical design examples

Bonded Steel Elements:
e.g.: bonded steel plate to existing steel beam.

Design Calculations:

Existing simply supported steel beam 406UB54 of 8 m span
New loading service *D.L.*= 20 kn/m
service *L.L.*= 30 kn/m
For ease of welding select a plate that is wider than the beam
Try 9 mm * 250 plate fy =400 n/mm
W = *D.L.* + *L.L.*
W = 20 + 30 =50 kn/m

$M^* = \frac{WL^2}{8}$ = 400 kn/m

Required $Z_X = \frac{M^*}{fy}$ = $1000*10^3$ mm^3 > Z_X =$930*10^3$ mm^3

Required plastic moment to carry the load = fy * ($Z_{x,\text{ required}}$) = 400 kn m

Max plastic moment the beam can resist = fy * ($Z_{x,\text{ provided}}$) = 372 kn m

Properties of UB:
b_f = 177.7 mm d= 402.6 mm $Z_x = 930*10^3$ mm^3
t_f = 10.9 mm t_w= 7.7 mm
K= 21 mm $A_s = 69.0*10^2$ mm^2
Properties of plate:
$A_{PL} = 22.5 * 10^2$ mm^2
$A_{f\text{ (flange area)}} = b_f * t_f$ = 1936.93 mm^2
$A_{w\text{ (web area)}} = (d - 2K)\ t_w$ = 2776.62 mm^2
$K_{dep} = K - t_f$ = 10.1 mm

$A_k = \frac{(A_s - 2A_f - A_w)}{2}$ = 124.76 mm^2

$\frac{A_k}{K_{dep}}$ = 12.35 mm

$K_{dep} + t_f = K$ = 21 mm

Since the section is under a uniform yield stress, the area in tension must equal the area in compression.
Determine the location of the PNA (natural axis); assume if falls within the web for the first try,

Area in compression = Area in tension

$= \frac{(A_s + 2A_{PL})}{2}$ = 4575 mm^2

$A_f + A_k + t_w\ (y - K)$ = 4575 mm^2

y = 347.4 mm from top.
Check, $d - y$ = 55.2 mm > K
$\therefore$ The PNA is located within the web.

Find plastic force in various component of the section

Force = *(F_y) (Area)*

$$C_1 = \frac{400 * 1936.93}{10^3} = 774.77 \text{ kn}$$

$$C_2 = \frac{400 * 7.7}{10^3} = 3.08 \text{ kn}$$

$$C_3 = \frac{400 * (347.4 - 21) * 7.7}{10^3} = 1005.31 \text{ kn}$$

$$T_1 = \frac{400 * (402.6 - 347.4 - 21) * 7.7}{10^3} = 105.33\text{kn kn}$$

$$T_2 = \frac{400 * 124.76}{10^3} = 49.90 \text{ kn}$$

$$T_3 = \frac{400 * 1936.93}{10^3} = 774.77 \text{ kn}$$

$$T_4 = \frac{400 * 22.5 * 10^2}{10^3} = 900 \text{ kn}$$

Sum the moments from those forces about the PNA
Force * Distance from PNA = Plastic moment M_p

Force kn	Distance mm	Plastic moment kn m
C_1 = 774.77 kn	341.95	264.93
C_2 = 3.08 kn	331.45	1.02
C_3 = 1005.31 kn	163.2	164.07
T_1 = 105.33kn	17.1	1.80
T_2 = 49.90 kn	39.25	1.96
T_3 = 774.77 kn	49.75	38.54

T_4 = 900 kn	59.7	53.73

526.05 kn m

M_P = 526.05 kn m > M^* = 400 kn
$\therefore$ OK

$\therefore$ use 9 mm* 250 mm plate

Find the required length of plate

First, determine the theoretical cutoff points x where the moment does not exceed that resisted by beam section alone

W = 50 kn/m

$R_u = \dfrac{50*8}{2}$ = 200 kn

$200\,x - 50\,x^2/2 = 372$

$25\,x^2 - 200\,x + 372 = 0$

$x^2 - 8\,x + 15 = 0$

$(x - 5)(x - 3) = 0$

x= 5 m & 3 m

The actual cutoff points are moved closer to the supports by the amount of required weldings

