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Integrating Deconstruction into the Project Delivery Process

Chinwe Isidianso

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

December 2007

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DEDICATION

To the immortal, invisible and only wise God, in whom I live and have my being
many thanks for the fortitude to complete this research.
ACKNOWLEDGEMENT

I am deeply grateful to my supervisors Professor Chimay Anumba and Dr. Jamal El-Rimawi for their guidance, support, and insight throughout this research. I would also like to thank the academic and support staff in the department who through various means have assisted my work.

Many thanks to the respondents and participants who took time from their busy schedules to complete questionnaires. I would also like to thank Mr Hans Vos the project manager at SEV Realisatie, who took time from his busy schedule to give me an interview for the case study.

I am forever indebted to my mum who has supported me unconditionally through the rigours of this research. To my friends and research colleagues for their patience and kind assistance throughout the last three years.

Finally, to my friend Ruth who has always believed in me.
ABSTRACT

Considering deconstruction as a means of achieving sustainable construction, would enable the construction industry to address some of its environmental problems. In addition, the growing pressure from the public and legislation for environmental considerations, means that there is now a need for the construction industry to increasingly consider the recycling and reuse of building components used in constructing buildings.

The deconstruction of buildings provides the construction industry with the opportunities to effectively deal with its unsustainable construction practices. One of the approaches taken by industry to facilitate the adoption of deconstruction is designing a building with the intention of disassembly instead of demolition at the end of its useful life. This concept is known as Design for Deconstruction (DFD). Although some research works have been undertaken to support and establish deconstruction into current construction practice, there is little or no guidance for practitioners on how best to do this. This need to fully integrate the concept of design for deconstruction into the current project delivery process is the basis of this research.

In order to contextualise, corroborate and develop the research, a review of existing literature on sustainable construction and deconstruction was undertaken. Following from the review of literature, a survey and case study were undertaken to explore the current practice of deconstruction and investigate a practical example of sustainable construction practice that reflects the integration of deconstruction principles within the building process. The findings from the review of literature, the survey and case study were used to develop a mechanism for integrating deconstruction into the building process. The mechanism is a process model for the construction industry to implement the concept of DFD from inception to completion of a building project and throughout a building’s lifecycle. Evaluation of the developed process model was carried out by industry practitioners to assess its suitability and practicability. The feedback from the evaluation established that the process model is effective in enabling some aspects of sustainability principles such as designing to minimise waste and encouraging the reuse and recycle of building materials and components. Several benefits and potentials of the process model were also identified.
Thus, in this research, it can be concluded that integrating the concept of deconstruction into the construction project delivery process can assist the industry to better reuse and recycle building materials and achieve a sustainable environment. Furthermore, the expected impact of the research on the construction industry is a practical process model that can be used to incorporate the concept of deconstruction into the project delivery process. This can be adopted at all the stages of the building process and would benefit the industry as it offers a solution to reduce the environmental impacts caused by its activities.

Key Words: deconstruction; project delivery process; DFD; sustainable construction
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CHAPTER 1 INTRODUCTION

1.1 Introduction

This chapter presents the background to this research, the justification for the research, the research aim and objectives, and an outline of the research methodology. The thesis structure is also presented to guide and inform the reader about the direction and content of the thesis.

1.2 Background to the Research

This research is concerned with the complex issue of achieving sustainability in construction. Studies have suggested that during the design, construction and demolition of buildings, the construction industry produces large quantities of waste, depletes natural resources and pollute the environment (Floodman and Lenseen, 1995; Spence and Mulligan, 1995). As a result, the International Council for Research and Innovation in Building and Construction (CIB) has set up a number of initiatives (such as TG08 on Environmental Assessment of Buildings, TG16 on best practice for Sustainable Construction and TG39 on Deconstruction) aimed at achieving sustainable development and addressing the negative environmental impacts resulting from its activities (Sjostrom and Bakens, 1999). Deconstruction or dismantling of buildings has been identified as one of the possible solutions to achieving sustainability and addressing the negative environmental impacts associated with construction activities (Hurley et al, 2001; Addis and Schouten, 2004; Morgan and Stevenson, 2005).

The main problem of achieving sustainability in construction is how to design and construct buildings, such that waste minimisation and possible reuse or recycling of building components and materials becomes part of the building process. The conventional life cycle of a building process is usually design, construction, use, maintenance, demolition and, finally, disposal. Generally, no consideration is given to the reuse or recycling of building materials and components during the design and construction process. However, the construction industry must change its approach to producing buildings as construction has been identified as a major user of energy
resources, pollutes the environment, generates considerable waste and depletes natural resources. For example, data from the European commission indicate that construction activities consume more raw materials by weight (as much as 50%) than any other industrial sector. In addition, the data shows that the built environment accounts for the largest share of greenhouse gas emissions (about 40%) in terms of energy usage (Roodman and Lenssen, 1992). Clearly, the construction sector has a major impact on the environment.

Following the publication of the Bruntland report, which defined the process of 'sustainable development', Agenda 21 was initiated (UNCED, 1992) for the sole purpose of setting targets and objectives on how best to achieve sustainable development in a global, national and local levels. It also provided a conceptual framework for industries (such as the construction industry) to address sustainability issues. These issues are mainly defined and described within the three broad themes of social, economic and environmental objectives and goals. Others (e.g. Zhou and Lowe, 2003) have defined the concept of sustainability in construction in terms of 'hard issues' (e.g. materials, building components, construction technologies and energy related design concepts) and 'soft issues' (e.g. social, culture, economic and management issues). Various research studies (Kibert, 1994; CIB, 1998; Bourdeau, 1999) suggest that through the exploration of all these issues in the building process, the construction industry may achieve sustainable development objectives.

The industry is beginning to respond to the challenge of addressing sustainable issues particularly the negative impacts of its activities on the environment (see Figure 1.1). Addressing these environmental issues in a sustainable way would involve changing the life cycle of a building from a linear process to a cyclic process. That is, instead of the demolition and disposal of a building at the end of its life (which has a negative impact on the environment) deconstruction or dismantling of the building should be encouraged. For this purpose, deconstruction is defined (Guy and Shell, 2002; Durmisevic and Brouwer, 2002; Dantata et al., 2004) as the selective dismantling or disassembly of building structures to facilitate the efficient reuse or recycling of components and building materials to reduce environmental damage.

Clearly, integrating this concept of deconstruction into the current building process should result in a better reuse and recycling of building materials and components, thus
achieving better sustainable development. Therefore, there is a need for finding a lasting solution for improving, and perhaps changing, the current building lifecycle approach.

1.3 Justification for the Research

The concept of sustainable development is leading to a fundamental re-evaluation of the contribution that industries and services make to the quality of life. The construction industry, as a major sector of most national economies must contribute to the sustainability agenda. The construction industry is responsible for creating buildings in the built environment and the decision whether to demolish or retain an existing building has considerable significance in the pursuit of sustainable development in the built environment. Economically, the decision may seem relatively simple but if the principles of sustainable development are to be adopted, the implications become more complex (Sayce et al., 2004). These principles involve addressing environmental and social issues in decision making to achieve the objectives of sustainability. Incorporating sustainability principles can be viewed as a new paradigm within the building process. This means sustainability objectives have to be considered at all stages of the life-cycle of a building (Kibert, 1994). Furthermore, to align these principles with the traditional criteria of building design (such as cost, performance and quality), the construction
industry must change the linear process of creating buildings to a cyclical process (Miyatake, 1996). This provides professional practitioners and researchers a unique opportunity to find effective solutions and approaches by which sustainability principles can be integrated into the building process.

The bulk of the research to date on the building process has focused on environmental assessment and evaluation tools, life-cycle assessments/analyses of building materials, and energy efficiency of buildings. There is insufficient research on the integration of sustainability principles (such as the reuse and recycle of buildings and materials) throughout the life cycle of a building. Deconstruction of buildings is part of the drive to achieve a more sustainable practice especially in the area of waste management and environmental issues (McGrath et al., 2000). Deconstruction encompasses a thorough and comprehensive approach to whole building disassembly (which is different from selectively picking specialty items), allowing the majority of the materials to be salvaged for reuse (Languell and Kibert, 2000). Therefore, implementing deconstruction principles throughout the life-cycle of a building process would assist the industry in achieving sustainable construction practice. This makes deconstruction a viable alternative to demolition and land filling at the end of a building’s life.

Thus there is a need to investigate how to effectively integrate deconstruction into the project delivery process, as a means of enhancing sustainability in the construction industry.

1.4 Research Questions

The research questions based on the background and justification for the research are listed below:

- What are the current issues of sustainable construction and its implications to the building process?
- What are the current challenges for implementing Design for Deconstruction (DFD) into the building process?
- What is the level of awareness and practice of sustainability with respect to deconstruction in the UK?
• What practical examples in construction practice relate to the deconstruction principles?
• How can deconstruction be integrated effectively into the project delivery process in construction?

1.5 Research Aim and objectives

The overall aim of this research is to propose a mechanism for integrating the concept of deconstruction into the project delivery process. The specific objectives of the project include:

• to review the concept of sustainable development and identify the current issues and implications for the construction industry;
• to review the concept of design for deconstruction (DFD) and related concepts in the construction industry;
• to obtain a broad based knowledge from the construction industry in the UK on the awareness and practice of sustainability with respect to deconstruction;
• to undertake a case study of a practical example of implementing sustainable construction which reflects deconstruction principles in conventional building practice; and
• to propose a mechanism for the integration of deconstruction principles into the project delivery process.

1.6 Research Methodology

An outline of the research process and methods are presented in Figure 1.2, which shows the main activities undertaken. The research was divided into five parts based on the research objectives with each part linked to the outputs (in this case the chapters) leading to the aim of the research. A brief summary of the research methods are described below. Full details of the research methodology with the justification of methods used are given in Chapter 2.
WHY?

To review the concept of sustainable development and identify the current issues and implications for the construction industry.

To review the concept of design for deconstruction (DFD) and related concepts in the construction industry.

To obtain a broad based knowledge from the construction industry in the UK on the awareness and practice of sustainability with respect to deconstruction.

To undertake a case study of a practical example of implementing sustainable construction which reflects deconstruction principles in conventional building practice.

To propose a mechanism (with guidelines) for the integration of deconstruction principles into the project delivery process.

WHERE?

Chapter 1: Introduction

Chapter 2: Research Methodology

Chapter 3: Sustainable Development in Construction

Chapter 4: Design for Deconstruction

Chapter 5: Investigation of Current Deconstruction Practice

Chapter 6: Development of the Deconstruction process Model

Chapter 7: Development of Building Deconstruction model

Chapter 8: Evaluation of the Deconstruction Process Model

Chapter 9: Summary and Conclusions

HOW?

Literature review

Questionnaire Survey and Case Study

Process Model Analysis

Focus Groups

Figure 1.2: Outline of Research Methodology
Literature Review: An initial literature review was carried out on the subject of sustainable development and sustainable construction so as to identify the research gaps and the areas of concern for sustainability in construction. This was mainly to narrow the scope and aim of the research, as the concept of sustainable development is complex and far-reaching. The concept of deconstruction in construction was then identified as the research area. A work programme was then developed, which included the objectives of the research, tasks and activities to be undertaken as means of designing appropriate data collection and analysis methods to carry out the research.

A further literature review was carried out on the subject of sustainable construction with respect to deconstruction. The structured review investigated the role of deconstruction in sustainable construction, design for deconstruction (DFD), DFD in manufacturing, enablers and barriers to DFD in construction and requirements for applying DFD in construction. The literature review was aimed at identifying the particular issues of the deconstruction process in the construction industry that can encourage the integration of design for deconstruction into the building process.

Questionnaire Survey and Case Study: An exploratory survey has been undertaken in the form of questionnaires with phone interviews to professionals, practitioners and researchers. This helped in clarifying the current needs of the industry in order to achieve sustainability through the concept of deconstruction. In addition, it identified the main barriers to implementing deconstruction and the type of tools that industry would require. The survey broadened the understanding of the research issues. It highlighted the specific issues that can encourage the integration of deconstruction into the building process. This led to a case study of an organisation, that has carried out demonstration projects (which reflects deconstruction principles in conventional building practice). The analysis of the case study indicated that there was a need to incorporate deconstruction into the project delivery process, as it would be beneficial significant for the construction industry to achieve sustainability. Therefore, an extensive literature review covering process models used by construction professionals to execute the building process has been conducted.

Process Model Analysis: The development of the process model was as a result of the findings from the survey and case study. A number of process models (such as RIBA...
Plan of Works, ADePT, Process Protocol) have been developed for process modelling in construction. Having examined and reviewed some of the existing process models, the 'Process Protocol' was adopted as the best option for integrating the concept of deconstruction into current construction practice. As a result, a detailed analysis was carried out and a process model for deconstruction was developed. A further complimentary model was also developed for decomposing the building based on the concept of “system of systems”. This model is part of the proposed deconstruction process model and is implemented from Phase 4 through to Phase 10. The aim of the model is to facilitate the building decomposition process.

Focus Group: This was carried out through workshops to evaluate the proposed Deconstruction Process Model (DPM). Participants in the workshops, mainly construction professionals and researchers, were then selected to fill out a questionnaire to assess the effectiveness, scope and usability of the DPM.

1.7 Thesis Structure

Chapter One: Introduction
This chapter presents the general introduction to the research and discusses the background to the research. It justifies the need for the research and outlines the aim and objectives. It also provides a brief summary of the research methodology and structure of the thesis.

Chapter Two: Research Methodology
This chapter reviews a number of research methods. It describes the development and application of the research methodology in this research with justification for adopting the various research methods.

Chapter Three: Sustainable Development in Construction
The literature review on sustainable development, sustainable construction is undertaken in chapter 3. It focuses mainly on the framework for implementing sustainability in construction, the principles of sustainable construction and the existing tools for implementing sustainability in construction. Having examined the key issues in sustainable construction, deconstruction was identified as one of the solutions for implementing sustainable construction practices.
Chapter Four: Design for Deconstruction
This chapter introduces and describes the process of deconstruction in the Construction industry. It focuses on the role of deconstruction in sustainable construction, design for deconstruction, other related concepts in construction and design for disassembly in manufacturing. It concludes with identifying the barriers and enablers of implementing deconstruction and the issues that need to be addressed so as to meet the requirements of DFD in construction.

Chapter Five: Investigation of Current Deconstruction Practice
Based on findings obtained from chapter 3 and 4 a questionnaire and a case study were implemented. The development of these, and analysis of the main results are presented in this chapter. The chapter concludes with recommendation for the implementation of deconstruction into the project delivery process.

Chapter Six: Development of Deconstruction Process Model
In this chapter the steps taken to develop the deconstruction process model are presented. In addition existing process models in construction are reviewed, the most suitable process model is selected and reasons for choosing it is discussed. The process model is then considered, together with the factors and issues of deconstruction identified in chapters 5, to develop the deconstruction process model. A detailed description of the model and its main features is also presented in this chapter.

Chapter Seven: Development of Building Decomposition Model
In this chapter important issues related to building decomposition model have been considered. This includes, a discussion of the needs for developing the model, an assessment of existing models, and an evaluation of the criteria and requirements defining decomposition models in construction. In addition, a description of the building decomposition model and the important issues related to its implementation are also presented. and finally, a discussion of the benefits of using the model in the project delivery process is presented.

Chapter Eight: Evaluation of the DPM
A description of the aim and objectives of the process adopted for evaluating the models is presented in this chapter. This includes a description of the methodology used and the
feedback from participants. Based on these results, suggestions for improving the DPM have been considered. The benefits and limitations for using the DPM are discussed. A summary of the chapter is given with comments on the appropriateness of evaluation approach.

Chapter Nine: Summary and Conclusions
This chapter summarises the findings of this research, presents its limitations and offers recommendations for future research. It includes a summary of the general findings of this research, a comprehensive conclusion, and a discussion of the main limitations affecting its findings. Finally, recommendations for extending the scope of the current research have been made.

1.8 Summary

This chapter presented an overall view of this research. It defined the general scope covered and the main aim and objectives to be achieved. The need for implementing and achieving sustainability in construction projects, and the problems associated with its application in the building process have been identified. One important finding is the conclusion that the concept of deconstruction needs to be integrated into the building process.

The importance of the research and its significance to the construction industry's pursuit of sustainable construction was also highlighted. The general outline of this report and the logical development of the main ideas has been described.
CHAPTER 2 RESEARCH METHODOLOGY

2.1 Introduction

This chapter reviews existing research methodologies used in construction research. It discusses the relevance and adoption of these methods in undertaking this research. A justification is also provided for the choice of methods.

2.2 Concepts of ‘Research’ and ‘Research Methodology’

Research has been described as a systematic and a methodical approach of investigating a problem that requires a solution (Fellows and Liu, 2003; Neuman, 2006). The application of research to problem solving is generally dependent on two broad approaches: pure and applied research (see Table 2.1).

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Pure research</th>
<th>Applied research</th>
</tr>
</thead>
<tbody>
<tr>
<td>Purpose</td>
<td>focused on developing or enhancing theory</td>
<td>conducted to solve current problems</td>
</tr>
<tr>
<td>Reasoning Method</td>
<td>research is carried out for the advancement of knowledge, without working for long-term economic or social benefits and with no positive efforts being made to apply the results to practical problems or to transfer the results to sectors responsible for its application.</td>
<td>Applied research is original investigation undertaken in order to acquire new knowledge. It is, however, directed primarily towards a specific practical aim or objective.</td>
</tr>
<tr>
<td>Hypothesis</td>
<td>Pure research is for the sake of curiosity and functions to advance knowledge for its own sake. A typical example is government funded projects carried out by a university research facility.</td>
<td>Applied research is for the sake of technological advancements. This research anticipates that the results found will lead to the development of commercially viable goods or processes.</td>
</tr>
</tbody>
</table>

Source: (Fellows and Liu, 2003)

There is a relationship between these two types of research: pure research generates new knowledge and applied research is directed at the practical application of knowledge.
Chapter 2: Research Methodology

to develop new products or processes (Fellows and Liu, 2003). This is a simple paradigm to understand research methodology.

Research methodology has been described as the application of principles and procedures through a logical thought process to investigate a problem (Melville and Goddard, 1996; Fellows and Liu, 2003). The framework of investigating a problem is generally influenced by the different philosophical assumptions and research methods (Creswell, 2003; Bryman, 2004). Thus, in common with most research investigations the research philosophy and research methods which guided this research is described in the next sections.

2.3 Research Philosophy

Within the research community, several perspectives exist on the appropriate paradigm for conducting and understanding the philosophical position of a research (Bryman, 2004). According to Easterby-smith et al., (2003), it is important that the researcher understands the philosophical position of a research and its relationship to the research methodology by:

- making an informed decision to clarify the research approach;
- identifying the constraints that may affect the research methods; and
- identifying the appropriate research method(s) that will be suitable for the research.

The philosophical position or assumptions used to describe the nature and characteristics of a research include the terms 'ontology' and 'epistemology'. Ontology is concerned with the nature of social entities and how they exist within a structure of reality (Bryman, 2004). While, epistemology involves the question of what is (or should be) the acceptable knowledge in a discipline and the methods used to investigate the development of this knowledge (Bryman, 2004). According to Crotty (2003), ontological and epistemological issues in a research are likely to be interrelated. This is because the theoretical perspective of a research would involve a process of understanding 'what is' (ontology) and a way of understanding 'what it means to know' (epistemology) a particular issue. The nature and characteristics of both theoretical positions are summarised in Table 2.2.
### Table 2.2: Summaries of Philosophical Assumptions.

<table>
<thead>
<tr>
<th>Ontological considerations</th>
<th>Epistemological considerations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Realist</td>
<td>Positivist</td>
</tr>
<tr>
<td>• external world comprises pre-existing hard and tangible structures.</td>
<td>• Considers social world exists externally and is objective in nature</td>
</tr>
<tr>
<td>• Structures exist independent of individual's ability to acquire knowledge</td>
<td>• Advocates application of the methods from natural sciences</td>
</tr>
<tr>
<td></td>
<td>• quantifiable observations are measured with statistical analysis to draw inferences about a phenomenon.</td>
</tr>
<tr>
<td>Relativist</td>
<td>Interpretivist</td>
</tr>
<tr>
<td>• Existence of multiple realities as subjective construction of the mind</td>
<td>• reality is constructed by researcher's understanding and interpretation of real world</td>
</tr>
<tr>
<td>• Perception of reality is directed by varying socially transmitted terms</td>
<td>• Is concerned with meanings and experiences people associate with the real world.</td>
</tr>
<tr>
<td></td>
<td>• denotes an alternative to the positivist orientation.</td>
</tr>
</tbody>
</table>

Source: (Love et al., 2002; Bryman, 2004).

#### 2.3.1 Philosophical Position of this Research

The ontological and epistemological position was not defined at the outset of this research but a position is assumed to guide the selection of appropriate research methods.

This research was instigated by the researcher's belief that the concept of design for deconstruction can assist the construction industry to better implement sustainable design in the building process and, thus attain sustainable development objectives. The research is not concerned with the intricacies of the building methods and techniques of design for deconstruction but more with the process in which the construction industry can use to adopt and integrate DFD into the current building process.

Thus in this research, the ontological and epistemological considerations that were assumed is identified. The realist position is assumed from a theoretical perspective because the research can explore associated practices (academic and industrial) in the construction industry that are related to the concept of design for deconstruction. This
means the researcher is able to reflect on the existing ideas and identify a different view of the situation, which sometimes may be regarded as new theory (Remenyi et al., 1998).