Force in the weld = Plastic Capacity pf plate = $A_{PL}\,(F_Y)$

$F_{(weld)} = 22.5\ m^2 * 10^2 * 400 / 10^3 = 900$ kn

Use 6 mm fillet welt for joining a flange & a plate. Use two welds at each end of the plate

Capacity of 3 m weld = $0.6\ f_{uw}\ t_t\ k_r$

$= 0.6 * 410 * 6 * 1 / 1000$

= 1.476 kn/mm

required length of weld = $F_{(weld)}$ / 1.476 = 900 / 1.476

= 610 mm = 0.61 m

The actual cutoff point 3- 0.61 m = 2.33 $\approx$ 2.3 m

& 5 + 0.61 m = 5.61 $\approx$ 5.6 m

Total length plate is 5.6 – 2.3 = 3.3 m

The plate should be cantered between supports

Bonded Steel element : Cost

Cost for welding 9 mm thick 250 m wide plate to 406 *178 * 54.1 kg/m UB = A $ 119 / m run

External Post tensioning
Sample calculations given in CRC Report 2 – 2002-005-C (Setunge et al, 2005)

Cost:

Cost for external tensioning of 800 * 450 beam with 6 * 12.7 mm strands = $ 600 /m

Cost for external tensioning of 1200 * 450 beam with 6 * 12.7 mm strands = $ 750 /m

FRP
Sample calculations are given in Setunge et al, 2005)

Cost for wrapping on concrete surface 80 mm wide 1.2 mm thick fabric = $ 154.00

Cost for wrapping on concrete surface 90 mm wide 1.2 mm thick fabric = $ 168.00

Cost for wrapping on concrete surface 120 mm wide 1.2 mm thick fabric = $ 252.00

Cost for wrapping on concrete surface 120 mm wide 1.4 mm thick fabric = $ 280.00

Section Enlargement

e.g. Beam.

Initial size = 1000 *500 ,   Initial load = 100 kn/m

New size = 1000 * 900   Initial rebar = 6N32 (tension)

Design Calculation

f_{cu} = 32 MPa , f_y= 500 MPa , L= 10 m

Beam to carrty 50% more load

M^* = $W L^2$ / 8 = 1875 kn m

$R_u = \frac{M^*}{bd^2}$ = 2.57

$P = \frac{A_{st}}{bd}$ = 0.0069

A_{st} = 6210 mm^2

Additional A_{st} = 2000 mm^2

Additional rebar = 4N24

Cost

Beam enlargement cost = A$ 1150 / m run

(1000*500 to 1000 * 900 & to carry 50% more load)

Span shortening system

e.g. Beam (350 wc230)

Initial load = 100 kn/m span = 10 m

50% increase in load, how much to shorten the span

Initial $M^* = WL^2 / 8 = 100 * 10^2 /8 = 1250$ kn m

New $M^* = WL^2 / 8 = 150 * L^2 /8$

$1250 = 150 * L^2 /8$

$L = 8.1$ m

Provide additional support (e.g. steel column) at mot more than 8.1 m span to increase load carrying capacity of beam by 50%

Span shortening Cost

Cost for shortening of 10 m span steel beam with 175 * 175 * 32.8 kg/m UC = A$ 269.00 / m run

Appendix D-4 Table D1 Typical floor loading for office floors AS1170.1 (2004)

REFERENCE VALUES OF IMPOSED FLOOR ACTIONS			
Type of activity/occupancy for part of the building or structure	**Specific uses**	**Uniformly distributed actions kPa**	**Concentrated actions kN**
A Domestic and residential activities (also see Category C)			
A1 Self-contained	General areas, private kitchens and laundries in self-contained dwellings	1.5	1.8(1)
	Balconies, and roofs used for floor type activities, in self-contained dwellings—		
	(a) less than 1 m above ground level	1.5	1.5 kN/m run along edge
	(b) other	2.0	1.8(1)
	Stairs(2) and landings in self-contained dwellings	2.0	2.7
	Non-habitable roof spaces in self-contained dwellings	0.5	1.4
A2 Other	General areas, bedrooms, hospital wards, hotel rooms, toilet areas	2.0	1.8(1)
	Communal kitchens	3.0	2.7
	Balconies, and roofs used for floor type activities, with community access	same as areas providing access but not less than 4.0	1.8
B Offices and work areas not covered elsewhere	Operating theatres, X-ray rooms, utility rooms	3.0	4.5
	Work rooms (light industrial) without storage	3.0	3.5
	Offices for general use	3.0	2.7(3)
	Communal kitchens	3.0	2.7
	Commercial/institutional kitchens	5.0	4.5
	Laundries	3.0	4.5
	Laboratories	3.0	4.5
	Factories, workshops and similar buildings (general industrial)	5.0	4.5
	Balconies, and roofs used for floor type activities	same as areas providing access but not less than 4.0	1.8
	Fly galleries (in theatres, etc.)	4.5 kN/m run uniformly distributed over the width	—
	Grids (over the area of proscenium width by stage depth)	2.8	—