Furthermore the positivist position is about applying natural sciences methods to study a social phenomenon by using evidence of formal propositions, quantifiable measures of variables, hypothesis testing to draw inferences (Easter-Smith et al., 2001; Bryman, 2004). It emphasises objectivity, through clarifying, measuring and controlling a social phenomenon (Easter-Smith et al., 2001). The implication for the researcher is an objective perspective that possibly maintains a neutral stance in conducting a research. In contrast, to the positivist position, the researcher can adopt an interpretivist position to understand a social phenomenon through generalisations (Bryman, 2004). Harriss (1998) points out that the interpretivist position is subjective in perspective and based on the preconceived beliefs and background knowledge of the researcher.

Thus, in this research an interpretivist position is adopted, acknowledging that there are studies which have identified the concept of design for deconstruction as one of the approaches to assist sustainable building design. However, the need and how best to integrate design for deconstruction into the project delivery process is the subject of this research.

2.4 Review of Research Methods

2.4.1 Research design

Research design is about exploring appropriate methodologies that would ultimately provide a solution to the initial research objectives of a study (O'Leary, 2004). It is also a logical sequence that links general empirical data to the objectives of a study as well as reaching a conclusion (Yin 1994). Various research methods have been developed in order to address research questions with objectives (Creswell, 1994). These research methods can be put together to support and complement one another (FrankFort-Nachmais and Nachmias, 2000). However, choosing the most appropriate method(s) can be very difficult, and consideration must be given to the purpose and nature of the study (Robson, 2002; O'Leary, 2004). Historically, research methods can be classified
into two types: qualitative and quantitative. However, certain research questions lend themselves more to quantitative approaches, whereas others are more suitable for investigation by qualitative methods (see Table 2.3). It is important to utilise and appreciate both quantitative and qualitative research methods as both can complement each other. Although a number of studies insist that they are very different, drawing on their similarities would help to make a better research (Onwuegbuzie and Leech, 2005).

Table: 2.3: Characteristics of the Research Methods

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Quantitative research (aka. Empirical or Analytical)</th>
<th>Qualitative research (aka. Interpretive)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Purpose</td>
<td>To generalise about or control phenomena</td>
<td>To provide in-depth descriptions of settings and people</td>
</tr>
<tr>
<td>Reasoning Method</td>
<td>Primarily Deductive: Specific predictions based on general observations, principles, or experiences.</td>
<td>Primarily inductive: Generalisation based on specific observations and experiences.</td>
</tr>
<tr>
<td>Hypothesis</td>
<td>Identified prior to research purpose of research is to test it.</td>
<td>Begins with guiding research questions, which will be refined during data collection and analysis.</td>
</tr>
<tr>
<td>Nature</td>
<td>More narrowly focused and outcome oriented</td>
<td>Holistic and process oriented</td>
</tr>
<tr>
<td>Design</td>
<td>Clear, well-ordered sequence of steps</td>
<td>Flexible and changeable during research</td>
</tr>
<tr>
<td>Interaction with context</td>
<td>Tries to eliminate the influence of contextual variables</td>
<td>Tries to capture the richness of the context of the subjects and their perspectives</td>
</tr>
<tr>
<td>Data Collection</td>
<td>Primarily numerical data through paper-and-pencil, non-interactive instruments (can also include narrative data)</td>
<td>Primarily narrative data, collected from field work( can include narrative data)</td>
</tr>
</tbody>
</table>

Source (Gay and Airasian, 2003)

2.4.2 Quantitative Research

Quantitative research is objective in nature and can provide explanations for social phenomena or processes such as standardisation (Sarantakos, 1998). It is defined as
an inquiry into a social or human problem, based on testing hypothesis or theory composed of variables, measured with numbers, and analysed with statistical procedure to determine whether the hypothesis or theory holds true’ (Creswell, 1994). There are two main types of quantitative research: experiments and surveys. A brief description on each of these research methods is presented below. Table 2.4 describes the advantages and disadvantages of utilising these methods.

Table 2.4: The Advantages and Disadvantages of Quantitative Methods

<table>
<thead>
<tr>
<th>Quantitative methods</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
</table>
| Surveys              | • Very good for factual information gathering  
                      • Cost of execution is low compared to other methods  
                      • Reduced limitations on geographical reach especially with e-mails | • Not entirely effective with complex and sensitive data  
                      • Questions can often be misinterpreted and no chance for clarification especially when mailed  
                      • Responses can be subjective |
| Experiments          | • The ability of the researcher to control the variables.  
                      • The researcher is able to measure the extent of change.  
                      • The researcher is able to evaluate the cause and effect of relationships. | • It is difficult to use this method when studying people-related issues  
                      • It is often done in a controlled environment without external factors  
                      • It is often time-consuming |

Source: (McQueen and Knussen, 2002)

2.4.1.1 Surveys

A survey is described as a blend of sampling, question design and data collection of the characteristics, actions, or opinions of a certain group of people (Fowler, 2002). The
different ways in which a survey is carried out to collect data amongst a group of people and/or on a subject area include: mail and telephone interviews. These means of collecting data when applied to a research or study, requires that information to be collected in a standardised and scientific way.

2.4.1.2 Experiments

Experiments measure the effect of manipulating one variable with another variable and seeks to establish causal relationships between variables (Keepel, 1991). The experimental method can be carried out systematically, through observation and a trail; trail because the answer is not known beforehand, observation because the result must be carefully recorded (Melville and Goddard 1996). Experimental research can be classified into: causal-comparative, true experiment and quasi-experiment. The main characteristic of experimental research is that it involves manipulation, randomisation and utilisation of controlled groups or variables.

2.4.2 Qualitative research

Qualitative research can be described as being multi-method in focus, involving an interpretive and naturalistic approach to the subject matter (Denzin and Lincoln, 2000). It is often designed to observe detailed descriptions of situations, social interaction, understand behaviours and perspectives, as well as give insight to peoples experiences (Patton, 1990). The reasons for choosing a qualitative approach instead of a quantitative one include the following:

- the research question must consider the how or what to describe the given topic or phenomena;
- there must be a need to explore the topic or phenomena;
- a detailed view of the topic or phenomena must be presented;
- the topic or phenomena must be studied in a practical or natural setting;
- the literal style of writing must be employed to narrate the findings;
- there should be sufficient time and resources involved in data collection and analysis;
- the results of the study should be useful and have implications for the future; and


- the researcher must be perceived as a participant or active learner (Creswell, 1998).

Just like quantitative research, qualitative research involves a variety of methods. Some of these methods include grounded theory, ethnography and case studies (see Table 2.5 for a comparison of these methods). Data collection in qualitative research design is usually determined by the qualitative research method used to carry out the study. For example, the case study approach would involve documents and records, interviews, observation, and physical artefacts (Creswell, 1998).

### Table 2.5: Comparison of Qualitative Research Methods

<table>
<thead>
<tr>
<th>Dimension</th>
<th>Grounded Theory</th>
<th>Ethnography</th>
<th>Case Study</th>
</tr>
</thead>
<tbody>
<tr>
<td>Focus</td>
<td>Developing a theory</td>
<td>Describing and interpreting a cultural and social group</td>
<td>Developing an in-depth analysis of a single case or multiple cases</td>
</tr>
<tr>
<td>Discipline origin</td>
<td>Sociology</td>
<td>Cultural anthropology, Sociology</td>
<td>Political science, sociology, evaluation, urban studies, many other social science</td>
</tr>
<tr>
<td>Data collection</td>
<td>Typically interviews with 20-30 individuals to 'saturate' categories and detail a theory</td>
<td>Primarily observation and interviews during extended time in the field</td>
<td>Multiple sources - documents, archival records, interviews, observations, physical artefacts</td>
</tr>
<tr>
<td>Data analysis</td>
<td>Open coding, axial coding, selective coding, conditional matrix</td>
<td>Description analysis, interpretation</td>
<td>Description, themes, assertions</td>
</tr>
<tr>
<td>Narrative form</td>
<td>Theory or theoretical model</td>
<td>Description of the cultural behaviour of the group</td>
<td>In-depth Study of a 'case' or cases</td>
</tr>
</tbody>
</table>


### 2.4.3 Triangulation

The term ‘Triangulation’ can be interpreted in social research as a methodology which involves the use of multiple research methods and/or measures of a phenomenon for validity and to minimise issues of bias (Black, 1993). Creswell (2003) describes triangulation as a mixed method approach, which involves both quantitative and approaches qualitative in a single study or multiple studies in a sustained program of inquiry. Triangulation is a logical way of representing the true picture of a study or
Chapter 2: Research Methodology

phenomena by carrying out multiple measurements (Denzin, 1989). A combination of quantitative and qualitative methods can be described as triangulation. A number of studies have advocated the benefits of combining both quantitative and qualitative research methods (Kelle, 2001; Eldabi et al, 2002; Love et al, 2002). Onwuegbuzie and Leech (2005) point out that both methods have inherent strengths and weaknesses, therefore, researchers should harness these strengths to maximise research objectives and questions. Creswell (2003) advocates that the integration of both quantitative and qualitative methods in a single study would enhance the effectiveness of a study and the validity of the outcomes.

Table 2.6: Comparison of Quantitative and Qualitative Research

<table>
<thead>
<tr>
<th>Points of comparisons</th>
<th>Quantitative Research</th>
<th>Qualitative Research</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paradigm/assumptions</td>
<td>Positivism/empiricism</td>
<td>Subjectivism, interpretivism, constructivism</td>
</tr>
<tr>
<td>Methodology</td>
<td>Scientific method, hypothesis-driven, deductive, reliable, valid, reproducible, objective, generalisable</td>
<td>Ethnomethodology, phenomenology, ethnography, action research, inductive, subjective, idiographic, intuitive</td>
</tr>
<tr>
<td>Methods/Samples</td>
<td>Large-scale, generally surveying, randomly selected respondents</td>
<td>Small-scale, interviewing, observation, document analysis, respondents selected to fulfill a given quota or requirement</td>
</tr>
<tr>
<td>Data type</td>
<td>Self-administered questionnaires, experiments, structured observation, structured interview</td>
<td>Conversation and analysis, focus groups, unstructured and semi-structured interviews</td>
</tr>
<tr>
<td>Outcome/Analysis</td>
<td>Content analysis/statistical analysis and a recommended final course of action</td>
<td>Non-statistical, thematic exploration, findings can be generalised</td>
</tr>
</tbody>
</table>


Clearly, combining the two methods should lead to a better understanding of the study under investigation as additional information would be revealed that will otherwise remain undiscovered with a single methodical approach. This agrees with Robson (2002) who suggests that using a single method limits the researcher to having one standpoint as the results obtained are restricted to aspects and attributes of that method. The researcher therefore would benefit from combining both methods in order to realise the best results for the study. For example using a quantitative method such as a questionnaire can provide a broad view on the subject of study and combining it with a qualitative method
Chapter 2: Research Methodology

(such as a case study) would provide a better understanding and result. A comparison of both qualitative and quantitative methods is shown in Table 2.6.

2.5 Methods Adopted

The effectiveness of the selected methods depends mainly on the nature of the research (Bernard, 2000). The subject of this research is concerned with the process of designing and constructing buildings in a sustainable way. This is part of the broader field of construction management. Research in construction management can be described as the convergence of applied science and social science (Love et al, 2002; Eldabi et al, 2002). This study combines both qualitative and quantitative research methodologies so as to reflect and represent both aspects of the sciences in construction management research. The framework of the adopted research methodology has been based on five components: the purpose of the research, the theory, the research questions, the methods and the sampling strategy. The following section describes the methods.

2.5.1 Literature Review

In order to establish the state of art in the subject of the research, a literature review on the vast subject of sustainable development and sustainable construction was undertaken. The importance of carrying out a literature review was based on the premise that the generation of new knowledge on the concept of deconstruction in construction is fundamentally dependent on past knowledge (Fellows and Liu, 2003). The review helped in developing the theoretical basis of the research, provided the context and the main themes for addressing the objectives of the research, and helped in identifying the gaps in knowledge and research methods that were relevant to this research. O'Leary (2004) points out that literature review is essential in research and gives the researcher a criterion for establishing the credibility of the research. Therefore, an extensive review of existing literature (professional and academic publications, and information on the internet) was conducted. In addition, seminars, conferences and workshops were attended to develop a better understanding of the relevance of the research to industry.

2.5.2 Questionnaire Survey

20
A comprehensive questionnaire survey based on question design, sampling and data collection and analysis was undertaken. It was used as a basis for addressing the objectives of the research and for gathering information on the views of construction professionals on integrating the concept of deconstruction into the building process.

**Questionnaire design** — This is an important aspect of a Questionnaire survey as it has an influence on the return, accuracy and success of the results (Fellows and Liu, 2003; Creswell, 2003). The questionnaire is ‘a prepared set of questions in which respondents record their answers in an administered survey’ (Sekaran, 2003). The questions can be open-ended or closed or a combination of both types of questions. The choice of which type of a question largely depends on what the researcher aims to achieve. In this research both types of questions were used. The advantage of open-ended questions is that the respondent’s answer is not limited within the frame of reference, thus there is less bias in the findings (Marshall, 1997).

**Sampling** - The purpose of the survey was exploratory in nature, therefore it provided a straightforward approach for identifying the views of a number of construction professionals on the subject of deconstruction. Sampling has been described as a unit of analysis used to evaluate the phenomena of interest from the sample population of respondents targeted for the research (Patton, 1990). The importance of the sampling frame is based on the source of the eligible population from which the survey sample is drawn. The sampling strategy depends on the prior decision of an adequate unit of analysis for the study. The various types of sampling plan can be divided into two categories: probability and non-probability samples (Robson, 2002). Probability samples are often based on circumstantial evidence of the population being studied through statistics, while non-probability samples are not based on statistics. Based on the latter, a sampling approach known as purposive sampling was adopted. This type of sampling allows for addressing specific needs of a project or a research. For example, the specific needs of this research were to identify professionals in their organisations who indicated interest in implementing sustainable construction practice.

**Data collection** — There are two main methods of administering questionnaires: electronic (Web-based or e-mail) and postal. A postal mail survey was used and considered more appropriate for the research, as it was cost effective and can ensure a
high degree of respondents’ anonymity. Chapter 5 gives a full description of how the questionnaire survey was undertaken.

2.5.3 Case-study

The purpose of the case study was to describe and discover the implementation of deconstruction principles in the project delivery process. There are several opinions on what constitutes a case study. A case study can be viewed as the aim of a research (Stake, 1995; Blimas, 2001) or it can be regarded as a methodology to explore and explain the research phenomena in detail (Merriam, 1998; Yin 2003). It can also be described as an exploration of a ‘limited system’ or a case (or multiple cases) over time through a detailed and an in-depth data collection involving multiple sources of rich information in context (Creswell 1998). The context of a case involves positioning a case within its setting which may be physical, social, historical or economical. There are three main classifications of case studies: single or collective, multi-sited or within-site, has a focus on a case or an issue (unique, instrumental) (Stake, 1995; Yin 2003). The approach used by the researcher is dependent on the aim and objectives of conducting the research. Thus, in choosing a case study, it is important to consider how the case would highlight the different perspectives of the problem, process or event under study or selection based on accessibility or uniqueness of the case. This often presents the following challenges:

- identifying the bounded system of study and its relevance in addressing the issue or selected case;
- the choice between a single or multiple case study;
- establishing the rationale or purpose behind the case study;
- having sufficient information to present an in-depth picture of the case so as not to limit the value of the case; and
- deciding the “boundaries” of the case (i.e. constraints such as time, events and processes) (Creswell, 1998).

The data collection process of a case study often involves gathering information from multiple sources. Yin (2003) recommends six sources of information: documentation, archival records, interviews, direct observations and physical artefacts. After the data collection process, there is a need to give a detailed description of the case by analysing the themes that have emerged from the case or interpretation of the issues and making
an assertion of the case (Stake, 1995). This sets the precedence for analysing the case and arriving at conclusions or lessons. Yin (2003) points out that the analysis should be holistic covering the entire case or an embedded part of the case addressing a specific aspect. A number of critics suggest that the case study method (especially a single case study) have no grounds for establishing reliability or generality of findings. However, in general, the case study methodology has potential for increased validity because of the multiple data-collection techniques (interview, document study, observation, quantitative statistical analysis) which are used (Robson, 2002). The weakness of each technique can be counter-balanced by the strengths of the other techniques, thereby providing validation.

2.5.4 Development of the Deconstruction Process Model

The findings from the literature review on sustainable construction and design for deconstruction provided the basis and relevant information for developing a deconstruction process model. The results of the survey and case study also provided information on the current industry practice of sustainability with respect to deconstruction.

In addition, a review of existing process models in construction was carried out. This provided guidance and a holistic approach in developing the model. Furthermore, to ensure the relevance and functionality of the model in construction practice, continuous review of the model was carried out with various construction professionals (including researchers, architects, engineers). Finally, the model was evaluated by industry practitioners. A full description of the model is presented in chapter six and seven.

2.5.5 Evaluation of the Model

Evaluation is an important aspect of developing any construction process improvement. The evaluation process was undertaken to ascertain the general perception of the acceptance and practicality of the deconstruction process model. An evaluation approach can be used to solve important problems as well as contribute to the refining of a proposal. It is also designed to capture relevant data and feedback from participants involved in the evaluation process. Stufflebeam, (1985) suggests that several approaches should be applied in evaluating a proposal in terms of the uniqueness and
underlying principles. On the other hand, Miser, 1993 points out that there are no universal criteria for validation, and that any validity judgement depends on the situation in which a model is used and the phenomena being modelled. As a result, a model can be validated with a qualitative approach such as focus group (smith, 1993).

The focus group method is a widely accepted qualitative research technique that is used to collect data through group interaction (Morgan, 1997; Puchta and Potter, 2004). It contains elements of two methods: the group interview, in which participants discuss a number of issues related to a particular situation; and a focused interview, in which participants are selected because they are known to have been involved in a particular situation. This means a focus group technique is a form of group interview in which (Bryman, 2004):

- participants are selected because they are known to have been involved in a particular situation or have a certain experience;
- a moderator/facilitator must guide the sessions using predetermined questions;
- a form of interaction amongst the participants is encouraged to explore in depth the topic that is the subject of the research.

However, a focus group technique typically differs from the group interview in that it is dependent on the interaction within a group to explore and discover an in-depth interpretation of a topic (Morgan, 1997). The researcher facilitates the interaction by providing a topic to guide the process of interaction between participants. On the other hand, a group interview would involve a process of interviewing a number of people at the same time, were the emphasis is on questions and responses between the researcher and participants.

This implies that the main purpose of focus group research is to draw upon participants experiences and reactions in a way in which would not be feasible using other methods such as questionnaire surveys and interviews (Morgan 1998). The researcher (facilitator) is then offered the opportunity to study the ways in which participants collectively make sense of a particular topic by gathering responses and transcribing it in a useful way to construct meanings.

This is clearly an important consideration in the context of this research since the viewpoints of participants (construction professionals in the industry) in assessing the
suitability of the DPM for integrating deconstruction into the project delivery process is significant in evaluating the model. The details of the evaluation approach and results are presented in chapter Eight.

2.6 Summary

A review of research methodologies was undertaken. This chapter described the overall research methods adopted in carrying out the research project. The research methods used to address the research objectives and questions are summarised in Table 2.7 below. Each research question is addressed by adopting a research method. The primary method used to achieve each objective of the research is supported by a secondary method which agrees with the notion that a mixed method approach or triangulation should be used in construction management research (Love et al, 2002). This suggests a balanced approach to the research and eliminates the shortcomings of using a single research method.

The relevance of adopting and implementing these research methods were discussed in accordance with the objectives of the research. The next chapter reviews sustainable development in the construction industry.
Table 2.7: Summary of Research Methods Used

<table>
<thead>
<tr>
<th>Objectives</th>
<th>Research Questions</th>
<th>Literature Review</th>
<th>Questionnaire Survey</th>
<th>Case Study</th>
<th>Process Model Analysis</th>
<th>Focus Groups</th>
</tr>
</thead>
<tbody>
<tr>
<td>To review the concept of sustainable development and identify the current issues and implications for the construction industry.</td>
<td>What are the current issues of sustainable construction and its implications to the building process?</td>
<td>P</td>
<td>S</td>
<td>S</td>
<td></td>
<td></td>
</tr>
<tr>
<td>To review the concept of design for deconstruction (DFD) and related concepts in the construction industry.</td>
<td>What are the current challenges for implementing Design for Deconstruction (DFD) into the building process?</td>
<td>P</td>
<td>S</td>
<td>S</td>
<td></td>
<td></td>
</tr>
<tr>
<td>To obtain a broad based knowledge from the construction industry in the UK on the awareness and practice of sustainability with respect to deconstruction.</td>
<td>What is the level of awareness and practice of sustainability with respect to deconstruction in the UK?</td>
<td>S</td>
<td>P</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>To undertake a case study of a practical example of implementing sustainable construction which reflects deconstruction principles in conventional building practice.</td>
<td>What practical examples in construction practice relate to the deconstruction principles?</td>
<td>S</td>
<td>S</td>
<td>P</td>
<td></td>
<td></td>
</tr>
<tr>
<td>To propose a mechanism (with guidelines) for the integration of deconstruction principles into the project delivery process.</td>
<td>How can deconstruction be effectively integrated into the project delivery process in construction?</td>
<td>S</td>
<td>S</td>
<td>S</td>
<td>P</td>
<td>P</td>
</tr>
</tbody>
</table>

Key:
P - Primary Method
S - Supporting Method
CHAPTER 3 SUSTAINABLE DEVELOPMENT IN CONSTRUCTION

3.1 Introduction

In recent years, the concept of sustainability and its implementation within the built environment has grown into a global concern with most countries setting objectives to achieve the perceived goals. This has led to a general awareness with a wide range of meanings and interpretations by various groups on the concept of sustainable development. It has also created on-going discussions, considerable literature and demonstrations of sustainable development. As a result the knowledge of sustainability is far-reaching, comprehensive, and adaptable, and standards are being developed to ensure appropriate implementation. In this chapter the concept of sustainable development will be reviewed, and the current issues of sustainability and its implications for the construction industry will be identified.

3.2 Definition

The term 'sustainability' is often used interchangeably with the term 'sustainable development' and the definition in this study refers to both. Various interest groups (industrialists, professionals, policy leaders, entrepreneurs, government officials, and academicians) have used numerous contexts, approaches and perspectives to define the concept of sustainable development. The most popular and widely accepted definition is:

"development that meets the needs of the present without compromising the ability of future generations to meet their own needs"

(the Brundtland Report, 1987).

The Brundtland Report also expounded on the definition as:
Chapter 3: Sustainable Development in Construction

"a process of change in which the exploitation of resources, the direction of investments, the orientation of technological development, and institutional change are all in harmony and enhance both current and future potential to meet human needs and aspirations"

(WCED, 1987)

However, there is an ambiguity present in the definition of sustainable development by the Brundtland Report. This ambiguity can be described as deliberate because it encourages diverse interpretations of sustainability issues in various disciplines and groups (Chaharbaghi and Willis, 1999). Other definitions are a modification of the 'Brundtland Reports' definition and are indicative of the framework for implementing sustainability within various interest groups (Table 3.1).

Table 3.1: Various Definitions of Sustainable Development

<table>
<thead>
<tr>
<th>AUTHORS</th>
<th>DEFINITIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Caring for the Earth, IUCN/UNEP 1991</td>
<td>&quot;Improving the quality of human life while living within the carrying capacity of supporting ecosystems&quot;</td>
</tr>
<tr>
<td>The Local Agenda 21 Planning Guide, ICLEI 1996</td>
<td>&quot;Development that delivers basic environmental, social and economic services to all residences of a community without threatening the viability of natural, built and social systems upon which the delivery of the system depends&quot;</td>
</tr>
<tr>
<td>CERF 1996</td>
<td>&quot;Sustainable development is the challenge of meeting the needs of natural resources, industrial products, energy, food, transportation, shelter and effective waste management, while conserving and protecting environmental quality and the natural resource base for future development&quot;</td>
</tr>
</tbody>
</table>
| Centre for Indigenous Economic Resources (CIER 2004) | "To an ecologist, sustainability is the ability of ecosystems, such as a lake ecosystem, to maintain its structure and function and to remain resilient in order to continue to give and support life."
| Centre for Indigenous Economic Resources (CIER 2004) | To an economist, sustainability is the ability of the market to optimally allocate scarce resources, to send proper price signals, to provide a mechanism for investment, and to maintain a healthy labour market. |
| Centre for Indigenous Economic Resources (CIER, 2004) | To a sociologist, sustainability is the ability of individuals and communities to remain in good health physically, mentally, emotionally and spiritually, and ensure equity among and between generations" |
A common feature in all these definitions is the recognition and need to sustain the present development of society, its economic growth, and the limitations of the environment, for the present and future generations. This common feature provides the foundation for which all definitions align their goals towards implementing sustainable development within industries and organisations.

Therefore for the purpose of this research, sustainable development is defined as: consideration for the future and current generations in the design and construction of the built environment, with a definite exploration of the roles of social, economic and environmental factors in the design and construction process (Isiadinso, 2005). This implies, that the effective Integration of the social, economic and environmental factors in building design and construction can facilitate the achievement of the basic tenet of sustainable development, which is balancing present and future demands in the construction industry.

3.3 The Framework for Sustainability

Over the last three decades the concept of sustainability has become a mainstream issue globally, nationally and locally (Table 3.2). From research and a review of literature, the prospect of identifying a definitive framework for carrying out sustainable development is difficult and involves a continuous process (Hendstorm and Isenberg, 2002; Courtney, 1999; Charter and Tischner, 2001). However, to facilitate the implementation of sustainability in industries, policies and legislation have been initiated as drivers on a global, national and local level. This has led to a fundamental re-evaluation of the contribution that industries and services make to the quality of life. Thus, industries can no longer focus on profits and sales but also contributions must be made to the wider aspects of the economy, environment and the society.

A typical example is seen in the four measures that 160 world governments committed to adopt towards implementing sustainable development. They include:

- Agenda 21: a comprehensive programme of action to achieve a more sustainable pattern of development for the next century;
- The Climate Change Convention: an agreement between countries establishing a framework for action to reduce the risks of global warming by limiting the emission of so-called 'greenhouse gases';
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- The Biodiversity Convention: an agreement between countries about how to protect the diversity of species and habitats in the world;
- A statement of principles: for the management, conservation and sustainable development of all the world’s forests (Edwards, 1996)

These measures set out the framework for implementation and creates a way forward for governments and major groups to pursue sustainable development. Researchers and practitioners in the construction community have an active role to play by demonstrating to governments that the built environment can take a major role in positively responding to agendas and specific targets.

Table 3.2: Chronological Development of Sustainability

<table>
<thead>
<tr>
<th>Date</th>
<th>Development</th>
</tr>
</thead>
<tbody>
<tr>
<td>1972</td>
<td>The Stockholm declaration</td>
</tr>
<tr>
<td>1983</td>
<td>World Commission on the Environment and Development</td>
</tr>
<tr>
<td>1987</td>
<td>The Brundtland Report Published</td>
</tr>
<tr>
<td>1992</td>
<td>U.N Conference on environment and development (UNCED) – Results in Agenda 21 and Commission on sustainable development (CSD)</td>
</tr>
<tr>
<td>1997</td>
<td>Kyoto protocol on climate change</td>
</tr>
<tr>
<td>2000</td>
<td>UNEP’s Global environment outlook 2000</td>
</tr>
<tr>
<td>2002</td>
<td>U.N Conference on SD (World summit on SD (WSSD))</td>
</tr>
</tbody>
</table>

Accomplishing these agendas and targets within the construction industry involves an understanding of the three broad themes of sustainable development – social, economic and environmental issues. The widely accepted model of sustainable development is represented as a Venn diagram (Figure 3.1). It illustrates the complex interconnections of the three themes of sustainability and indicates the need for a balanced approach towards attainment. These three themes, also known as the ‘triple bottom line’, refer to a way of encouraging accountability through performance by stakeholders and organisations within the sustainability context (Elkington, 1997).
The idea of reporting against these three themes (or bottom lines) of performance serves as the framework for meeting the sustainability challenge as well as measuring progress. The issues of sustainability as it relates to the construction industry are highlighted in Table 3.3 and discussed in the next few sections.

Table 3.3: Sustainability Issues in the Construction Industry

<table>
<thead>
<tr>
<th>Social</th>
<th>Economy</th>
<th>Environment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Community Involvement</td>
<td>Social Benefits/Cost</td>
<td>Land Use</td>
</tr>
<tr>
<td>Social Inclusion</td>
<td>Transport(Infrastructure)</td>
<td>Ecology</td>
</tr>
<tr>
<td>Health And Welfare</td>
<td>Employment Skills Base</td>
<td>Air Quality</td>
</tr>
<tr>
<td>User</td>
<td>Viability</td>
<td>Water Quality</td>
</tr>
<tr>
<td>Comfort/Satisfaction</td>
<td>Regional Vibrancy</td>
<td>Design &amp; Operation</td>
</tr>
<tr>
<td>Access</td>
<td>Ethical &amp; Equity Issues</td>
<td>Transport Impact</td>
</tr>
<tr>
<td>Public Amenity</td>
<td></td>
<td>Visual Impact</td>
</tr>
<tr>
<td>Crime Prevention</td>
<td></td>
<td>Noise Impact</td>
</tr>
<tr>
<td>Planning issues</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Source: CIRIA, (2001)

3.3.1 Social

The social aspect of sustainability recognises and involves the well being of a society in general. Social values and contexts differ across regions, countries and continents but the fundamental social needs of people and society do not change. Within the context of sustainability, the social aspect is about adapting and building on the values and
behaviour of communities. For the construction industry, this means responding to the local conditions, cultures and goals of a society during the building process. For example, the role of designer would be to optimise a fit between the cultural and functional goals of a building. On the other hand, the social aspect of sustainability is notably very difficult to measure (Henriques and Raynard, 2001) as it tends to be mostly intangible issues (see Appendix B). Nevertheless, the construction industry must address key social issues related to the built environment so as to have a holistic approach towards the implementation of sustainability.

A number of publications in the UK have suggested ways by which the construction industry can effectively integrate social aspects of sustainability in construction practice (Latham, 1994; Egan, 1998; CIRIA, 2001). The main focus has been on health and safety, ethical practice, stakeholders engagement, training and development that has guided new building legislations (such as the new Code for Sustainable Homes (BRE, 2007). Consequently, social sustainability of buildings must be seen from the perspectives of both the internal and external stakeholders (Sayce et al., 2004). The internal stakeholders are those who most likely contribute financially and otherwise to the erection of buildings. External stakeholders are those (such as shoppers in a shopping complex, office workers in an office building) who use the building on a day to day basis. The implications for the construction industry in terms of socially sustainable buildings involves (amongst others) the suitability of the work environment (for example, temperature, lighting), and the capacity of the space to meet the occupants' needs. Other issues, such as crime in neighbourhoods, are sometimes associated with building design, and layout factors can play a critical role in determining whether or not a building should be retained or demolished. In summary, the social issues are becoming highly relevant in building design, thus there is a need for an effective mechanism to address users (building owners/occupants) changing demand for sustainable buildings.

3.3.2 Economic

The economic aspect of sustainability focuses on assets. Assets in construction refer to existing and proposed buildings. There are great economic potentials that can be derived from the existing building stock within a city or nation. For example, a building is often regarded as a physical capital which, when sold or leased, can generate financial capital. Furthermore, the construction of new buildings provides work and boosts the economy of
In the UK, the construction industry contributes 8.2% to the annual GDP and employs about 2.1 million people (BERR, 2007)

On the other hand, the reuse of existing buildings instead of new builds, is more sustainable as natural resources are conserved. However, the cost of reusing buildings can sometimes be more than that of constructing new ones, as operation and maintenance costs, with refurbishments can be higher than initial capital costs. The industry is beginning to re-examine the life cycle cost of most buildings. The concept is known as ‘whole life-cycle cost’. It provides a thorough account of all the resources required to acquire, operate, maintain and eventually dispose of a building (Boussabaine and Kirkham, 2004). Other key aspects of economic sustainability as it relates to the construction industry are listed in Table 3.3 and presented in Appendix B.

3.3.3 Environment

The environmental aspect of sustainability is part of the model of sustainable development; it comprises the built and natural environment. The built environment focuses on building sustainability whilst the natural environment aspect is about conserving natural resources and protecting the earth from damage. The resulting effects of construction activities on the environment include: pollution, depletion of natural resources, contamination of land and waste disposal (see Table 3.3 and Appendix B). Although the environment is not the most important part of sustainable development, it has been at the forefront of discussions and implementation strategies for achieving sustainable development in construction. It has led to the development of various assessment tools for buildings to achieve sustainability. Studies (Sayce et al., 2004; John et al., 2005) have pointed out that this could be because issues relating to environmental sustainability can easily be identified and measured. For example, factors such as temperature, moisture, solar radiation that react with the building both internally and externally are tangible and measurable.

On the other hand, these assessment tools have focused primarily on environmental issues (such as reducing resource depletion and pollution) not necessarily on the social and economic issues of buildings (Cooper, 1999). Therefore the development of assessment tools which can focus on all aspects of sustainable development is essential. Rees (1999) points out that construction professionals (urban planners and
designers, architects, building contractors and manufacturers of building materials) have a
great challenge to ensure the development of tools which encourage sustainability in
construction practice.

3.3.4 Other Aspects of Sustainability

Sustainability is a multi-faceted concept cutting across a broad spectrum of disciplines.
Hence, the term 'sustainable development' which was categorically accepted by the
world community during the Rio Earth Summit in 1992 became a common goal to be
achieved by all nations especially for industries and organisations. Furthermore, the
notion of "sustainability" is understood as a general regulative idea which initiates and
accompanies a process of learning and searching, with the more concrete notion of
considering principles leading to practical measures (Jahanke and Nutzinger, 2003).
These principles of sustainability expound the concept from different dimensions and
perspectives to provide a model framework for practical implementation or practice. For
example, a 'resource' in the concept of sustainable development can be deemed as
capital that is accessible to development. Capital is essential for growth and development
in business and the economy. Forum for the Future (2004) identifies five types of
sustainable capital from which the goods and services needed to improve the quality
lives are derived. They include natural, financial, human, man-made and social capital.
Figure 3.2 illustrates how these five capitals enable sustainable development within the
construction industry.
3.4 Sustainable Construction

Sustainable construction may be described as the application of sustainable principles in construction. According to DETR (1999) sustainable construction is part of sustainable development, which aims to ensure a better quality of life for everyone, now and for future generations to come. This description identifies and encompasses the three broad themes of sustainability. Clearly, sustainable construction is a process for describing the stakes and issues of sustainable development that relate to the construction sector.

3.4.1 Definitions of Sustainable Construction

There are several definitions of sustainable construction based on the review of related works. Some of these definitions include:
3. Chapter 3: Sustainable Development in Construction

a. "A process by which a profitable and competitive industry delivers built assets:
   o building structures, supporting infrastructure and immediate surroundings, which enhance the quality of life of people and offer customer satisfaction;
   o provide flexibility and support desirable natural and social environments; and
   o maximise the efficient use of resources while minimising wastage" (Watuka and Aligula 2000).

b. "the creation and responsible management of a healthy built environment based on resource efficient and ecological principles (Kibert et al., 1994)".

c. "a new way for the building industry to work towards achieving sustainable development on the various environmental, socio-economic and cultural facets (CIB, 1998).

d. "is best described as a subset of sustainable development, which encapsulates matters such as design, tendering, site planning and organisation, material selection, recycling, and waste minimisation" (Langston and Ding, 2001).

These very broad definitions of sustainable construction provide a starting point to build a more concrete definition of the concept of sustainable construction (Bourdeau, 1999). In addition, the variance in terms of scope and context cuts across different issues in building construction. These definitions can be summarised as follows:

- a process of designing and constructing buildings that offers equal priority to economic, social and environmental factors;
- construction professionals must incorporate the three themes of sustainability throughout the life cycle of a building project; and
- a new way of evaluating the building process to ensure a holistic approach.

3.4.2 Principles of Sustainable Construction

The challenge towards achieving sustainable development puts the construction industry in the spotlight as it is primarily responsible for creating the built environment. Buildings are the end product of construction activities and through sustainable construction the entire life cycle of a building is addressed to promote sustainable practices. The relationship between the lifecycle stages of a building, including the resources needed for construction and the principles of sustainable construction is illustrated in Figure 3.3. Miyatake (1996) expounds on these principles of sustainable construction proposed by
Kibert (1994) on the future of construction within the sustainability context. These principles include:

- minimisation of resource consumption;
- maximisation of resource reuse;
- use of renewable and recyclable resources;
- protect the natural environment;
- create a healthy and non-toxic environment; and
- pursue quality in creating the built environment.

These six principles provide a framework for the construction industry to implement and achieve sustainability in the building process. Arguably, to achieve sustainable construction the process of creating buildings and the built environment must change to adopt sustainable principles. Table 3.4. shows the proposed approaches to sustainable construction compared with conventional construction through the life cycle stages of a building. Clearly, the principles of sustainable construction are in line with sustainable development and thus significant action is needed from all those engaged in the building process to implement these new approaches.
Chapter 3: Sustainable Development in Construction

Some of the actions taken within the construction industry towards achieving sustainable construction include:

- emphasis by clients of certain environmental requirements that their buildings should satisfy;
- designers which have established a name for themselves for the environmental-consciousness of their designs (Vale and Vale, 1991);
- contractors which have adopted environmentally conscious techniques (Ofori, 1992);
- professional bodies which have prepared ‘policy papers’ to guide members on good practice in relation to the environment (For example, CIB, 1989) and are organising activities to increase the level of awareness and education of members;
- international agencies which have published manuals offering guidelines for environmentally conscious construction (UNCHS, 1993); and
- international discussion groups such as Task Group 8 (TG08) of the CIB on Environmental Assessment of Buildings (Ofori, 1997).

Furthermore, a review of the strategy for sustainable construction in the UK published in 2000 was carried out and updated in October 2006. The review recognised that the industry had made considerable progress through the following actions:

- Implementation of a UK climate change programme,
- Implementation of an energy efficient action plan;
- Revision of part L of the existing building regulation,
- Provision of a code for sustainable homes;
- Implementation of site waste management plans,
- Creation of a sustainable and secure building act;
- Consideration of design for manufacture,
- Implementation of aggregates levy and landfill tax;
- formation of sector skills councils: construction skills, asset skills and summit skills; and
- launch of respect for people code of good working health and safety practices
All these actions indicate that the construction industry is actively addressing issues and practices that bring about sustainability in the built environment.

Table 3.4: Conventional Built Environment Life Cycle Stages Compared to Sustainable Construction Stages

<table>
<thead>
<tr>
<th>Life cycle stage</th>
<th>Conventional Built environment</th>
<th>Sustainable Construction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Planning</td>
<td>Urban Design</td>
<td>New Urbanism</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Transit Oriented Development</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Conservation Subdivision Design</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Biourbanism</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Bioregionalism</td>
</tr>
<tr>
<td>Design</td>
<td>Conventional Architecture</td>
<td>Ecological Design</td>
</tr>
<tr>
<td></td>
<td>Conventional Landscape Architecture</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Conventional Interior Design</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Conventional Engineering</td>
<td></td>
</tr>
<tr>
<td>Construction</td>
<td>Building Construction</td>
<td>‘Green’ Building Construction</td>
</tr>
<tr>
<td>Operation</td>
<td>Facilities Management</td>
<td>‘Green’ Facilities Management</td>
</tr>
<tr>
<td>Renovation/Retrofit</td>
<td>Conventional Design</td>
<td>Ecological Design</td>
</tr>
<tr>
<td>Disposal</td>
<td>Demolition</td>
<td>Deconstruction</td>
</tr>
</tbody>
</table>


3.4.3 Sustainable Construction in the Building Process

In this research, sustainable construction in the building process refers to designing and constructing ‘sustainable buildings’. The latter may be defined as those buildings that have minimum adverse impacts on the built and natural environment (OECD, 2003). Another term associated with sustainable construction in the building process is “Green buildings”. These are buildings designed with a focus on the health of its occupants, on the environment and on conservation of resources (Birkeland, 2002). The term green building and sustainable building are often used interchangeably. As concepts, they offer the construction industry a holistic and integrated approach for minimising environmental impact during the building process (Keeping and Shiers, 2004). It is a response by construction professionals especially designers on how best to implement sustainable construction in current construction practice (Edwards, 1998).
Chapter 3: Sustainable Development in Construction

Table 3.5: Problems vs. Solutions through Sustainable Design Considerations

<table>
<thead>
<tr>
<th>Problems</th>
<th>Solutions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Green house gas emissions such as CO₂</td>
<td>Minimisation of the negative ecological impact of using natural resources by supporting the design of pedestrians, bicycle, mass transit routes and other alternatives to fossil-fuelled vehicles</td>
</tr>
<tr>
<td>Generation of construction waste</td>
<td>Implementing design solutions that increase the efficiency by which buildings and their sites are used to harvest energy, water, and materials thereby reducing waste generation. For example, introduce waste management strategies at the early stages of design through to the detailed design stage.</td>
</tr>
<tr>
<td>Pollution</td>
<td>Reduction of human exposure to noxious materials by reducing building impacts on human health and the environment. For example, protect and restore local air, water, soils, flora and fauna by using plants and trees through the design of green roofs. This improves indoor air quality of buildings.</td>
</tr>
<tr>
<td>Waste of natural resources</td>
<td>Reducing embodied energy and resource depletion and preserving scarce materials, by emphasising design features that would implement the use of renewable energy resources such as sunlight as a source of energy through solar and photovoltaic techniques.</td>
</tr>
</tbody>
</table>


The design approach used for implementing sustainable buildings is known as sustainable design. The main focus of sustainable design is to apply solutions that minimise the negative environmental impacts of the building process. Some of these are shown in Table 3.5 together with solutions offered through sustainable design considerations. The practice of sustainable design provides the following benefits:

- reduction in the operating costs of building maintenance by carefully selecting efficient heating, cooling and ventilation systems that would ensure future savings;
- maximum efficiency in using of resources (such as materials with low embodied energy) during the construction and operation of buildings which would result in conservation of natural resources;
- improvement in public and occupant health due to improved indoor air quality from the choice of design features; and
• overall reduction of the negative environmental impacts caused by the building process.

In addition, various assessment methods and tools have been developed to address and implement sustainable construction through sustainable design. These are discussed in the next section.

3.5 Tools for Implementing Sustainability in Construction

In the last few years, the construction industry has developed and recommended a range of tools and frameworks in order to address sustainability issues in construction. These tools have been developed in different countries as a means to further develop the emerging issues of sustainable buildings. The tools were mainly used for developing guidance and assessment or rating systems for reducing the negative environmental impacts of buildings. These assessment techniques and rating methods are significant as they would enable the industry to demonstrate and compare various building schemes with their environmental impacts (Larsson and Cole, 2001; Gowri, 2005). Accordingly, these tools can be classified as follows:

Knowledge-Based (KB) – These are typically design manuals and information sources that designers can use as reference materials for design strategies, new technologies, material properties, cost data or case study information;

Performance Evaluation (PE) – These include lifecycle impact assessment, new technology assessment tools used for selection of materials and technologies, analysis; and simulation tools for calculating energy consumption, lighting and indoor environmental quality. They are used for the preliminary design stages and the whole building performance evaluation process; and

Green Building Rating (GBR) – these are resources available to determine the performance requirements and the level of green building rating based on the methodology used (Gowri, 2005).