Type of activity/occupancy for part of the building or structure	Specific uses	Uniformly distributed actions kPa	Concentrated actions kN
C Areas where people may congregate			
C1 Areas with tables	Public, institutional and communal dining rooms and lounges, cafes and restaurants(5)	2.0	2.7
	Reading rooms with no book storage	2.5	4.5
	Classrooms	3.0	2.7
C2 Areas with fixed seats(6)	Institutional assembly areas such as classrooms, lecture theatres and similar	3.0	2.7
	Public assembly areas such as public halls, theatres, courts of law, auditoria, conference centres and similar	4.0	2.7
	Places of worship	4.0	2.7
C3 Areas without obstacles for moving people	Corridors, hallways, aisles, stairs(2), landings(2), concourses, terraces, plazas, etc., not subject to wheeled vehicles	4.0	4.5
	Corridors, hallways, aisles, stairs(2), landings(2), etc. subject to wheeled vehicles, trolleys, etc.	5.0	4.5
	Footpaths, terraces and plazas at ground level subject to wheeled vehicles	5.0	31(4)
	Museum floors and art galleries for exhibition purposes	4.0	4.5
	Balconies, and roofs used for floor type activities	same as areas providing access but not less than 4.0	1.8
C4 Areas with possible physical activities (see Note to Clause 3.1(b))	Dance halls and studios, gymnasia	5.0	3.6
	Drill halls and drill rooms	5.0	9.0
C5 Areas susceptible to overcrowding (see Note to Clause 3.1(b))	Assembly areas without fixed seating (concert halls, bars, vestibules, public lounges, places of worship, shopping malls) and grandstands	5.0	3.6
	Stages in public assembly areas	7.5	4.5
D Shopping areas	Shop floors for the sale and display of merchandise	4.0	3.6

Appendix D-5

List of OH&S code of practise for all states *(Source: Australian Safety and Compensation Council http://www.ascc.gov.au/ascc/, 2006)*

Victoria: Victorian WorkCover Authority 1800 136 089
www.workcover.vic.gov.au

Australian Capital Territory: ACT WorkCover (02) 6205 0200
www.workcover.act.gov.au

New South Wales: WorkCover NSW 13 10 50
www.workcover.nsw.gov.au

Northern Territory: NT WorkSafe 1800 019 115
www.nt.gov.au/deet/worksafe

Queensland: Department of Industrial Relations QLD 1300 369 915
www.dir.qld.gov.au/workplace/index.htm
WorkCover QLD 1300 362 128
www.workcover.qld.gov.au

South Australia: WorkCover SA 13 18 55
www.workcover.com
SafeWork SA 1300 365 255
www.safework.sa.gov.au

Tasmania: WorkCover Tasmania 1300 366 322
www.workcover.tas.gov.au

Western Australia: WorkSafe WA 1300 307 877
www.safetyline.wa.gov.au
WorkCover WA 1300 794 744
www.workcover.wa.gov.au

Commonwealth : COMCARE 1300 366 979
www.comcare.gov.au

Appendix D-6 safety checklist published by the Victorian WorkCover Aurity

Job Safety Analysis worksheet

Company name: ____________________ Date: __________ JSA no. __________

Site name: ____________________ Permit to work required: Yes ☐ No ☐

Contractor: ____________________ Approved by: ____________________

Activity: ____________________

Activity *List the tasks required to perform the activity in the sequence they are carried out.*	**Hazards** *Against each task list the hazards that could cause injury when the task is performed.*	**Risk control measures** *List the control measures required to eliminate or minimise the risk of injury arising from the identified hazard.*	**Who is responsible** *Write the name of the person responsible (supervisor or above) to implement the control measure identified.*

Remember: Each JSA must be site specific. Include all workers in the development of this JSA

SAFETY CHECKLIST

Site and equipment safety

Contractor's name: ____________________

Type of job: ____________________

Site location: ____________________

Operator's name: ____________________

1. Check the SITE for SAFETY

On arrival at the site tick the correct answer where relevant to the job. If the answer is NO the situation is unsafe. Alert the office.