Some of the well known tools are identified and listed in Table 3.6. A brief description of these tools are given below.
### Table 3.6: Tools Used for Sustainable Construction

<table>
<thead>
<tr>
<th>Name</th>
<th>Classification</th>
<th>Description</th>
<th>Country/Web address</th>
</tr>
</thead>
<tbody>
<tr>
<td>BREEAM</td>
<td>Green building rating (GBR)</td>
<td>BRE Environmental assessment method</td>
<td>UK/www.breeam.org</td>
</tr>
<tr>
<td>ATHENA</td>
<td>Performance evaluation (PE)</td>
<td>Environment impact estimator</td>
<td>Canada/www.athenaSMI.ca</td>
</tr>
<tr>
<td>ENVEST2</td>
<td>Performance Evaluation (PE)</td>
<td>Environment Impact Assessment and Whole Life Cost Analysis</td>
<td>UK/<a href="http://envest2.bre.co.uk">http://envest2.bre.co.uk</a></td>
</tr>
<tr>
<td>GBTool</td>
<td>Green building rating (GBR)</td>
<td>An international collaborative effort to develop</td>
<td><a href="http://greenbuilding.ca/gbc2k/gbtool/gbtool-main.htm">http://greenbuilding.ca/gbc2k/gbtool/gbtool-main.htm</a></td>
</tr>
<tr>
<td>CEEQUAL</td>
<td>Performance Evaluation (PE)</td>
<td>Civil Engineering Environmental Quality Award</td>
<td>UK/www.ceequal.com</td>
</tr>
</tbody>
</table>

**BREEAM (GBR)** – The Building Research Establishment Environmental Assessment Method was developed by BRE in 1990. It was launched as a building assessment scheme for two main categories of buildings: homes (known as EcoHomes) and offices.
Over the years BRE has improved and expanded on these two categories. It has also developed a series of rating systems for other building types such as industrial and commercial buildings. The rating system provides guidance to reduce the effect of buildings on the global and local environment and enables developers as well as designers to address environmental issues. Points or credits are awarded according to the criteria specific to the building type and depending on the level attained. Awards are made in the categories of pass, good, very good and excellent. The maximum credit achievable is 188; a score of 68 is a pass; a score of 90 is good; a score of 113 is very good; and a score of 132 or above is excellent.

**LEED (GBR)** – Leadership in Energy and Environmental Design rating system was developed by the Green Building Council in the US, as a national standard (benchmark) for a green building. Designed originally for commercial buildings, it is a set of design guidelines, combined with third-party certification procedures. It has a points award system like BREEAM but this is simpler and the maximum score possible is 69. The majority of the points are awarded as single units attributed to specific design features (such as materials and resources, indoor environmental quality, sustainable sites); only in the optimization of energy performance is more than one credit available. The LEED award categories are as follows: certified 26-32 points; silver, 33-38 points; gold, 39-51 points; platinum, 52-69 points.

**GBTool (GBR)** – The Green Building Challenge (GBC) was one of the early assessment frameworks developed to address the debatable aspects of rating systems. It was not developed for any particular market or for any specific building type. Its purpose was to develop and contribute to the state of the art of research into building performance assessment and provide a forum to discuss, identify and test potential approaches to building performance and assessment (Todd, 2001). The intention was to facilitate the full description of the building with its performance, and to allow national teams to participate in the GBC process and carry out the assessments relative to regional benchmarks (Larsson and Cole, 2001). It is a software application designed to enable research and development in sustainable building design globally and does not offer any certification unlike BREEAM or LEED.

**BEES (PE)** – The Building for Environment and Economic Sustainability system was developed in the USA by the National Institute of Standards and Technology as an
interactive software to aid designers. It provides a technique for selecting cost-effective, environmentally preferable building products for commercial and housing projects. The environmental impact assessment is based on raw material acquisition, manufacture, transportation, installation, use, recycling and waste management; and the economic impact is calculated using the costs of initial investment, replacement, operation, maintenance and repair, and disposal. The outputs produced from the evaluation relate to a range of approximately 200 building elements. It is based on the life cycle assessment approach. The assessment is based on the following environmental and economic: ozone depletion, global warming, air pollutants, ecological toxicity, first cost, future cost and indoor air quality.

**ENVEST2 (PE)** – The focus of this is on environmental impact assessment and whole life cost analysis. It is a software assessment tool developed by the Building Research Establishment (BRE) in the UK. It enables and facilitates the measurement of whole life costs with environmental impacts per square metre of a building's floor area. It also allows the client (developers) to optimise the concept of best value according to their priorities based on environmental and financial tradeoffs explicit to the design process. In this way it is possible to make comparisons between different versions of the same building and also between different buildings. The method is based on an Ecopoints system similar to the BEES system.

**ATHENA (PE)** – The ATHENA software is an Environmental Impact estimator developed by the ATHENA Institute in Canada. It is based on lifecycle assessment approach of products (building). The environmental issues are placed on the same level with traditional building project criteria such as cost, quality and time. It comprises a database which stores 90% - 95% of the structural and envelope systems of typical residential and non-residential buildings. The software is capable of generating over 1000 different assembly combinations to guide the designer in making an informed decision on the environmental impacts of each conceptual building design option. Design implications of issues such as embodied energy use, global warming potential, solid waste emissions, pollutants to air and natural resource use are taken into consideration. Through the estimator, construction professionals are able to model the following: a building's complete structure and envelope; maintenance and replacement effects based on a building type, location and user-defined life for the building and end-of-life scenarios.
Whole Building Design Guide (KB) – This consists of two components: an integrated design approach and an integrated team process. The purpose of the integrated design approach is to allow stakeholders involved in the building process to examine the project objectives with a holistic design philosophy. This approach is different from the typical planning and design process whereby the construction professionals often work in their respective specialties, to some extent, in isolation from each other. The Whole Building Design Guide's approach is to ensure that each of the stakeholders involved in the planning, design, use, construction, operation, and maintenance of the building has a full understanding of the issues and concerns of all the other parties, and to interact closely together throughout all phases of the project. Figure 3.4 illustrates the concept of the Integrated Design team process and integrated design approach. The expected outcome are buildings which can be described as "high-performance buildings", as they are indicative of the design features of environmental design considerations as well as low energy and cost-effective use of building materials and components.
Chapter 3: Sustainable Development in Construction

**Sustainability Checklist for Developments (KB)** – This is a text-based resource developed by BRE in the UK. Its purpose is to facilitate and assist designers with large scale developments such as urban village or housing estates and regeneration projects. The focus is mainly on site development, buildings and infrastructure and its relationship with sustainability. The checklist can be used in full or in part in some of the following circumstances; to aid in the writing of development briefs or proposals; to demonstrate the sustainability features of a proposal; for authorities to specify standards to be met; or to provide a scoring system for comparison of options.

**CEEQUAL (PE)** – This is the Civil Engineering Environmental Quality Award scheme used in assessing the environmental quality of civil engineering projects. It is comparable to BREEAM, which is used for buildings. Its objective is to encourage the attainment of environmental excellence in civil engineering projects, and thus to deliver improved environmental performance in project specification, design and construction. It is a credit-based assessment framework used to assess any civil engineering project. Some of the environmental assessment include: the use of water, energy and land, ecology, landscape, nuisance to neighbours, archaeology, waste minimisation and management, and community amenity. The awards are made to projects in which the clients, designers and contractors go beyond the legal and environmental minimum to achieve distinctive environmental standards of performance.

The tools described above are some of the sustainable design tools available within the construction industry in various countries. They provide general design information, documentation for integrated assessments, guidelines for sustainable building technology, estimation of design performance at the early and detailed design stages. They offer several benefits to construction professionals (especially designers) when implementing sustainable construction practices. Some of these are:

- the ability to assess buildings across a broad range of considerations such as maximising energy consumption, site selection, environmental design features etc;
- better communication and interaction between the design team and other construction professionals to achieve sustainable building design and performance;
more research and the development of useful frameworks for improving design performance and evaluation;

provides a focus for discussing and integrating environmental issues into projects from the feasibility stage to detailed design; and

should assist designers to identify and understand the requirements of design strategies that would ensure integration of sustainable construction practices.

Nevertheless, there is a general consensus amongst researchers and practitioners that these assessment methods are not sufficient to address all sustainability issues raised by building process (Cooper, 1999; Cole, 2001). This is because some of the tools such as BREEAM and LEED tend to assess performance of buildings based on a relative, criteria rather than absolute one. As a result there is no guarantee that buildings which score highly against the rating systems are making a substantial contribution to the increased sustainable construction practice. However, these tools lay the foundation for the research and development of better techniques and methodologies to improve design considerations for sustainable buildings.

3.6 Summary

This chapter has presented the concept of sustainability and described the framework by which sustainability is considered in construction. It was established that the three main principles of sustainability: social, economic and environment provide the basis for sustainable construction practice. The application of these principles in the building process is a challenging prospect because there is a need to achieve a balance between the divergent issues they comprise.

The construction industry has through a number of action plans and initiatives made considerable progress in implementing sustainability in current construction practice. For example, in the UK, the strategy for sustainable construction published in 2000 has been updated in 2006 to introduce some of the following: site waste management plans, a sustainable and secure building act and design for manufacture - into the building process to ensure that sustainability is achieved.

In addition numerous assessment tools (such as BREEAM AND CEEQUAL) have been developed by the construction industry to encourage and incorporate sustainable design
issues in order to reduce the negative impacts of buildings to the natural and built environment. This research seeks to build upon these initiatives by considering an approach that can facilitate the further integration of sustainable design into the current building process.

The next chapter reviews the concept of design for deconstruction, which is one of approaches that can serve as a practical solution that could assist the industry in implementing sustainability from the early stages of the project delivery process in building construction.
CHAPTER 4 DESIGN FOR DECONSTRUCTION

4.1 Introduction
The aim of this chapter is to review the concept of design for deconstruction (DFD) in the construction industry. The role of deconstruction in assisting the industry to achieve some aspects of sustainable construction practice is explored. Other concepts in construction that are related to design for deconstruction and similar design approaches in manufacturing are discussed. The chapter also highlights the drivers, enablers and barriers associated with DFD, and the requirements for integrating DFD into the building process.

4.2 Deconstruction

4.2.1 Definition
The term 'deconstruction' is a wide-reaching term, which has several meanings depending on the viewpoint of any particular study. The definitions of deconstruction as suggested by researchers and practitioners in the construction industry include:

- "the disassembly of structures for the purpose of reusing the components and building materials. The primary intent is to divert the maximum amount of building materials from the waste stream" (Languell and Kibert, 2000);
- "an effective means for reducing construction and demolition (C&D) debris at a time of diminishing landfill capacities and increased environmental awareness" (Dantata et al., 2004);
- "the process of dismantling building components in the reverse order as how they are originally constructed" (Guy and McClendon, 2000);
- "serves as a means to an end, its purpose is the recovery of building elements, components, sub-components, and materials for either reuse or recycling in the most cost effective manner" (Guy and Shell, 2002); and
Chapter 4: Design for Deconstruction

- "seeks to maintain the highest possible value for materials in existing buildings by dismantling buildings in a manner that will allow the reuse or efficient recycling of the materials that comprises of structures" (Durmisevic and Brouwer, 2002).

From the foregoing, the definitions of the term 'deconstruction' can be summarised as:

- The selective dismantling or disassembly of building materials and components.
- A means to encourage the efficient reuse or recycling of building materials and components.
- A process to assist the construction and demolition industries to minimise design and construction waste.

Therefore, for the purposes of this research, 'Deconstruction' is defined as selective dismantling or disassembly of building materials and components in order to encourage efficient reuse or recycling, which has the potential to support waste minimisation in construction and demolition activities.

Deconstruction can be classified into two main types: structural and non-structural (see Table 4.1). This classification supports the current practice in the C&D industries. Non-structural deconstruction is not necessarily a new process in C&D. For example, the recovery of building components that have architectural value. However, due to pressure from legislation and increasing landfill costs, the industry is becoming more proactive in this area. On the other hand, the structural deconstruction process is an emerging concept in the industry, to address negative environmental damage, reduce waste and support sustainable construction practice.
Table 4.1: Types of deconstruction

<table>
<thead>
<tr>
<th>Types of Deconstruction</th>
<th>Definition</th>
<th>Characteristics</th>
<th>Types of Materials</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-structural</td>
<td>Non-structural deconstruction involves the removal, for salvage/reuse of any building components or contents that are not a part of or whose removal is not dependent on the structural integrity of the building</td>
<td>Usually light, can be salvaged relatively easily and with minimum safety concerns. Material can be viewed without much destructive access. Typically does not require support or bracing to salvage.</td>
<td>Floor Finishes, Appliances/Mechanical, Cabinetry, Windows/doors, Trim, Fixtures/hardware, Fireplace Mantels</td>
</tr>
<tr>
<td>Structural</td>
<td>Structural deconstruction involves the removal for salvage/reuse of building components that are an integral part of the building or contribute to the structural integrity of the building</td>
<td>Disassembling a structure to salvage the structural building components such as beams, joist, and brick. Materials are typically large, rough products that are to be reused as building materials or remanufactured into value added products such as chairs, tables, and surface coverings</td>
<td>Framing, Sheathing, Roof systems, Brick/Masonry, Wood Timbers/beams, Wood rafters, Floor joist system</td>
</tr>
</tbody>
</table>

Source: HUD, (2001)

4.2.2 The Role of Deconstruction in Sustainable Construction

The conventional approach to designing and constructing buildings has become increasingly important. This is because the process of carrying out C& D activities throughout a building's life cycle generates vast quantities of building material and component waste. The resulting effect is negative impacts on the environment and for social and economic reasons is becoming more an unacceptable practice.
Generally there are three reasons why it is important for the industry to rethink its approach to designing and constructing buildings. Firstly, the increasing scarcity of landfill sites, higher landfill tax and rising waste disposal costs are driving the need for this. Secondly, government legislation (such as the Environmental Protection Acts of 1990 and 1995 in the UK) is encouraging industries to reconsider recycling of resources and reduction of waste. Thirdly, vast quantities of building material and component waste are generated throughout C&D activities.

Figure 4.1: Typical Building Demolition Processes Showing Waste Generation.
Source: www.webshots.com

Furthermore, a review of sustainable construction practice in the UK (DTI, 2006) indicates that the construction sector has developed a number of initiatives to reduce waste generation. Some of these initiatives include: the development of the Demolition Protocol by the ICE, London Remade and Envirocentre (November 2003); the development of a Guidance for Contractors and Clients for Site Waste Management Plans as a voluntary Code of practice (July 2004) and the Environmental Agency's Building and Construction Projects (such as the Red Kite House at Wallingford) which demonstrates good practice measures by including natural ventilation and cooling systems, energy efficiency and sustainable drainage (2005). Other initiatives include driving down energy and water use in buildings, reducing waste, having waste management plans on all new construction sites and maximising the use of recycled aggregates. These initiatives have come as a result of the initial UK government strategy for sustainable building published in 2000.

Thus, the need to continually improve the process of constructing buildings and reduce the negative environmental impacts makes the process of deconstruction a suitable
alternative to the demolition process (see Figure 4.1) that often generates waste. In addition, deconstruction can assist the C&D industries to reduce creation of waste by encouraging reuse and recycling of building materials. Table 4.2 compares some of the aspects of deconstruction and demolition that can assist the industry to determine how best to deal with a building’s disposal at the end of its useful life.

Table 4.2: Comparison of Deconstruction and Demolition

<table>
<thead>
<tr>
<th>Demolition</th>
<th>Deconstruction</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Less labour intensive</td>
<td>• More labour intensive and requires specialist skills</td>
</tr>
<tr>
<td>• Requires less time as mostly robotic and power assisted tools are used.</td>
<td>• More time is required as materials and components have to be carefully dismantled to avoid damage.</td>
</tr>
<tr>
<td>• Cost less to execute although disposal costs arise for landfill sites.</td>
<td>• Higher cost to execute but savings on disposal costs</td>
</tr>
<tr>
<td>• Materials are usually contaminated due to techniques used in the demolition process.</td>
<td>• Selective dismantling of building ensures reduced contamination of recovered materials.</td>
</tr>
<tr>
<td>• The debris generated during demolition does not encourage reuse</td>
<td>• Encourages reuse and recycling of building materials</td>
</tr>
<tr>
<td>• The demolition industry is more established</td>
<td>• Sales of building materials recovered can subsidise cost of new construction</td>
</tr>
</tbody>
</table>

The production of C&D waste not only concerns the final phase of the life cycle of a building, but also involves every stage of its life: the construction; the use period (duration of occupancy) which often requires maintenance and restructuring interventions; and the demolition, during which is the main cause for the production of the bulk of construction and demolition waste is produced (te Dorsthorst and Kowalczyk, 2002).

Furthermore, the process of deconstruction conforms to the waste hierarchy framework (see Figure 4.2) and could serve as a possible strategy to effectively manage waste generation during C&D activities. This is because it offers the potential to recover C&D materials for recycling and reuse instead of disposal. In the waste hierarchy framework, reuse and recycling are higher than disposal which is the last alternative to dealing with waste. Thus, deconstruction satisfies the requirements of environmental sustainability and conservation of natural resources as waste generation is considered throughout the design and construction process of a building (Isiadinso et al, 2006).
Within the context of waste management strategies, deconstruction can serve as a tool in the building process to encourage the reuse and recycling of materials and components (Isiadinso et al., 2006). Consequently, there is a recognition that integrating the process of deconstruction into the current building life cycle could potentially assist C&D industries to address its negative impacts on the environment (Hurley et al., 2001; Kibert, 2003). This recognition has led to several studies (Durmisevic and Brouwer, 2002; Addis and Schouten, 2004; Morgan and Stevenson, 2005; Durmisevic, 2006) giving consideration to the following:

- the need to design efficiently to reduce waste;
- efficient use of materials and components during design and construction;
- appropriate construction methods and techniques to ease disassembly of components and materials;
- specification of materials and components using their different life cycles to enable deconstruction; and
- the need to improve the detailing and connections of components.
Clearly, these studies have identified and shown that implementing the process of deconstruction in the building process can possibly assist the industry towards achieving some aspects of sustainable construction practice.

However, it must be recognised that not all buildings can be successfully deconstructed or merit deconstruction. Therefore, it becomes necessary to develop an approach in the building process that would favour deconstruction. This approach can encourage the substitution of the demolition stage with deconstruction at the disposal phase of a building’s life cycle and could assist in maximising component reuse and material recycling. It can be achieved by integrating deconstruction through the concept of design for deconstruction (DFD). Consequently, applying the principles of deconstruction though the design process into current C & D practices should facilitate design for sustainable construction.

4.3 The Design Process

The design process in the construction industry plays a significant role in the production and construction of buildings. It has been described as a detailed description of a building which consists of several phases whereby the initial ideas are transformed step by step to meet clients’ needs (i.e. translates the client’s functional needs in an ‘optimal’ form and materialisation within a given time and budget constraints) (Wilde et al., 2002). It often involves a design team with the appropriate expertise, undertaking a process and sequence of activities arranged into phases and steps, to define a product (building) through its configuration, components, materials and construction (Wallace et al., 2005). It is also recognised as a complex system to be broken down into development phases, units of work and product components (Gray and Hughes, 2001).

According to Lawson (1997), the design process can be divided into 4 phases. These include:

- **Phase 1: Assimilation** – The accumulation and ordering of general information and information specifically related to the problem in hand;
- **Phase 2: General study** – The investigation of the problem. The investigation of possible solutions or means of solution;
- **Phase 3:- Development** – the development and refinement of one or more of the tentative solutions isolated during phase 2;
- **Phase 4:- Communication** – The communication of one or more solutions to people inside or outside the design team.

The RIBA Plan of Work (2007) divides building design and management into 11 phases. Three phases focus on the design process. They include: Stage C (Concept); Stage D (Design Development); and Stage E (Technical design). Furthermore, Huovila et al., (1997) proposed a conceptual framework for managing the design process. These include:

- design as a conversion of inputs into outputs;
- design as a flow of materials and information; and
- design as a value generating process for the client.

These phases of the design process are prescriptive as well as descriptive and offer guidance to designers on how to implement appropriate solutions in creating a building. The expectation is that designers have an understanding of these phases to carry out their corresponding activities. Therefore, through knowledge, designers are able to link everything together and take actions to make decisions that direct the process and determine the appropriate outcome (Pahl and Beitz, 1996). The challenge for many designers is to maintain an adequate overview of the complex emerging product (building) and, equally, its complex design process (Sebastian, 2005).

Research has shown that most design issues addressed at the early stages of the building process are most likely to be implemented successfully at the construction and later stages of a building’s life cycle (Faniran et al., 2001). Thus design decisions at the early stages are important as they can assist in determining the future use of a building and consequently how it would be disposed of at the end of its useful life (Isiadinso et al, 2006).

In addition, Griffiths et al (2003) point out that the design phase offers the greatest potential for improving of resource efficiency in the drive to achieve sustainable construction. They suggest that designers such as engineers and architects can focus on the following factors whilst dealing with the design aspects of a building: design for
longevity; design for flexibility of use; lean design; design for deconstruction; design for recycling; and efficient material use.

Although Design for Deconstruction (DFD) has been identified as one of the design aspects of a building that, if considered, can facilitate resource efficiency. Its principles, however, go a step further combining all the design aspects listed above to achieve sustainable construction practice. Therefore, the opportunities to reduce waste and encourage resource efficiency can begin with the initial design decisions taken by the designer at the early stages of the building process. In this case, the process of deconstruction is integrated into the early design stages through the concept of Design for Deconstruction (DFD).

4.4 Design for Deconstruction (DFD)

4.4.1 Introduction

The concept of Design for Deconstruction (DFD) is an approach that is being considered in the construction industry to design a building with the intention of disassembly instead of demolition at the end of its useful life (Languell and Kibert, 2000; Crowther, 2000; Macozoma, 2002). Its purpose is to assist the industry to address environmental issues and also reduce disposal costs by reusing and recycling greater proportions of building components and materials. Several studies have defined DFD as follows:

- an attempt to raise materials and components up the waste management hierarchy, away from recycling and up to a more environmentally preferable point of reuse. Therefore it is primarily, but not exclusively, an issue of design for the reuse of materials (Crowther, 2000);
- the disassembly of a building for the purpose of reusing the structural components and building materials, with the primary intent of minimising the production of waste (Languell and Kibert, 2000);
- designing a building and its components with the intention of managing its end-of-life more efficiently (Macozoma, 2002); and
Chapter 4: Design for Deconstruction

- increasing the efficiency in a building’s adaptability and disassembly, and reducing the impact of pollution with the recovery of building materials for reuse and recycling (Pulaski et al., 2004).

Thus, DFD can be seen as dealing with the design of a building, for reuse in preference to recycling or disposal of building materials and components. It should therefore assist in managing the unavoidable waste and potentially provide a method to facilitate the minimisation of waste throughout C&D activities. This means that as a strategy in the building process, it can be used to address design issues that would enable deconstruction at the end of a building’s life (Crowther, 2001). Furthermore, through DFD the industry can develop a design strategy that will transform inflexible building structures into dynamic and flexible structures whose parts could be easily disassembled and later reused or recycled (Durmisevic and Brouwer, 2002; Macozoma, 2002). This implies that the key issues and determinants to achieving successful building disassembly should involve the application of deconstruction principles through DFD. As a result, adopting DFD into the building process can serve as an effective system in the building process as its principles are grounded in sustainable construction practices (Kibert, 2003).

4.4.2 Principles of Design to Facilitate DFD

The design of buildings that can easily be dismantled or disassembled is possible, except in practice most buildings are not designed to be deconstructed. In addition, the associated and perceived cost of dismantling a building with traditional construction methods have over the years determined the very small scale of the practice of deconstruction in the industry. However, the concepts of buildability\(^1\) (or constructability in the USA) and maintainability\(^2\) can be associated with the ease of assembly and disassembly of building components in construction (Meier and Russell, 2000; Low, 2001; Pulaski and Horman, 2005). This is because there is a growing demand for the industry to improve the process of designing and constructing buildings (Egan, 1998; 2002).

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\(^1\) Buildability is the extent to which the design of a building facilitates ease of construction, subject to the overall requirements for the completed building (CIRIA, 1983).

\(^2\) Maintainability is the design characteristics that pertains to the ease, accuracy, safety, and economy in the performance of maintenance actions (Blanchard et el. 1995)
A number of research studies (Crowther, 2002; Addis and Schouten, 2004; Pulaski et al., 2004) have shown that the practice of buildability and maintainability if considered carefully should be able to facilitate the practice of DFD in the industry. Accordingly, Pulaski et al (2004) suggests the following design principles to facilitate the integration of DFD into the current building process:

- design for prefabrication, preassembly and modular construction;
- simplify and standardise connections and details;
- simplify and separate building systems;
- consider worker safety;
- minimise building components and materials;
- select fittings, fasteners, adhesives and sealants that can facilitate the removal of reusable materials;
- design to accommodate deconstruction logistics;
- reduce building complexity;
- design to incorporate reusable materials; and
- design for flexibility and adaptability.

Another aspect of construction practice which involves design principles that can facilitate building disassembly are the erection of temporary and demountable buildings. These types of structures, by their composition, are primarily designed to be disassembled after a specific period of time and re-erected at a new location. Examples of these structures include: tents and marquees, grandstands, platforms, stage structures, portakabins and, exhibition pavilions (see Figure 4.3).

![Figure 4.3: Pictures Showing a Portakabin (left) and a Tent (right)](www.webshots.com)
A comparison between the approach used to design and construct temporary and permanent structures (see Table 4.3) indicates that there are several differences between the approaches used for both types of buildings. It is clear that the approach used for temporary and demountable structures can provide experience and knowledge for construction professionals (especially architects and structural engineers) to design and construct buildings which can easily be deconstructed. Through this experience and knowledge, construction professionals can begin to assess the potential of integrating DFD into the building process.

<table>
<thead>
<tr>
<th>Temporary/demountable buildings</th>
<th>Permanent buildings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Usually assembled from readily connected components.</td>
<td>Not necessarily assembled from readily connected components.</td>
</tr>
<tr>
<td>Slender components and lightweight materials are used to erect structures.</td>
<td>More robust components and heavy materials are used to erect structures.</td>
</tr>
<tr>
<td>They are rapidly assembled, readily dismantled and reusable.</td>
<td>They are not generally designed to be disassembled.</td>
</tr>
<tr>
<td>Life load of the structure is for a short period of time (with a minimum life span of 1 day to a maximum of about 5 years or more).</td>
<td>Life load of the structure is for a longer period (with a minimum life span of 5 years to a maximum of 50 to 100 years and beyond).</td>
</tr>
<tr>
<td>Often required for a short period of time so decision making process is relatively quick.</td>
<td>Mainly required for a long period of time with decision making process often taking a long time.</td>
</tr>
<tr>
<td>They are mainly designed to be easily erected, dismantled and relocated.</td>
<td>They are designed to be fixed to a location.</td>
</tr>
<tr>
<td>Ability to adapt to different situations and locations.</td>
<td>Often designed for a specific location and therefore tends not be flexible or adaptable.</td>
</tr>
</tbody>
</table>

4.4.3 Assessing the Potential for Integrating DFD into the Building Process

There are several ways to assess the potential for integrating DFD into the building process. In order to assess this consideration should be given to the following (Durmisevic and Brouwer, 2002; Chini and Balachadran, 2002; IStructE 2007):

The types of materials and components used - This potential is based on assessing the ability of materials to ease the process of deconstruction. This can be based on the choice of materials (see Table 4.4) and consideration of the different lifecycles inherent in each building element.
Chapter 4: Design for Deconstruction

The type of building foundation used – This potential is based on considering the load bearing capacity of the building foundation to accommodate a variety of changes for future building use.

The techniques and methods used to connect and assemble building components – This potential is based on assessing the appropriate methods and techniques for assembling building components. The assessment would, to a large extent, be determined by the connection details and the durability of the components to withstand assembly and disassembly.

The durability, flexibility and adaptability of the components – This potential is based on ensuring that the materials and components used are durable, adaptable and flexible to withstand different design changes and alternative construction scenarios to facilitate the deconstruction process.

The location of the building and components – This potential is based on the physical space available for erecting the building as well as the allocation of space to various components and building systems with sufficient dimensions and coordination.

The decision making process – This potential is based on ensuring that, from the inception of the building process, ownership and responsibility for the building are specified, as this can facilitate the establishment of significant mechanisms for deconstruction to be achieved.

The considerations suggested here can serve as a guide towards achieving and implementing DFD in the building process. Further discussions on the enablers and drivers that can facilitate the deconstruction process are highlighted in Sections 4.6 and 4.7.
Table 4.4: The Choice of Materials

<table>
<thead>
<tr>
<th>Material</th>
<th>Opportunities</th>
<th>Barriers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concrete – Masonry blocks, paving slabs, roof tiles</td>
<td>a) Most concrete products have no fixtures, fittings or joints, therefore lend themselves to be easily dismantled and reused. b) Alterations to the design of pipe work, paving slabs and blocks after dismantling can encourage reuse.</td>
<td>a) Pre-cast concrete and in-situ joints have low potential for reuse as it is almost impossible to dismantle them. b) The cost of buying new concrete products such as tiles and paving slabs, is relatively low compared to reusing the deconstructed ones. c) The dimension of each concrete component or structural unit is often different as individual buildings are usually unique in design.</td>
</tr>
<tr>
<td>Masonry Components– bricks, stone, blocks, paving, slates, tiles</td>
<td>a) Lime mortar used in construction of bricks enables ease of deconstruction. b) Damaged bricks and blocks can be used as aggregates. c) Large pieces of stone can be reused compared to small ones especially if lime mortar is used for construction. d) Slates and tiles are usually fixed through a hole to the roof purlins with wood and metal pegs. They can easily be deconstructed. e) There is also a market for used roof slates and tiles.</td>
<td>a) Contemporary bricks used in construction are often bonded using cement mortar making deconstruction almost impossible. b) Blocks and paving slabs are mostly recycled as aggregates instead of being reused. They are often damaged during dismantling because of cement mortar used for bonding. c) The cost and time spent to dismantle slates and tiles often discourages deconstruction, although there is a market for it.</td>
</tr>
<tr>
<td>Timber Components– Timber framed walls, trussed rafter roofs and bracing, DIY and scaffolds, Cladding and windows</td>
<td>a) Most timber products can be deconstructed with little modification required. b) Timber products are usually fixed in position by nails, screws, bolts, staples, glued joints, metal plates and mechanical bonding. c) The use of bolts, dowels, screws or pressed metal plate connectors greatly eases the deconstruction of components. d) These fixtures, fittings and joints also enable the reuse of timber components.</td>
<td>a) Timber undergoes a very slow process of thermal and UV degradation that occurs when exposed to the sun or in close proximity to a heat source. This results in darkening of the cell structure. The reprocessing is usually not economically viable for most timber products. b) The process of deconstructing timber is often labour-intensive as it involves careful manual removal of timber elements to ensure reuse. c) Taking out nails and staples is often very labour-intensive and damages the timber. d) Glazing can cause particular problem for deconstruction of windows as the bars can be prone to damage.</td>
</tr>
<tr>
<td>Steel – Hot rolled products, universal beams, universal columns, joists, bearing piles, circular hollow sections.</td>
<td>a) The demolition industry is already proficient at recycling steel materials. b) An increase in the use of light gauge steel for industrial, commercial and residential buildings provides potential to increase the quality of structural members to be reused. c) The steel units such as floor decking or floor joists are usually screw fixed, therefore easy to dismantle without damage.</td>
<td>a) Although steel products are easily dismantled, a great obstacle to recovery is the economics of reusing them. b) Any slight damage or deformation to steel beams or columns through elongation or thread stripping will result in disposal instead of reuse. c) There are technical difficulties and health and safety issues in removing individual steel sections where it is used with other materials especially with composite steel-concrete construction. d) Contamination through corrosion and sprayed products for fire protection can also create a barrier for reuse.</td>
</tr>
</tbody>
</table>

Adapted from Hurley et al., (2002)
4.4.4 Related Concepts in Construction

The concept of DFD in construction can be associated with industrialisation in construction (Isiadinso et al., 2006). The association of industrialisation with the design and construction process of a building has been defined in the following ways:

- The application of modern systemised methods of design, production planning and control as well as mechanised and automated manufacturing processes to the building process (Sarja, 1998).
- The rationalisation of the whole building process (which includes: the process of design and the types of construction method used and adopted), in order to achieve integration of design, supply of materials, fabrication and assembly so that building work is carried out more quickly and with less labour on site and, if possible, at less cost (CIB TG57, 2007).
- An organisational process, which involves continuity in production demand; standardisation; the integration of different stages of the whole production process; a high degree of organised work; mechanisation to replace human labour where possible; and research and experimentation of the production process (Foster, 2007).

The key points that can be summed up from these definitions is that industrialisation in construction involves various approaches to ensure the following: effective manufacturing, supply and delivery of materials and components during the building process; the process of organising building design and construction; and the application of an integrated method to manage and execute the building process. Some of these approaches which are related to the concept of DFD include:

1. Open Building (OB)

The Open Building (OB) approach emerged as a result of the need to effectively improve the building process. In addition the social, political and economical pressures in the construction industry of most of the countries was influential in its development (Kendall and Teicher, 2000). It describes a set of principles and techniques developed by various individuals, with Habraken (1961) being one of the pioneers of the open building
approach. There are several ways to describe the open building approach. Sarja (1998) outlined these to include:

**Open architecture** - This means allowing designers and architects to work together in a whole new way to bring diverse design solutions in order to facilitate flexibility and adaptability of different building elements for the interior and exterior parts of a building.

**Open building practice** - This can be described as changing the order of control and responsibilities of the builders or owners, and tenants of non-residential buildings such as offices to replicate an openness in decision making.

**Open industrialised building** - This refers to an openness in the capability of using products from different suppliers to be assembled together into a building and for information to be exchanged between partners of the building process and inside the consortia and business networks.

**Open system building** - This is a general framework for the building industry (which includes modular systems of products, organisation and information, dimensional co-ordination, tolerance system, performance-based product specifications, product data models, etc) in order to encourage suppliers to provide products and service modules that will fit together.

Most Open Building projects have been implemented through concerted long-term research and development with activities conducted by individuals, corporations, associations, industries and government agencies (Sarja, 1998; Kendall and Teicher, 2000). Through these OB projects, some of the challenges (such as decision-making, choice for owners/occupants, logistics in material and component supply and production) facing the construction industry have been successfully met. This has been achieved through the implementation of innovative changes to the building process, products, manufacturing methods and management. A typical example of such a project is the Next 21: an 18-unit housing project in Osaka, Japan (see Figures 4.4 and 4.5).
The Next 21 project used the OB approach in the following ways:

(a) **Open Architecture and Open Building Practice** - each unit was designed by 13 different architects. The architect's could freely design each unit's exterior and interior layout, using their own system of rules for positioning various elements. This ensured flexibility and created units with freely determined layouts for occupants and/or for occupants to change the interior layouts and carry out renovations in the future.

(b) **Open system building and Open Industrialised Building** - extra floor heights were provided above the ceilings and floors raised to allow space for ducts and piping to be routed for independent structural elements. In addition, the building was divided into separate building subsystems – building frame, exterior cladding, interior finishes, and mechanical system. Each subsystem was seen as having a different life cycle, which should be replaced and/or maintained at different times. The idea was to provide an opportunity to use and adapt different products and alternative building systems in the future (Kendall, 1999 and Kim et al., 2002).
Figure 4. 4: Various Cladding Materials Used

Source http://www.arch.hku.hk

Figure 4. 5: The approach view

Source http://www.arch.hku.hk
More recently, the OB approach is being associated with sustainable development in the following ways:

- its potential to reduce waste;
- focus on consumer choice that responds to end users requirements;
- building and subsystem lifecycles;
- increasing the efficiency of resource usage such as materials and components; and
- the capacity to change and adapt buildings in order to extend their useful lives.

2. Offsite Construction

Offsite Construction can be described as a process of utilising as much of the manufacturing process as is appropriate within the context of a construction project (Gibb, 2005). It involves the production of whole building systems in the factory (that is the manufacture and pre-assembly of components, elements or modules) before they are assembled on site (BRE, 2004; Goodier and Gibb 2007). In general, there are four main classifications of offsite construction (see Table 4.5), that are associated with building systems produced in the factory (Gibb, 2001).
Table 4.5: Classification of offsite construction

<table>
<thead>
<tr>
<th>No</th>
<th>Classification</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Component manufacture &amp; sub-assembly</td>
<td>These items includes all small-scale sub-assemblies that would never be considered for on-site assembly such as door furniture or light fittings.</td>
</tr>
<tr>
<td>2</td>
<td>Non-Volumetric pre-assembly</td>
<td>These items are assembled in a factory, or at least prior to being placed in their final position. They may include several sub-assemblies and constitute a significant part of a building or structure. Examples include wall panels, structural sections and pipe work assemblies.</td>
</tr>
<tr>
<td>3</td>
<td>Volumetric Pre-assembly</td>
<td>These items are produced and assembled in the factory. They differ from non-volumetric in that they enclose usable space and are usually installed on-site within and independent structural frame. Examples include toilet pods, plant room units, pre-assembled building services risers and modular lift shafts.</td>
</tr>
<tr>
<td>4</td>
<td>Modular Building</td>
<td>These items are similar to volumetric units, but the units make up the building, as well as enclose the usable space. They may be clad externally cladding such as brickwork or timber frame buildings. (see figures 4.7 &amp; 4.8). Examples include out-of-town retail outlets, office blocks and motels and concrete multi-storey modular units.</td>
</tr>
</tbody>
</table>

Source: Gibb, (2001)

Overall, offsite construction offers the industry techniques and methods that are efficient and fast for the building process (National Audit Office, 2005). Therefore, there is widespread use of offsite construction in modern methods of construction (MMC) to meet the needs of building types such as schools, hospitals and residential homes. Accordingly, about 13% of homes in the UK are now built with offsite construction (BRE, 2004) and about 99% of MMC is associated with offsite manufacturing (Goodier and Gibb, 2004).

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The Cross-Industry Group defines Modern Methods of Construction (MMC) as follows: MMC are about better products and processes. They aim to improve efficiency, quality, customer satisfaction, environmental performance, sustainability and the predictability of delivery time scales. MMC are, therefore, more broadly based than a particular focus on product. They engage people to seek improvement, through better processes, in the delivery and performance of construction (Baker 33 Review, 2006).
Figure 4.6: Brick finish modular building
Source: www.wernick.co.uk

Figure 4.7: Timber Frame building
Source: Kingspanoffiste.com
Some of the building materials and components associated with offsite construction include: timber framing, light gauge steel frames, and pre-cast concrete systems. In general, the benefits of off-site construction can be seen as the following:

- controlled environment leading to benefits in health and safety, handling and storage of materials;
- ability to manufacture in shapes and styles impossible to achieve on site, thereby reducing levels of defects;
- reduction of waste and time savings with volumetric units;
- encourages the cost per unit of volumetric units to go down as production increases;
- improves the performance of the final product;
- social benefits from improved working conditions; and
- greater efficiency in the use of resources materials, labour and transport (Gorgolewski, 2003; BRE, 2004).

3. Prefabrication and Standardisation

Prefabrication is similar to offsite construction as building components are produced in the factory and assembled on site. However, the main aim of prefabrication is to reduce costs, increase the speed of the construction process, and improve quality and performance of the construction process (Gann, 1996). There are two types of prefabricated components. These are: building components produced without prior knowledge of the design or type of building, and components produced for a specific building design (Kendall and Sewada, 1987). The former is mass-produced to meet general demand, while the latter is produced to meet a specific design. The technology used for prefabricated building components is characterised by the following features: the materials used for production; the sequence of operations that comprise the production process; and the equipment used for this purpose (Warszawski, 1999).

Furthermore, Warszawski (1999) points out that prefabricated components are used to create prefabricated building systems and these are made to form three main geometrical configurations of frame systems. These include: the linear (skeletal) frame; the planar (panel) frame and the three-dimensional frame (box). The most widely used
building system is the panel frame. Examples include: floor slabs, vertical supports, partitions and exterior walls.

An important aspect in the design of prefabricated systems is the integration of building services (such as electrical and communication systems, water supply system, sewage disposal system, heating/air conditioning system) into and/or as part of the assembly of various building systems (Warszawski, 1999). Through this integration the industry is able to strive towards an efficient co-ordination of the design, prefabrication and erection of building systems on site. This has, to a large extent, encouraged the development of standardisation of various building components.

Standardisation in construction emerged as a result of the need to manufacture building components in the factory. It has been described as the extensive use of components, methods and processes in which there is regularity, repetition and a background of successful practice and predictability (Gibb, 2001). It provides a means to accurately fit and exchange different components and modular categories. This, in turn, facilitates building assembly as the attributes or functions of components are tested for performance, structural integrity, tolerance and installation (Gann, 1996). For example, dimensional coordination has a great influence on the assembly of most buildings, as a three-dimensional modular grid is used as a guide by designers to locate and place most building elements during the design and construction process. Therefore, various prefabricated components such as walls and slabs are installed with grid lines and modular lengths. In addition, modular coordination contributes to the rules of the standardisation process and assists in reducing the variability of the main building components without imposing excessive constraints on the architectural flexibility (Warszawski, 1999).

Other building components such as doors, windows, stairs and kitchen equipment also come in modular preferred sizes and are defined by national standards. According to Gann, (1996) and Gibb, (2001), full standardisation of building components offers the construction industry the following benefits:

- an improvement in the techniques and methods of assembly on site;
- emphasis on effective performance and quality control; and
- provision of a flexible and versatile design of systems and components.
Despite these benefits of prefabrication and standardisation in the building process, the industry is yet to attain an ideal, were components of different products and technologies can be interchanged freely without restrictions. One of the mechanisms that has been adopted by the construction industry to address the variations and dimensions of different building products is known as ‘construction tolerances’. In general, designers create drawings for building assembly with the assumption that all building materials have specific dimensions and would fit within a specific position of assembly. In practice, this is often not the case as most building elements vary in composition and structure and have to be assembled together in a seamless way. Thus, ‘construction tolerances’ is used as a means to provide a single-source of reference to the thousands of industry-standard tolerances for the manufacture, fabrication, and installation of construction materials and components in a building (Ballast, 2007). This is important as it can facilitate how materials are assembled together on site. The key lessons that can be learnt from industrialisation in construction is summarised in Table 4.6.