SITE EVACUATION	Checked with client	YES ☐	NO ☐
	Located first aid/accessible	YES ☐	NO ☐
SCAFFOLDING	Erected as required	YES ☐	NO ☐
SERVICES located/marked	Electricity	YES ☐	NO ☐
	Gas	YES ☐	NO ☐
	Other	YES ☐	NO ☐
VENTILATION	Adequate	YES ☐	NO ☐
LIGHTING	Barricades in position	YES ☐	NO ☐
	Warning signs displayed	YES ☐	NO ☐
	Lighting in place	YES ☐	NO ☐
	Traffic control in place	YES ☐	NO ☐
TRAFFIC/PUBLIC SAFETY	Barricades/signs in place	YES ☐	NO ☐
FIRST AID	Located	YES ☐	NO ☐

2. Check the EQUIPMENT for SAFETY

On setting up tick the correct answer, where relevant to the job and equipment. If the answer is NO the situation is unsafe. Alert your employer.

FLOOR SAW	Shaft nut secure	YES ☐	NO ☐
	Belt tensioned and undamaged	YES ☐	NO ☐
	Adequate water and waterways clear	YES ☐	NO ☐
	Flaps in place	YES ☐	NO ☐
	Guards in place	YES ☐	NO ☐
HAND HELD SAW	Belts tensioned and OK	YES ☐	NO ☐
	Flange locking nut secure	YES ☐	NO ☐
	Water supply adequate	YES ☐	NO ☐
	Guards in place	YES ☐	NO ☐
WALL SAW	Tracks securely fastened	YES ☐	NO ☐
	Blade secured	YES ☐	NO ☐
	Job wedged/securely supported	YES ☐	NO ☐
WIRE SAW	Pulleys secure	YES ☐	NO ☐
	Hydraulic pressure correct	YES ☐	NO ☐
DRILLS	Electric switch, plug and lead safe	YES ☐	NO ☐
	Water collar operable	YES ☐	NO ☐
	Carriage clamp and shims operable	YES ☐	NO ☐
BLADES AND BITS	No undercutting evident	YES ☐	NO ☐
	Blanks free of cracks	YES ☐	NO ☐
	All segments secure	YES ☐	NO ☐
ELECTRICAL LEADS	Plugs in good condition	YES ☐	NO ☐
	Outer casing intact	YES ☐	NO ☐
	Correctly tagged	YES ☐	NO ☐
	RCDs fitted	YES ☐	NO ☐

8. OVERALL CONCLUSION

This project focused on the timely issues of refitting office building projects in the wake of increased interests and demand on these types of projects. The project team forms the view that there is a significant stock of ageing buildings that will require re-lifing and at the same time, there is an increased commitment to sustainability which encourages the exploration of all re-life options.

In dealing with the complex issue of relifing throughout the project lifecycle, industry opinions were sought then incorporated into the development of decision-making tools. Combined with researcher's independent input and wide ranged literature study, these opinions have then been tested and consolidated to knowledge input of decision making that will meet industry expectations. The best practice guidelines provide an integrated and consistent way of examining whole of life issues for buildings intended for refurbishment, thus avoiding ad hoc decisions made in isolation by particular stakeholders.

Due to the unavailability of case study projects, there is a need for on-going research to cover issues identified for the development phases of *Construction* and *Operation*. Cross referencing with other research projects will also be beneficial. The research team looks forward to working with the industry partners to disseminate the information of this research. Proposals have been made to the CRC-CI to convert the modules of the Best Practice Guide into web-based computer tools, and to further develop the lessons learned into educational materials and publication for the benefits of the whole industry. This will further raise the profile and public awareness on the importance of relifing projects.

List of Figure

List of Photo

List of Table