<table>
<thead>
<tr>
<th>Open building approach</th>
<th>Offsite Construction</th>
<th>Prefabrication and Standardisation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Encourages flexibility in architectural design</td>
<td>Reduces manufacturing waste and impacts on the environment</td>
<td>Increases the speed of the construction process</td>
</tr>
<tr>
<td>Allows easy alterations of interior layout during the buildings use life</td>
<td>Opportunity to manufacture in shapes and styles impossible to achieve on site</td>
<td>Reduces the overall cost of the building process</td>
</tr>
<tr>
<td>Encourages future changes and modernisation of building systems and components.</td>
<td>Time saving on site</td>
<td>Improves quality and performance</td>
</tr>
<tr>
<td>Provides consideration for a wide range of uses during a buildings life span</td>
<td>Greater efficiency in the use of materials</td>
<td>Reduces wastage on site because of factory produced components</td>
</tr>
<tr>
<td>Recognises the different lifecycles of products and building elements</td>
<td>Improves detailing and connections of building assembly</td>
<td>Facilitation of the integration of various building services system.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Encourages economies of scale</td>
</tr>
</tbody>
</table>

4 Tolerance in construction can be described as the acceptable amount of variation of a material or installed position of the material. Some materials can be custom-cut and fit at the job site, while others (such as prefabricated factory based material with a fixed size) has to be attached to a construction frame on site (Ballast, 2007).
4.5 DFD in Manufacturing

The manufacturing industry has, in the last few decades successfully implemented Design for Disassembly and Design for Environment (DFE) in its production process. Both concepts have emerged as a result of concerns for the environmental damage that is associated with the manufacturing and disposal of products. Furthermore, Design for Disassembly and DFE are terms formulated in the manufacturing industry with the aim of integrating environmental considerations into product design and development. They both involve life-cycle thinking, which means a product designed for all the stages of its life-cycle (Dowie, 2005) with particular considerations of environmental impacts.

Design for Disassembly focuses on the ability of a product's part to be easily reused, remanufactured or recycled at the end of its useful life instead of disposal (Boothroyd and Dewhurst, 1990; Dewhurst, 1993). According to Ljungberg (2005), DFE is about recognising and implementing the following strategies: use of materials with low environmental impact; choosing cleaner production processes; avoiding hazardous and toxic materials; maximising efficient use of energy both for production and when product is in use; and designing for waste management and recycling. Other approaches used by product designers, which recognise environmental impacts, include: design for recycling, design for disposability, design for service, design for energy recovery, etc (Ljungberg, 2005). In addition, the manufacturing industry has developed a number of tools to assist product designers to effectively integrate all these design approaches into product development and the manufacturing process. Examples of some of these tools are listed below in Table 4.7.
Table 4.7: Tools Developed for Design for Disassembly

<table>
<thead>
<tr>
<th>Name of Tool</th>
<th>Purpose of Tool</th>
<th>Organisation</th>
</tr>
</thead>
<tbody>
<tr>
<td>ReStar</td>
<td>A software programme to support the design for disassembly, recycling and repairs</td>
<td>Carnegie Mellon University, USA, 1995</td>
</tr>
<tr>
<td>Ametide</td>
<td>An efficient tool for the designer to optimise disassembly</td>
<td>University of California, Berkeley, 2000</td>
</tr>
<tr>
<td>euroMAT</td>
<td>It assists the engineering designer on information and decision support on the environmental and recycling implications of choosing a material</td>
<td>Technical University Berlin, 1998</td>
</tr>
<tr>
<td>DFMA</td>
<td>It is used by engineers to reduce the cost of a product by consolidating parts into elegant and multifunctional designs</td>
<td>Boothroyd Dewhurst Inc (BDI), 1983</td>
</tr>
<tr>
<td>LASer</td>
<td>A tool for Life-cycle Assembly Service and recycling of products</td>
<td>Manufacturing Engineering, Stanford University, 1994</td>
</tr>
<tr>
<td>DAISY</td>
<td>A tool developed by BMW to be used at the early phase of car design and development, to analyse and support recycling</td>
<td>Dismantling Analysis Information System (Fried at al, 2002)</td>
</tr>
</tbody>
</table>

Clearly, most of these design approaches in manufacturing are similar to and based on, the same principles as DFD. Thus it could be necessary for the construction industry to adopt some of the principles and techniques used by the manufacturing industry to implement the various design approaches.

To a large extent, the construction industry has, in the past successfully adopted and embraced some manufacturing principles and techniques (Gann, 1996; Warszawski, 1999; Fox et al., 2001). These principles and techniques such as lean production, logistics and supply chain management and mass customisation have assisted the industry in improving some aspects of the building process. Nevertheless, it is important to recognise that there are limits to which these techniques and methods can be applied to the building process, as there are considerable differences between the construction and manufacturing processes (Crowley, 1998; Ballard and Howell, 1998). The key differences are summarised in Table 4.8.
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Table 4.8 Construction versus manufacturing process

<table>
<thead>
<tr>
<th>Manufacturing</th>
<th>Construction</th>
</tr>
</thead>
<tbody>
<tr>
<td>• All the work performed at one permanent location.</td>
<td>• Work dispersed among many temporary locations</td>
</tr>
<tr>
<td>• Short to medium service life of a typical product</td>
<td>• Long service life of a particular product.</td>
</tr>
<tr>
<td>• High degree of repetition and standardisation.</td>
<td>• Small extent of standardisation; each project has distinctive features</td>
</tr>
<tr>
<td>• Small number of simplified tasks necessary to produce a typical product.</td>
<td>• Large number of tasks requiring a high degree of manual skills necessary to complete a typical construction project</td>
</tr>
<tr>
<td>• All tasks performed at static workstations.</td>
<td>• Each task performed over a large work area with workers moving from one place to another</td>
</tr>
<tr>
<td>• Work place carefully adjusted to human needs</td>
<td>• Rugged and harsh work environment</td>
</tr>
<tr>
<td>• Comparatively stable work force</td>
<td>• High turnover of workers.</td>
</tr>
<tr>
<td>• Unified decision-making authority for design and production marketing.</td>
<td>• Authority divided among sponsor, designers, local government, contractor and subcontractors</td>
</tr>
</tbody>
</table>


In spite of these differences, the construction industry would benefit from adopting DFD and DFE methods and techniques, as both concepts have emerged as a result of concerns for environmental damage during the manufacture, production and disposal of products. Isiadinso et al., (2006) identified the ways through which the construction industry can benefit from this adoption to include:

• implementation of proven techniques and methods (such as Design for Disassembly) as both products (buildings and complex products) have similar development processes (see Figure 4.8);

• implementation of environmental legislation such as the End-of-Life Vehicles (ELVs) Directive (2000/53/EC) that would encourage reuse and recycling of building components;

• implementation of standards (such as ISO 14001) would encourage the integration of the deconstruction process into conventional construction practices;

• forming partnerships with manufacturers and suppliers of building materials will encourage the re-manufacture of used materials; and

• adopting the life-cycle assessment concept in the early stages of the building process can enable the effective consideration of different life spans of building materials.
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To successfully adopt techniques and approaches from manufacturing, the construction industry needs to consider the following: legislation, the composition of building elements and systems, and encouraging alternative design approaches for future scenarios of building use.

4.6 Enablers and Barriers to DFD in Construction

As discussed earlier in Section 4.4.2, designing a building with the intention of dismantling it at the end of its useful life for the purpose of reuse or recycling is possible and practiced to some extent in the construction industry. However, the prospect of embedding it within the building process as part of the current practice is significant towards designing buildings that can easily be deconstructed. There are several factors which can influence the implementation and integration of DFD into the building process. These are discussed below.
4.6.1 Drivers and Enablers for DFD

Several drivers that can facilitate the integration of DFD into the building process have been identified to include: socio-economic, environmental, political, commercial and legislative factors/considerations (Guy and Shell, 2002; Addis and Schouten, 2004; Morgan and Stevenson, 2005).

Socio-economic - The Society stands to benefit in the long term as the conservation of land and resources are realised through reduced extraction of materials and limited use of landfill sites. New business and job opportunities would be created as a result of markets that would emerge for reusable materials and components. It could also provide low cost materials for affordable homes for low income earners if the government subscribes to using recycled and reclaimed materials.

Economic - A key economic benefit of encouraging DFD can be seen as future-proofing the building in terms of minimising maintenance costs and any necessary upgrading, as this will be done with minimum disruption and cost. The adoption of DFD can also lead to reduction of whole-life environmental impact of building projects by maximising the value of a building and its elements, when it is required for a short period of time (Morgan and Stevenson, 2005).

Environmental – A reduction in the extraction of raw materials used in constructing buildings and reduced transportation and production of these materials should consequently reduce environmental impacts such as CO$_2$ emissions and general degradation of the environment.

Business/Commercial – The increasing cost of landfill tax will serve as a deterrent and discourage waste disposal to landfill sites. Landfill tax has been imposed by several governments within the member states of the EU and is set to increase in the next few years. For example, in the UK, since 1996 the landfill tax has been imposed and the standard rate of landfill tax in 2006/07 was £21 per tonne. It is set to increase to £35 per tonne (with an annual rate of £3 per tonne since April 2001). In addition the aggregate levy is charged at £1.60 per tonne since April 2002 and this aimed to encourage the use of reclaimable and recyclable materials to meet the governments' targets to reduce the use of primary aggregates by 20%. This is used as a 'stick' to ensure that the C&D
industries can find alternative ways to address waste disposal and possibly encourage the reuse of materials.

**Political** – In order to reduce overall waste generation during construction activities and achieve sustainable construction the government has made available several incentives and guidelines to facilitate this process. This includes planning regulations which require that most building projects have an environmental impact assessment plan and tools (such as ENVEST2 and BREEAM) developed by BRE to encourage implementation of sustainable construction practice. In addition, a strategy for action published in 2000 for more sustainable construction entitled ‘Building a Better Quality of Life’ identifies the following actions: reuse of existing built assets, design for minimum waste, aim for lean construction, minimise energy in construction, minimise energy in building use, avoid polluting the environment, preserve and enhance bio-diversity, conserve water resources, respect people and their local environment and set targets (benchmarks & performance indicators). A review of the sustainable construction strategy in 2006 carried out by BERR indicates that considerable progress has been made by the construction industry and further works would need to be done to effectively manage the built environment by minimising energy use and reducing waste during construction activities (BERR, 2006).

**Legislation** – In the UK, a waste strategy that stresses the importance of producer waste responsibility in waste management related to prevention, recovery and minimisation of disposal is encouraged through the adoption of the EU Waste Framework Directive (75/442/EEC and 92/43/EEC) (DETR, 2000). It challenges the C&D industries to manage their resources effectively and acts as a driver to waste reduction and a way of encouraging reuse and recycling of building materials. These regulations are expected to get tougher and more focused on making industry take responsibility for waste generation (Hurely et al., 2001). Thus, the industry is expected to take steps to minimise its waste production in order to have a competitive edge towards the future. Some of the factors that act as enablers to implementation of DFD in the building process include:-

a) **Location of a Building**

When a building comes to the end of its useful life, the technique often used to demolish or dismantle the building can be affected by the location of the building. For example, if a
building is located in the centre of a town or city with numerous human activities, it is probably safer to disassemble than to demolish. This would help prevent and reduce the impact of noise/vibration/dust that often occurs during demolition activities. The size of a site and location will also determine the extent of demolition works that can be carried out. A construction site with sufficient space will facilitate storage and encourage recovery of materials compared to a site with insufficient space.

b) Quality of Information

The quality of information available at the end of a building's useful life (such as the original construction drawings, reports of maintenance works carried out) will assist in the efficient management of disassembling the building's components and materials. This information will assist in determining the possible future use of the structural components that comprise the building. On the other hand, the lack of information would discourage and reduce the speed with efficiency by which a building can be deconstructed.

c) Time and Cost

Time is a very important factor both in the process of construction and deconstruction. It would determine the technique and methods that can be used to build, dismantle and demolish a building. For example, if a property developer purchases a derelict building and has a short time frame to construct a new building, then demolition which is a faster and proven process will take precedence over deconstruction. Cost, efficiency and quality are some of the traditional goals of construction activities. The cost of dismantling a structure within a specific time frame can also be a disincentive if the property developer does not envisage any future benefits or financial gain. Therefore, there is a need to create cost effective mechanisms and incentives to encourage ease of building disassembly as it is vital to the process of deconstruction in construction practice.

d) Markets

At present within the industry, there is already a market for down cycled products such as concrete rubble and architectural artefacts. The market for architectural artefacts from buildings has always been in demand because of private collectors, who have a special interest in the historical features of buildings. On the hand, the need to introduce and
create a market for reusable components and materials cannot be ignored, as it could assist and encourage the practice of deconstruction. In addition, the introduction of a material grading system would assist designers to specify recycled building products and facilitate the deconstruction process.

e) Skill of Workers

Building disassembly is a very labour intensive process, which would require a considerable number of skilled workers. Presently, there are no specific tools for building disassembly and insufficient training for workers (Guy and Shell, 2002). This often acts as a deterrent to efficiently deconstruct buildings and determines the speed of deconstruction as well as ensuring minimum damage to materials recovery. Therefore, in order to facilitate the deconstruction process, there is a need to have specialised skilled workers (as for demolition business) and provide appropriate tools.

4.6.2 Barriers to DFD

There are several potential barriers to the implementation of DFD in the current building process (Addis and Schouten, 2004). These include:

Physical barriers – most buildings are designed and constructed with composite materials and the connection techniques used are mostly permanent. This would discourage disassembly and also make it difficult to separate and recover materials in good condition for reuse.

Practical barriers – there is currently insufficient information available in terms of standards and specifications for construction professionals to carry out deconstruction after a building's useful life.

Attitudinal barriers – the general perception of buildings by construction professionals and the general public is that buildings are permanent structures and the idea that they could be designed to be deconstructed is often perceived as not being practicable.
Economic barriers – the inclusion of DFD in the design process would involve additional time and cost as it is presently not part of the current project delivery process in building construction.

Legislative barriers – although there are a number of legislations and standards presently encourage the reuse, reclaiming and recycling of materials in order to minimise waste, there is no specific legislation that requires construction professionals to consider deconstruction at the design phase of buildings.

The fragmented nature of the building process – the design and construction process is often carried out in stages involving various construction professionals and organisations. This means that sometimes, there is insufficient information and coherence between the design and construction stages. In order to implement design for deconstruction there is a need to implement a coherent, co-ordinated and integrated design and construction process.

4.7 Requirements for Applying DFD in Construction

It is important to recognise that not all buildings can be designed to be deconstructed, but it is clearly evident a considerable percentage can. Therefore, there is a need to incorporate design for deconstruction principles into the building process. This is because of the potential benefits it offers the construction industry in minimising waste and reducing the environmental impacts of buildings. Requirements for an effective integration of DFD into the current building process include:

- review of the current techniques and methods used for assembling and constructing buildings in order to facilitate ease of deconstructability;
- creating increased awareness and market for reusable, reclaimed and recyclable materials in order to release financial benefits of undertaking deconstruction;
- establishing legislation and providing guidance to support standards and codes to encourage and facilitate DFD in a structured way;
- appraising the current practice of the building process in order to identify the appropriate mechanisms for incorporating DFD into the building process;
- facilitating the process of specifying building components with modular and standard measurements that would encourage ease of deconstruction;
• developing appropriate mechanisms to assist construction professionals in encouraging co-ordination of information as this would be essential in accomplishing DFD practice; and
• implementing the concept of DFD at the inception stage of a project as this will facilitate its integration in the overall building project plan in a cost-effective fashion.

4.8 Summary

This chapter has discussed the concept of design for deconstruction (DFD) and its potential to assist the construction industry in minimising waste and encouraging the reuse and recycling of building materials and components. In order to effectively maximise these potential benefits, there is a need for the industry to apply new principles to the current process of designing and constructing buildings. The challenge, therefore, is to integrate the concept of DFD into the current building process. This would involve exploring the extent to which the concept of deconstruction can be applied into current practice and the most effective way to integrate it. The next chapter explores this, through an investigation of current deconstruction practice by undertaking a survey and a case study.
CHAPTER 5 INVESTIGATION OF CURRENT DECONSTRUCTION PRACTICE

5.1 Introduction

This chapter presents an investigation of the process of the current industry practice with respect to deconstruction. The investigation adopted two main methods: a questionnaire to construction professionals and a case study of the Industrial, Flexible and Demountable (IFD) building programme. It describes the methods used to carry out the investigation and discusses the findings.

5.2 Approach to Investigation

The third objective was to obtain a broad based knowledge on the awareness and practice of sustainability in the UK with respect to deconstruction. A survey questionnaire was used to investigate this objective. The reason for using this approach was to capture in a short period of time the views of construction professionals in the UK on the concept of DFD. In addition, the survey approach allows respondents to give careful consideration to questions, thus potentially enhancing the reliability of the data. Nevertheless, data collected through a survey may not be assumed to be a full representation of a phenomenon, despite this short coming, this approach has been considered as an effective means to investigate and establish reliable and valid conclusions (Leedy and Ormrod, 2001).

The fourth objective of the research was to undertake a practical example of implementing sustainable construction which reflects deconstruction principles. A case study was used to investigate this. The reason for using a case study was to firstly, support the findings from the survey; Secondly, to potentially highlight the concepts related to DFD within the building process; and finally, to provide a basis to explore and understand the structure, process and people required to implement a concept similar to deconstruction within the building process in a real-life context. Accordingly, this agrees
with Gummesson (2000) and Yin (2004) on the reason why a case study approach should be used to effectively investigate a phenomenon within a real-life context.

5.3 Questionnaire Survey

The specific objectives were:

- To identify what types of buildings and structural forms are most likely to be partially demolished, deconstructed, or refurbished at the end of their useful life.
- To establish the extent to which construction organisations (during building projects) implement waste management strategies to incorporate reduction, recycle and reuse of building materials and components.
- To determine changes in the construction industry within the last 5 years that reflect the adoption of sustainable construction principles especially in the area of deconstruction.
- To determine to what extent construction professionals (such as architects and engineers) consider deconstruction principles in decision making during the design process of a building.
- To identify the criteria within the construction industry that can facilitate design for deconstruction.

5.3.1 Questionnaire and Sample Design

The questionnaire design was based on extensive review of literature on sustainable development, sustainable construction and deconstruction in the C&D industries. A pilot survey was administered to 5 construction professionals: 2 in academia and 3 in industry to ensure that the questions were appropriate and relevant to current practice. Based on the feedback from the pilot survey, a number of the questions were restructured and the total number was reduced to 17. The questionnaire comprised 3 sections: a) background information; b) the process of deconstruction; and c) the design process. A definition of deconstruction was included at the top of the questionnaire as a guide to ensure that all respondents understood the context of the survey. The questionnaire included three types of questions: (1) open ended questions with the option to answer ‘Yes’ or ‘No’ and a space provided for written reasons to support the answer. (2) five-point Likert rating
scale ranging from 1 to 5 with different options such as 1 (“never”) to 5 (“always”), 1 (“no opinion”) to 5 (“definitely important”) and 1 (“no opinion”) to 5 (“definite potential”). (3) open ended questions with the intention to measure the percentage of opinions based on a balanced scale of items, for example, (“strongly influence” to “uncertain” with a space provided for written reasons in support of the choice (see Appendix C).

The implementation of sustainability issues in the building design and construction process is considerably a new approach in construction practice (DETR, 2000). Therefore, the selection of organisations to administer the questionnaires was based on organisations that acknowledged to be incorporating some aspect of sustainability issues into their practices. This selection was done from the various professional Directories and Handbooks: RIBA for the architects, New Civil Engineering (NCE) and National Federation of Demolition Contractors (NFDC) website. The questionnaire was mailed with a covering letter to 250 organisations explaining the purpose of the survey and the relevance to sustainable development in the industry. This was followed up by telephone calls to boost response rates and generate interest in the research. The percentage of respondents and their professional background is shown in Figure 5.1 below.

![Figure 5.1 Professional Background of Respondents](image)

### 5.3.2 Results

The total number of questionnaires returned was 34 out 250 mailed, of which 26 were usable. This total number does not include questionnaires returned uncompleted as respondents stated that although they considered sustainability, they did not practice
deconstruction and therefore could not fill out the questionnaire. The response rate was 10.4% based on the number of usable questionnaires returned. The response was low probably because the practice of sustainability is relatively new and the concept of deconstruction is still in its infancy in construction practice (Sayce et al, 2004; SEDA, 2005). In addition, surveys related to sustainability are very much at exploratory stages and have not fully become part of traditional construction practice (Sterner, 2002; Myers, 2005). Bearing in mind that the survey was exploratory in nature, it was considered to be relevant in evaluating the attitude, perception and awareness of deconstruction in construction practice. The results are therefore indicative of how the construction industry takes into account deconstruction practice. The following section presents the results of the questionnaire survey. Its divided into two sections: the process of deconstruction and the design process.

5.3.3 The Process of Deconstruction

(A) Perception of deconstruction as an alternative to demolition

63% of the respondents acknowledged that deconstruction could serve as a better alternative to demolition (see Figure 5.3). However, they pointed out that several issues would need to be addressed in the building process before the industry can begin to practically implement deconstruction instead of demolition (see Table 5.1)

![Figure 5.2: Perception of Deconstruction as an Alternative to Demolition](image-url)
Table 5.1 How to Make Deconstruction Practicable

- Work with building demolition contractors to maximise resources
- Incorporate deconstruction as a part of the safety plan of any building project
- Develop and adopt a method that would be suitable for different types of structures
- Consider the site and space available to carry out deconstruction activities
- Create and encourage a market for recycled products
- Educate clients on the benefits of deconstruction
- Ensure that information on deconstruction is readily available

(B) Specification of recyclable materials in new construction or refurbishment projects in the last 5 years.

Figure 5.3 shows the percentage of respondents who have specified recyclable materials as against respondents who have not. 85% of the respondents compared to 15% indicated that they specify recyclable materials in refurbishment projects. However most of these specifications were mainly at a very low scale and dependent on the type of project work undertaken.
Some of the materials that were specified as indicated by respondents were recycled aggregates, reclaimed timber, built-up metal cladding system (instead of composite system so that the metal sheet and the insulation could be reused or recycled) and rebar (manufactured from scrap metal). The type of projects in which these recycled materials were used was mostly dependent on the client. For example, the Wessex Water, head quarters building project at Bath, used recycled crushed concrete railway sleepers in in-situ concrete for the superstructure. In addition, recycled crushed concrete are used for new builds as a sub-base layer, roads & civil works, and working on pre-planning application to help developers to agree on the percentage of recycling based on WRAP guidance.

(C) Types of building demolished in the last 5 years as an indication of building types mostly likely to be deconstructed.

The responses received indicated that residential buildings had the highest number of demolitions compared to other types of buildings (see Figure 5.4). Industrial buildings had the second highest number of demolition with leisure buildings being the least demolished building type in the last five years.

![Figure 5.4: Types of buildings most likely to be demolished in the last 5 years](image-url)
The respondents were also asked to rank from '1 to 3' which type of building was most likely to be deconstructed. The response did not indicate that any particular building type was likely to be deconstructed as each respondent listed different building types for each rank. This implies that building demolition, as well as deconstruction, would most likely be dependent on the building owner's decision and not on the type of building.

Respondents were also asked if the type of material or component used to construct the building types played a significant role in why these buildings were demolished. The general response indicated that the materials used to construct these buildings did not have a major influence in the decision to demolition these buildings. Most buildings that were demolished had been constructed with traditional materials such as concrete and bricks.

(D) Principles of Design Approach for Deconstruction

As shown in Figure 5.5, the percentage of respondents who 'always' applied all the principles of deconstruction was relatively low with an average of 8.75%.

![Figure 5.5: Considering principles of deconstruction in projects](image)

- d1 - design for flexibility and adaptability
- d2 - design to facilitate disassembly logistics
- d3 - design using prefabricated, preassembled and modular units
- d4 - design with the intention for materials and components to be reused in future building projects
- d5 - minimising the use of building components and materials
- d6 - recommending connection details that are simple and standardised
- d7 - specification of fittings, fasteners, adhesives and sealants that enable ease of disassembly
- d8 - using simplified and separated building system
However, a total of 60% 'always' or 'very often' considered flexibility and adaptability (d1). The average percentage of respondents who considered all deconstruction principles 'very often' was 26.63%, with 40% of the respondents 'fairly often' considering design for disassembly logistics (d2), 50% of the respondents 'sometimes' considered using simplified and separate building systems (d8). The results indicate that design for flexibility and adaptability (d1) on average had the highest consideration and specification of fittings, fasteners, adhesives, and sealants that enable ease of disassembly had the least consideration.

(E) The roles of construction professionals in influencing the adoption of deconstruction principles

From Figure 5.6, 78% of the respondents (particularly the architects and engineers) believed that construction professionals had a role in influencing the adoption of deconstruction principles whilst 19% (project managers) did not think so. The remaining 3% was made up of the demolition contractors who felt that their role in construction had no influence whatsoever.

![Pie chart showing respondents' role in adopting deconstruction principles](image)

Figure 5.6: Respondents' role in adopting deconstruction principles

5.2.4 The Design Process

(A) Assessing the importance of implementing DFD through 13 criteria.

The analysis of the response data produced mean importance values for both the external and internal criteria for implementing DFD in the design process (see Table 5.2).
The mean score values ranged from 3.33 to 4.7 for the external criteria while the internal criteria ranged from 3.625 to 4.666. The mean score range was not widely dispersed, suggesting that each criterion was deemed important in the design process. However, 'the materials and components available', ranked first in the survey analysis (see Table 5.2) with a mean score of 4.7 for the internal criteria, while 'time and cost' ranked first for the external criterion with a score of 4.666. On the other hand, the 'space layout' with a mean score of 3.333 was ranked as the least important criteria for internal factors and 'location of buildings' with a mean score of 3.625 was the least important of the external factors.

Table 5.2: Respondents perception of the importance of each criterion to the application of DFD

<table>
<thead>
<tr>
<th>Internal Criteria</th>
<th>Mean Score</th>
<th>Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type of building</td>
<td>4.04</td>
<td>4</td>
</tr>
<tr>
<td>Legislation and Standards</td>
<td>4.42</td>
<td>2</td>
</tr>
<tr>
<td>Structure of building</td>
<td>3.66</td>
<td>5</td>
</tr>
<tr>
<td>Space Layout</td>
<td>3.33</td>
<td>7</td>
</tr>
<tr>
<td>The material and component available</td>
<td>4.7</td>
<td>1</td>
</tr>
<tr>
<td>Technology (Building Technology, Information Technology)</td>
<td>3.56</td>
<td>6</td>
</tr>
<tr>
<td>Client</td>
<td>4.13</td>
<td>3</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>External Criteria</th>
<th>Mean Score</th>
<th>Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location of building</td>
<td>3.63</td>
<td>4</td>
</tr>
<tr>
<td>Quality of information (Construction and maintenance drawings)</td>
<td>4.04</td>
<td>3</td>
</tr>
<tr>
<td>Time and Cost</td>
<td>4.66</td>
<td>1</td>
</tr>
<tr>
<td>Markets for reusable, recycled materials and component</td>
<td>4.25</td>
<td>2</td>
</tr>
<tr>
<td>Skill of workers</td>
<td>4.04</td>
<td>3</td>
</tr>
</tbody>
</table>

change 4 to 5

(B) The choice of structural form (volume, size, and shape) at the design stage of a building project could influence the adoption of deconstruction principles

Figure 5.7 shows the opinion of respondents on how the structural form of a building can facilitate the adoption of DFD. 37% believed it had a 'strong influence' while 15% thought
it had no influence. However if one combines the percentage of those who thought it had a ‘strong influence’ and those that thought it had an ‘influence’ the total is 70%. This implies that, to a large extent the choice of structural form of a building can influence the adoption of deconstruction principles.

![Pie chart showing the influence of structural form on DFD](image)

**Figure 5.7: Opinion of respondents on the effect of structural form on DFD**

(C) Rating the potential of materials for adopting DFD into the design process

Table 5.3 shows the mean score of respondents’ opinion on popular materials used to design and construct buildings.

<table>
<thead>
<tr>
<th>Materials</th>
<th>Mean Score</th>
<th>Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concrete</td>
<td>3.73</td>
<td>4</td>
</tr>
<tr>
<td>Bricks</td>
<td>4.23</td>
<td>2</td>
</tr>
<tr>
<td>Timber</td>
<td>4.19</td>
<td>3</td>
</tr>
<tr>
<td>Steel</td>
<td>4.38</td>
<td>1</td>
</tr>
<tr>
<td>Glass</td>
<td>2.69</td>
<td>5</td>
</tr>
</tbody>
</table>

Steel as a building material had the highest potential with a mean score of 4.38 was ranked at No.1 while glass was ranked at No.5 with a mean score of 2.69 as having the
least potential. Bricks ranked at 2nd with a mean score of 4.23; this might be because bricks are a popular building material in the UK.

(D) Which part of a building if designed differently could facilitate deconstruction?

Table 5.4 shows the mean score of respondents’ opinion on the parts of a building which, if designed differently, would facilitate the adoption of DFD. The ranking from 1 to 5, shows that the wall with a mean score of 4.4 is deemed to be the part most likely to facilitate deconstruction. Furthermore, the roof and the floors with a joint mean score of 4.12 ranked as the second most important of the building that needs to be designed differently. The ‘doors and windows’ with a mean score of 2.84 was ranked the least important indicating that designing them differently would not necessarily facilitate deconstruction.

Table 5.4: Respondents perception of the part of a building if designed differently would facilitate deconstruction

<table>
<thead>
<tr>
<th>Typical Parts of a building</th>
<th>Mean Score</th>
<th>Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roof</td>
<td>4.12</td>
<td>2</td>
</tr>
<tr>
<td>Walls</td>
<td>4.4</td>
<td>1</td>
</tr>
<tr>
<td>Floor</td>
<td>4.12</td>
<td>2</td>
</tr>
<tr>
<td>Services</td>
<td>3.4</td>
<td>3</td>
</tr>
<tr>
<td>Doors and Windows</td>
<td>2.84</td>
<td>4</td>
</tr>
</tbody>
</table>

(E) What provisions are made in the design process in your organisation for deconstruction?

Figure 5.8 shows that 41% of respondents (mostly the architects and engineers) are of the opinion that their organisations currently make some provisions to incorporate deconstruction principles in the design process. On the other hand, 48% of the respondents did not think so, while 11% of the respondents stated that they were not involved and therefore could not indicate if provisions were made.
Chapter 5: Investigation of Current Deconstruction Practice

Figure 5.8: Respondents' opinion of provision in the design process to incorporate deconstruction principles

(F) What are the key issues that your organisation would need to address to facilitate the better integration of DFD into the building design process?

In order to facilitate the integration of DFD into the current design process the respondents suggested the following:

- Embarking on whole life cost analysis that focuses on the long term use of buildings instead of short term.
- Introducing prefabricated designs for building services to speed up the process of deconstruction.
- Encouraging the client (developer) to think of the whole life cost of the building.
- Providing a knowledge base of construction principles for DFD and reuse or reclamation of materials.
- Professionals would need to increase their knowledge base in order to be in the position to advise clients.
- Ensuring economic return of applying the principles of deconstruction.
- Providing legislative regulations that would enforce the practice of deconstruction.
- Creating awareness of deconstruction techniques that can be applicable to current buildings.
- Accommodating the clients' perception of value for money to incorporate DFD.
- Providing good knowledge of construction techniques to promote DFD and the LCA of materials including their cost implications.
Chapter 5: Investigation of Current Deconstruction Practice

- Understanding of building insurers’ coverage of using reuse and recycled materials.
- Meeting institutional standards on the value and ease of recycling materials and components such as British standards

(G) The current access to tools/techniques/methods (such as BREEAM, LEED) for incorporating deconstruction principles into the design process

Generally, most respondents were aware of and have used sustainability tools such as BREEAM (BRE) and the Demolition Protocol (ICE) (See Fig 5.8). However, they were of the opinion that most existing tools are used for environmental assessment and whole life cycle costing of buildings. One of the respondents indicated that their organisation had developed an in-house sustainability appraisal tool called Atkins Sustainability Appraisal (ASAp) that promotes the use of reusable and recyclable materials.

![Figure 5.9: Respondents awareness of tools to facilitate deconstruction principles](image)

(H) What incentives (for example building technology, legislation) would you require to adopt deconstruction principles in the design process?

The incentives as suggested by the respondents that would encourage the implementation of deconstruction are:

- Recyclable materials should be promoted through a legislative framework
- A legislative constraint should be set up to encourage designing for recovery with a restriction on disposal
• Increasing landfill tax significantly should ensure consideration for including deconstruction principles by developers
• The cost of labour for dismantling should be addressed considering that demolition often works out cheaper
• Contractors should be involved as early as possible especially at the procurement stage of projects.
• Strategic brief to be set by clients should include deconstruction principles as one of the key issues
• Production of comprehensive guidelines through building regulations by government recommending construction details to encourage DFD.
• The need to issue new legislation to set maximum standards of waste generated from buildings at the end of its life.
• A calculation tool to estimate the amount of waste and reusable components

(I) Have you received any feedback from building or demolition contractors on the 'ease of disassembly' of your building design? If yes, please state in which area of design?

Only 4% of respondents indicated that they had received feedback from a contractor on the ease of building disassembly. The building in this case was unique as it was a listed building. The majority may not have received feedback because very few buildings are actually deconstructed or demolished within the lifetime of the designer/contractor.

Figure 5.10: Respondents who got feedback from contractors
If a tool is developed to facilitate the adoption of DFD in the design process, what kind of features would you like included?

The ideal features of a deconstruction tool as suggested by the respondents are as follows:

- Reconciling the cost and calculating the waste stream in projects.
- Comparing the cost of implementing deconstruction with design and safety issues.
- It should be adaptable to different building types.
- The design features recommended should be easy to implement.
- A step by step guidance should be given to analyse feasibility of adopting DFD.
- If possible, adapt the same approach of existing tools such as BREEAM.
- Provision of a scoring matrix for different construction systems, different elevations and finishes.
- The key stages should relate to RIBA work stages.
- Show typical details of best practice case study.
- Inclusion of principles of structure and cladding.
- A database with retention of design data.

The features recommended by the respondents are diverse and indicate the relevance of giving consideration to various aspects of building design and the project delivery process in construction practice. Thus, all the aforementioned features (such as cost implications, options for different building types, technical aspects of a building and existing tools for environmental assessment) are considered significant in developing a model process for integrating deconstruction into the building process. However, the roles of each construction professional should be acknowledged in order to ensure a systematic and structured process of integrating the principles of deconstruction into the current building process. This means that the focus of the tool should be such that the requirements of building design are met within the framework of existing construction professionals roles in the building process, which can effectively drive implementation of DFD from inception to completion and possible future reuse of building components and materials.
5.4 Case Study

5.4.1 Introduction

A case study was carried out to support the questionnaire survey. It was aimed at identifying a practical example of implementing sustainable construction which reflects deconstruction principles in conventional building practice. Initially, temporary structures were considered because their design principles which can facilitate building disassembly are similar to deconstruction principles. However, the Dutch programme 'Demonstration projects Industrial, Flexible and Demountable Building (IFD)' was selected based on the following: the uniqueness of the programme, the concept used in implementing the building process and its objective to encourage sustainable building design which is similar to deconstruction principles. The objectives of the case study were:

- to clarify the findings from the literature review on deconstruction;
- identify the scope of integrating the process of deconstruction into the current building process;
- to investigate an approach which has used sustainable principles to implement the building process; and
- to identify the benefits gained with the implementation of deconstruction principles.

To achieve these objectives, a semi-structured interview was carried out and supported by documentation and archival reports. A questionnaire was prepared to guide the interview process (see Appendix D). A detailed description of the case study is given using a narrative structure to present the findings.

5.4.2 Background

The IFD building programme is a joint initiative between the Ministry of Economic Affairs and the Ministry of Housing, Spatial Planning and the Environment in the Netherlands. The programme was funded by a government subsidy and carried out as demonstration projects. The programme was implemented by the Steering Committee for Experiments
in Housing (SEV) and the foundation for Building Research (SBR). It was launched in December 1998 as a seven year programme and implementation of demonstration projects started in 1999. Prior to the official launch in December 1998 the ministries commissioned Damen Consultants in 1997 to investigate the market potential of the IFD building principles. The main findings suggested that the IFD building principles would provide the construction industry with an integrated approach to combining environmental and economic interests in the building process. As a result, two objectives were set out as a guide to ensure practical implications and outcomes. These included:

- The incorporation of 'industrial', 'flexible' and 'demountable' principles into conventional building construction practice using demonstration projects; and
- The stimulation and demonstration of the innovative use of IFD techniques in new construction and renovation, public housing and utility building projects.

Accordingly, the aim and purpose of demonstration projects are:

- to experiment with new sustainable technologies;
- to develop cooperation routines in the management of sustainable construction projects;
- to develop sustainable construction competence of the participating organisations: and
- to demonstrate the new possibilities in the field of sustainable construction (Bossink, 2002).

5.4.3 The Concept

The acronym IFD defines the concept and characteristics of the building programme (see Table 5.8). The programme was aimed at developing an industrialised, flexible, durable/demountable morphology and system for producing industrialised and user-oriented buildings. It also comprised an integrated approach which combined environmental and economic interests. It offered creative solutions to the industry on the use of natural resources, labour, construction professionals, building manufacturers and suppliers, and building technology.
In order to support these creative solutions, the primary focus of the IFD building programme was on the following: exploiting the possibilities of environmental industrial production methods; reduction of building waste; and flexibility in building design. This was carried out by ensuring that each project had a certain percentage of the underlying principles of the building programme (that is flexibility, industrialisation and demountability/durability\textsuperscript{5}). This was demonstrated in the 27 projects that were completed by June 2003. The IFD programme coordinators investigated the evidence of applying the 3 concepts and the results showed the following: half of the projects focused on flexibility, about a third on industrialisation, a fifth on demountability and overall a fifth of the projects focused on all 3 aspects. This suggests that at best most projects demonstrated the integral essence of the IFD concept and characteristics.

\textsuperscript{5} While durable and demountable may appear contradictory, they are used interchangeably to define in effect the strategic performance of the IFD Building System (that is the possibility to demount a component for reuse in a changed layout and the possibility to remove it, for maintenance works or repair makes IFD building durable (d' Architectettura, Unknown))
Chapter 5: Investigation of Current Deconstruction Practice

Table 5.6 The IFD Concept and Characteristics

<table>
<thead>
<tr>
<th>Industrialised</th>
<th>Flexibility</th>
<th>Durability</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Not necessarily dependent on prefabrication and preassembled components</td>
<td>• the building layouts and technical solutions</td>
<td>• It should be demountable and therefore should highly hence durability</td>
</tr>
<tr>
<td>• The design-production-delivery process is based upon the model of advanced manufacturing industries</td>
<td>• provision in the design and construction (production stage) for internal modification of layouts, size and shape of single spaces, building functional and technical equipment, components and finishing materials.</td>
<td>• Incorporate dry assembly technologies. This can allow for total or partial removal of building and service components. It should also support durability, adaptability and sustainability performance requirements such as:</td>
</tr>
<tr>
<td>• The process is managed by a consortium of architects, public and private clients, contractors, manufacturers, suppliers and other building operators</td>
<td>• wide range of components types that can facilitate selection of optimal solutions to meet client's functional needs and economy in building.</td>
<td>(a) Inter-changeability of components which facilitates maintenance and reduces the need for major and expensive replacement;</td>
</tr>
<tr>
<td>• A set of standard protocols regulates the building design, production and delivery phase</td>
<td>• possibility of functional, technical and aesthetic changes based on client's needs, with durability.</td>
<td>(b) possibility to remove in whole rather than demolish, reduces costs, optimizes results and minimizes users discomfort in maintenance and upgrading work; and</td>
</tr>
<tr>
<td>• An information database is provided for all the possible IFD building system options. The information should include: (a) compatibility of various components is checked against the IFD building concept; (b) a client/user is able to choose an IFD building solution closer to their needs/requirements; (c) an evaluation of technical, economic and social factory is done in terms of assembly requirements, compatibility between building and service component, costs, etc</td>
<td>• Large number of solutions for building morphology and opportunity to increase them on client's request</td>
<td>(c) re-use of demounted components in the functional re-arrangement of space and in other uses.</td>
</tr>
<tr>
<td>• It should incorporate prefabricated and semi-finished products</td>
<td>• possibility of changing technical solutions and finishes</td>
<td>• The temporal characteristic architectural elements with functionality should provide a strong assurance for building durability, maintainability and satisfaction of client needs.</td>
</tr>
<tr>
<td>• It should be possible to use both traditional and/or completely prefabricated components/systems depending on the client's requirements or on technical constraints.</td>
<td>• possibility of modifying spaces, dimensions, and functions</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• easy interface with 'additional system' components and technologies</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• adaptability to dimensional or geometrical restrictions depending on shape and size of building plot.</td>
<td></td>
</tr>
</tbody>
</table>

Source: d' Architectettura, (Unknown)
Chapter 5: Investigation of Current Deconstruction Practice

5.4.4 Method Used For Implementing IFD Building Programme

There is a general consensus in the construction industry that techniques or methods developed as a result of research must be relevant and applicable to current building practice (Bakens, 1997). To support this argument, the organisations (SEV and SBR) assigned with the task of managing the IFD programme used two approaches:

1. An invitation to the public (project developers, corporations and municipal councils). The invitation was in form of a tender to submit proposals for building projects. These invitations were sent out on four different occasions with a request for 100 applications each time. It was expected that each building proposal should have a definite plan, apply to a specific location and show a demonstration status of IFD principles.

2. A selection process. A team of experts that included architects, developers, government representatives, construction companies and consumers, carried out the selection process. It was carried out over a period of 4 months. The 3 concepts of the IFD building principles (industrialisation, flexibility and demountability/durability) and seven criteria were used to evaluate each proposal. The seven criteria included:

- what proportion of industrial production and co-operation is shown in the overall project proposal?
- is the design flexible enough to accommodate future use and discourage early demolition?
- to what extent had the proposal used industrial building methods which could facilitate demountability especially the implementation of modular construction to support the ease of the assembly/disassembly process of building components?
- to what extent had the proposal applied sustainability principles in terms of environmental considerations (such as reducing building waste) and boosting the economy through job creation?
- what innovative process had been used to encourage collaborative work between the suppliers, client and manufacturers to construct the building?
• does the approach of the building proposal show adaptability for future development in construction and/or demonstrate future lessons?; and
• does the proposal specific to housing show an innovative and inclusive design for the elderly and young.

The total number of applications received was 400. Out of the 400 applications, 92 were chosen and funding was provided for construction. Of the 92 projects selected, 60 have been built and are currently in use, 12 had to be stopped due to financial and political reasons and 10 are yet to be finished. The most innovative and/or exemplary proposals showing IFD principles were awarded a subsidy and given a time scale to complete the demonstration project.

The IFD programme was designed to last for 7 years and most projects were expected to be formally completed within two years of approval. However, this was not the case as some projects awarded as early as 1999 and as late as 2004 will not be completed until the end of 2007. Although 2007 is beyond the scope of the programme, the organisations (SEV and SBR) are expected to continue with the administrative aspects of managing the projects to ensure completion and compliance with IFD concepts. The projects were managed in the following ways:

• A regular project monitoring regime: IFD project managers were required to ensure that specifications and construction methods adhered to IFD building principles. This was carried out through frequent site visits.
• Flexibility in decision-making: In cases where exact specifications could not be applied to production and construction of buildings, immediate changes were made on site to reflect IFD building principles
• Regular publications and seminars were carried out to create awareness and promote IFD building principles. This was to ensure the possibility of the IFD concept and techniques being adopted into conventional construction practice.

5.4.5 The key implementation practices

The key implementation practices for the building process are highlighted in the following four sub-headings:
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1. Design Considerations: The design approach used can be described as a hybrid of the open building approach. It was used to encourage the following practice:

- a differentiation between permanent and variable building systems. For example, using cast-in-situ concrete for load bearing walls and composite components that are moveable for the internal walls to facilitate assembly and/or disassembly for adaptable reuse;
- a separation between the structural and architectural elements is essential. This should facilitate technological upgrades of building services such as insulation elements and mechanical components; and
- installation of building components that encourage easy access to operation and maintenance of buildings. For example, hollow steel sections are used for floors to achieve flexibility within the floor system to accommodate electrical cables.

In addition, IFD building principles must be realised through the design process, in the following ways:

- changing the conventional design process to include the suppliers and manufacturers at the early stages of the design process; and
- providing and agreeing a uniform solution amongst all the stakeholders (clients/users, architects, manufacturers, suppliers, contractors, etc) to achieve IFD building principles. For example, a standard building concept combining flexibility and demountable options is applied during the design stages of a project.

2. Structural Considerations: The structural approach used was mainly a flexible one. However, special considerations were given to the dimensions (length, height and width) and distance between the structural elements (such as the beams and columns) to accommodate changes. The main purpose was to encourage easy access for mechanical repairs and technology upgrades during the life of a building; and to encourage adaptable future use of the building that permits different changes to functional space layouts.

Furthermore, great importance was given to the assembly phase of the buildings. The intention was to facilitate demountability of components to encourage adaptable reuse
of buildings. Although building disassembly was not the main focus of the structural considerations, the structural form of most buildings were implemented with the intention of encouraging possible building disassembly in the future. This is because special attention was given to the stability of the structures for assembly, changes in technology and users’ future requirements. For example, the load bearing capacity of walls and the structural frames had to accommodate future capacity for expansion such that each building type and function would need different load bearing capacity and dimensions (length, width and height).

3. Construction Method with Building Components and Materials Requirements:

The construction method used was variable and involved both traditional and modern methods of construction. The most important aspect of the construction method was applying the 3 IFD building principles in order to erect the buildings. For example, the post and beam method was used to encourage flexibility and open plan layout. Building methods that involved building components that are usually fixed permanently was not acceptable. This was because it would discourage demountability and moveable components for future changes. Other important aspects of the construction method include:

- implementing prefabricated components as long as they can support the IFD building principles; that is, no restriction on using industrial manufactured components. However, if it is better to use cast-in-situ concrete to encourage IFD building principles then it could be used;
- the industrialised aspect of the concept does not necessarily mean that factory manufactured building components must be used;
- always allow for flexibility, industrial building method, and demountability where appropriate, such that there is a balance between these 3 main concepts of IFD building principles to encourage future reuse and adaptability; and
- there is no restriction whatsoever on the types of materials and components to be used on the project. However, steel was used in most of the projects because of the flexibility it offered through assembly and its high reliability. Another material that was used is wood as it is a traditional construction material in the Netherlands. The building components were mainly based on a ‘plug and play’ technology instead of large components to encourage fast assembly phase and demountability in future.
4. The future and sustainability considerations: The future use of most buildings is not necessarily predictable but within 10 to 15 years changes are often carried out within the functional space of buildings such as offices and schools. Therefore, assumptions were made about the future use of the buildings through flexibility of the design concept so as to accommodate future changes in building use. Therefore, most of the demonstration projects were analysed based on:

- Economic benefits - to boost the economy of the building sector and to reduce failure costs (the assumption is that using manufacturing building principles would create less failure on site thereby reducing cost.)
- Environmental benefits - to reduce cost and wastage, encourage the long life span of the building can eventually reduce waste in terms of material disposal
- Social benefits - social value in terms of housing for the elderly and young.

These three main themes of sustainability served as a guide to ensure future use of some buildings designed under the IFD programme. For example, a home for the elderly built in 2000 was designed with flexibility as the fundamental concept and approach. The apartments were built as a combination of small and large apartments. The bedrooms and sitting rooms could be converted to a nursing unit. These conversions could be done in one or two days instead of 2 weeks or more which is the usual construction practice. This implies that consideration must be given at the early stages of any building project to ensure significant incorporation of sustainability issues. This may be achieved through a mechanism that involves a concept and a process of assigning responsibilities to all stakeholders that are involved in the building process. The application of an appropriate mechanism may assist the construction industry to implement flexibility and disassemble options of building components and facilitate changes during the lifecycle of a building.

5.4.6 Benefits of implementing IFD building principles were seen as:

- Faster construction as the construction process is managed more effectively through collaboration between all stakeholders in the building project;
- Reduction on maintenance and refurbishment costs due to ease of disassembly for repair and replacement of building components;
- Efficient improvement in the construction process and better working conditions;
• better harmonisation on use duration of buildings based on ease of adaptability to new (functional) requirements;
• less demolition and construction waste;
• possibilities for reuse and recycling of components;
• possibility for the client to choose components, materials, and finishes from an IFD catalogue; and
• longer life span of buildings due to flexibility and demountability/durability.

5.5 Discussion

The industry has to a large extent been implementing principles similar to deconstruction through different approaches (such as modular construction, demountable buildings for exhibitions, and temporary structures). In addition, several studies have identified the process of deconstruction as a possible alternative to demolition at the end of a building's useful life (Durmisevic, 2006; Hurley et al, 2001; Crowther, 2001). They suggest that it could assist the C&D industries to minimise design and construction waste, reduce the negative environmental impacts of buildings and encourage the possible reuse and recycling of building materials.

A survey aimed at investigating the awareness of deconstruction by construction professionals was carried out. Subsequently, a case study aimed at identifying the practical implications of implementing a concept similar to deconstruction into the building process was also undertaken.

The results from the questionnaire survey and the case study indicate that the term 'deconstruction' is a new concept within conventional construction practice. The key points that can be highlighted from the survey are:

• the decision to demolish and/or deconstruct a building mostly depends on the building owner's decision rather than the building type and/or the structural form;
• most construction professionals (especially designers) have knowledge of deconstruction principles and would implement it if there is a specific need in a building project;
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- the type of building materials and components specified for construction can play an important role in facilitating the implementation of deconstruction practice;
- the demolition of buildings or partial deconstruction were mostly motivated by social, technological and financial issues and not necessarily because of the type of materials and components used;
- In the last five years, most construction professionals indicated that residential and housing were the most likely buildings to be demolished;
- the three main criteria which can encourage the integration of deconstruction into the design process are: legislation and standards; materials and components available; and the time and cost involved in implementing deconstruction; and
- a structured approach in the form of a step-by-step guide would encourage the adoption of deconstruction conventional construction practice.

The key points from the case study (the IFD building programme) are:

- the principles of deconstruction can be implemented through a tailored-made guide to illustrate the building process;
- effective collaboration can be used to facilitate the process of integrating deconstruction into the current building process;
- a catalogue of different solutions can be provided to encourage adaptable reuse of buildings;
- the relevance of providing a mechanism to ensure that deconstruction can be fully integrated into the building process;
- on-site revisions are critical means for ensuring the integration of deconstruction into the building process;
- the use of appropriate concept and building technique is significant in ensuring deconstructability, particularly during the early stages of a building project were cognisance of the possibility of deconstructing the building should be considered
- government support is an essential success factor for ensuring participation and increased awareness;
- the use of demonstration projects and other exemplar case studies can stimulate industry-wide interest and awareness regarding the benefits of deconstruction and
• although there is an additional cost implication for incorporating flexibility and adaptability, the value of the expected benefits outweighs the costs.

5.6 Summary

This chapter has investigated current deconstruction practice in conventional construction practice. From the survey, most respondents were aware of the principles of deconstruction and how it could assist the construction industry in achieving some aspects of sustainable construction practice (such as recycling and reuse of building materials and components). The case study (IFD building programme) showed that it is possible to integrate the concept throughout the building process and, to a large extent, realise the designated outcomes. On the hand, most buildings are not designed with the intention to be deconstructed. This means that it is difficult to disassemble building materials for reuse or recycling. Design for deconstruction (DFD) is an emerging concept that can ensure that deconstruction principles are integrated into the building process. In order to encourage this integration, there is a need to develop a structured approach through a process model. The process model should assist and encourage construction professionals (especially designers) to implement design for deconstruction at the early stages of the design process and throughout the project delivery process.

The next chapter discusses the rationale for developing a deconstruction process model.
6.1 Introduction

This chapter describes the development of the Deconstruction Process Model. It presents an overview of process modelling and reviews popular process models used in construction. The rationale behind developing a deconstruction process model is given with a description of the phases and activities.

6.2 Process Modelling in Construction

Prior to reviewing process modelling in construction, it is essential to explore the meaning of the terms ‘model’ and ‘process’. The meaning of process modelling is also explored.

6.2.1 Model

In general, there are many definitions of a model. These definitions are dependent on the purpose, objectives and application of the model devised. The Compact Oxford English dictionary (2003) defines a model as, ‘1: a three-dimensional representation of a person or thing, typically on a smaller scale; 2: (in sculpture) a figure made in clay or wax which is then reproduced in a more durable material; 3: something used as an example; 4: a simplified mathematical description of a system or process, used to assist calculations and predictions; 5: an excellent example of a quality; 6: a person employed to display clothes by wearing them; 7: a person employed to pose for an artist; 8: a particular design or version of a product’.

These distinguishable definitions can be seen in the different approaches applied in representing and developing a model. In generally, it depends on the representation of reality as intended by those who wish to use it to understand, to change, to manage and to control a process (Pidd, 2003; Eckert and Clarkson, 2005). This means a model is used to represent the reality of a process and how it is required to function (Friedman, 2003). In this research, the model is defined as a mechanism for assisting the construction industry to fully integrate the concept of DFD within the building process.
6.2.2 Process

Several definitions of the term 'process' can be found in academia and industry (Lindsay et al, 2003). This is due to the various ways in which practitioners in different areas of study (such as new product development, operations management and construction management) choose to describe the process of carrying out their activities. The concept of a process is a scientific framework of managing activities which can be transformed from inputs into outputs (Taylor, 1913). Davenport (1993) describes a process as a structured set of activities which can be measured and designed to produce a specific output from a particular input. Thus, to manage a process, a simple and structured approach would involve decomposing the process into various activities and tasks (Koskela, 2000; Slack et al, 2001). A process is therefore decomposed into subprocesses, activities and tasks which can be managed at different hierarchical levels (see figure 6.1) (Tzortopulos, 2004).

![Figure 6.1: Process Levels](source: Tzortopulos, 2004)

For example, the first level of a process can explore the specific requirements of a construction project. The second level, sub-processes, can involve identifying the design concept of the project. The third level, activity, can be developing the design concept. The fourth level, tasks, can focus on analysing the site information and contacting the planning authorities. Decomposing a process (such as a building project) into different
levels can encourage a cyclical approach to meeting project requirements. This may involve capturing and converting the process into several stages, in order to design and construct a building (Koskela, 2000; Kamara et al, 2000).

6.2.3 Process Modelling

Process modelling can be used to describe the activities, deliverables and functions that are necessary to allow the achievement of consistency and integration in the course of executing a project (Cooper, 2001). Accordingly, Winch and Carr (2001) describe two broad types of process modelling:

(a) True models. This is a process of what actually happens. A descriptive format is used to represent the actually activities of a process; and

(b) Protocols. This is a process of what ought to happen. Here a prescriptive format is used to describe the process as it ought to happen.

In addition, process modelling is carried out through two distinctive approaches. The first approach is based on IT implementation and associated with systems engineering. It also focuses specifically on the flow of information and process being modelled. Typically, it does not take into consideration the organisational context of a process (Kartam et al, 1997). An example of this approach is Integration Definition for Functional Modelling (IDEF0). On the other hand, the second approach is based on managing the business process. It is widely known as Business Process Reengineering (BPR). Its focus is on the actual flow of information within an organisation and between the different actors involved. Typically, it is structured as a two-dimensional model, which has a sequence or time along the horizontal axis, and the actors or functions responsible for each sub-process (task) on the vertical access. The flow of information and materials is then represented in the body of the model (Winch and Carr, 2001). A comparison of different process modelling approaches is shown in Table 6.1.
Chapter 6: Development of Deconstruction Process Model

Table 6.1 Comparison of Process Modelling approaches

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

Source: Anumba et al., (1998)

The benefits of process modelling as suggested by several studies (Cox and Hamilton, 1995; Smith and Morrow, 1999; Goulding and Alshawi, 1999) include:

- useful in mapping out ideas and concepts into identifiable processes for ease of understanding;
- allows users to conceptualise and appreciate the links and relationships between processes and sub-process more readily;
- enables elaboration on levels of generic detail of an issue;
- useful for analysing complicated structured and unstructured relationships;
- particularly useful for understanding points of view, identifying critical information flows and data relationships;
- suggests ways that a process can be controlled and managed; and
- provides as an effective planning and co-ordination tool that can be adapted to the particular requirements and objectives of a project.
This means developing and mapping a process in the appropriate context offers potential benefits to improve the project delivery process (Winch and Carr, 2001). As a result, process modelling practices in construction have been focused on both design process management (the focal point of managing the information) and on construction management (with a focus on managing the production of a building) (Tzortzopoulos, 2004).

6.3 A Brief Review of Construction Process Models

The construction industry has been using process models to manage, organise and provide a structure for implementing construction projects (Kagioglou et al., 2000; Tunstall, 2000; Gray and Hughes, 2000). The use of these process models has been dependent on the specific requirements of each project (Wilkinson and Gupta, 2005). In addition the changing pace of the construction industry has also led to the development of various types of process models. For example, RIBA Plan of Work (1964-2007), Project Initiation model (1983) and Sanvido's conceptual construction process model (1984). These respective construction process models are aimed at the following in construction projects:

- encouraging understanding and effective collaboration;
- facilitating efficiency and performance of construction projects;
- mapping out processes inherent in the design and construction of a building project;
- applying a rationale to model the decision-making process; and
- using systems engineering to model the building process.

A brief review of process models is carried out in the next section with a special focus on the RIBA Plan of work and Process Protocol. Other process models in construction are also presented.

6.3.1 RIBA Plan of Work

The RIBA Plan of Work (first published in 1964) is a model that maps out the processes inherent in a construction project. It provides a framework for organising the different
Chapter 6: Development of Deconstruction Process Model

stages of construction into a logical sequence of action and describes the different roles of professionals during the various stages of a construction project (Wilkinson and Gupta, 2005). It is the most widely acknowledged framework used and referenced for decades as a guide to organise and manage a construction project.

Originally published in 1964, it has two updated official versions and divides the construction project into phases and work stages (see Figure 6.2). It is used in a variety of ways to assist the management of projects and as a basis for administering building contracts for design and construction activities (see Table 6.2). Nevertheless, there is growing evidence that it is not necessarily the most appropriate framework for managing a construction project (Hughes, 2003; Cooper et al, 2005; Wilkinson and Gupta, 2005). This could be attributed to the following:

- it was developed specifically from the architect's perspective and their role as project managers;
- there is a demand for the construction industry to change and rethink the methods of implementing construction projects (Egan, 1998, 2000);
- it fails to fully recognise the significant roles that other construction professionals can contribute to the successful implementation of construction projects; and
- the traditional methods of procurement of construction projects are fast changing and evolving.

Clearly, the RIBA Plan of work as a construction process model does not meet all the requirements that are essential in contributing to current changes and demands required in the implementation of a construction project. Nonetheless, there is no perfect framework for managing and organising the building process. This, more often than not, depends on the specific objectives of each construction project (Moore, 2002).
Chapter 6: Development of Deconstruction Process Model

Figure 6.2: The phases and stages of the RIBA’s Plan of Work
**Chapter 6: Development of Deconstruction Process Model**

**Table 6.2 RIBA Outline Plan of Work**

<table>
<thead>
<tr>
<th>Stage</th>
<th>Purpose of work and decisions to be reached</th>
<th>Tasks to be done</th>
<th>People directly involved</th>
<th>usual terminology</th>
</tr>
</thead>
<tbody>
<tr>
<td>A Appraisal</td>
<td>Identification of client’s requirements and possible constraints on development. Preparation of studies to enable the client to decide whether to proceed and to select the probable procurement method.</td>
<td>Set up client organisation for briefing. Consider requirements, appoint architect.</td>
<td>All client interests, architect.</td>
<td>Briefing</td>
</tr>
<tr>
<td>B Strategic Briefing</td>
<td>Preparation of Strategic Brief by, or on behalf of, the client confirming key requirements and constraints. Identification of procedures, organisational structure and range of consultants and others to be engaged for the project. [Identifies the strategic brief (as CIB Guide) which becomes the clear responsibility of the client]</td>
<td>Carry out studies of user requirements, site conditions, planning, design and cost etc as necessary to reach decisions.</td>
<td>Clients’ representatives, architects, engineers and QS according to nature of project.</td>
<td></td>
</tr>
</tbody>
</table>

Stage C begins when the architect’s brief has been determined in sufficient detail.

<table>
<thead>
<tr>
<th>C Outline Proposals</th>
<th>Commence development of strategic brief into full project brief. Preparation of outline proposals and estimate of cost. Review of procurement route.</th>
<th>Develop the brief further. Carry out studies on user requirements, technical problems, planning, design and costs, as necessary to reach decisions.</th>
<th>All client interests, architects, engineers, QS and specialists as required.</th>
<th>Sketch plans</th>
</tr>
</thead>
<tbody>
<tr>
<td>D Detailed Proposals</td>
<td>Complete development of the project brief. Preparation of detailed proposals. Application for full development control approval.</td>
<td>Final development of the brief, full design of the project by architect, preliminary design by engineers, preparation of cost plan and full explanatory report. Submission of proposals for all approvals.</td>
<td>All client interests, architects, engineers, QS and specialists and all statutory and other approving authorities.</td>
<td></td>
</tr>
</tbody>
</table>

Brief should not be modified after this point.

<table>
<thead>
<tr>
<th>E Final Proposals</th>
<th>Preparation of final proposals for the Project sufficient for co-ordination of all components and elements of the Project.</th>
<th>Full design of every part and component of the building by collaboration of all concerned. Complete cost checking of designs.</th>
<th>Architects, QS, engineers and specialists, contractor (if appointed).</th>
<th>Working drawings</th>
</tr>
</thead>
</table>

Any further change in location, size, shape, or cost after this time will result in abortive work.
### Chapter 6: Development of Deconstruction Process Model

<table>
<thead>
<tr>
<th>Stage</th>
<th>Purpose of work and decisions to be reached</th>
<th>Tasks to be done</th>
<th>People directly involved</th>
<th>usual terminology</th>
</tr>
</thead>
</table>
| **F** Production Information | F1: Preparation of production information in sufficient detail to enable a tender or tenders to be obtained. Application for statutory approvals.  
F2: Preparation of further production information required under the building contract. (Now in two parts, F1 - the production information sufficient to obtain tenders and F2 - the balance required under the building contract to complete the information for construction) | Preparation of final production information in drawings, schedules and specifications. | Architects, engineers and specialists, contractor (if appointed).                      | Site operations  |
| **G** Tender Documentation | Preparation and collation of tender documentation in sufficient detail to enable a tender or tenders to be obtained for the construction of the Project. (Solely concerned with the documentation required for tenders. Particularly useful with D&B or management contracts) | Preparation of Bills of Quantities and tender documents.                          | Architects, QS, contractor (if appointed).                                               |                  |
| **H** Tender Action     | Identification and evaluation of potential contractors and/or specialists for the construction of the project. Obtaining and appraising tenders and submission of recommendations to the client. | Action as recommended in relevant NJCC Code of Procedure for Selective Tendering. | Architects, QS, engineers, contractor, client.                                           |                  |
| **J** Mobilisation      | Letting the building contract, appointing the contractor. Issuing of production information to the contractor. Arranging site handover to the contractor. | Action in accordance with RIBA Plan of Work.                                      | Contractor, sub-contractors.                                                            |                  |
| **K** Construction to Practical Completion | Administration of the building contract up to and including practical completion. Provision to the contractor of further information as and when reasonably required. | Action in accordance with RIBA Plan of Work.                                      | Architects, engineers, contractor, sub-contractors, QS, client.                          |                  |
| **L** After Completion  | Administration of the building contract after practical completion. Making final inspections and settling the final account. (Clearly separated from the construction phase) | Action in accordance with RIBA Plan of Work.                                      | Architects, engineers, contractor, QS, client.                                           |                  |

(Source: RIBA Publications, 2000)
6.3.2 Process Protocol

The Process Protocol is a generic design and construction process model (Kagioglou et al., 1998) with a common set of definitions, documentation and procedures that enables users (organisations and construction professionals) involved in a construction project to work together seamlessly (Zainul-Abidin et al., 2003). It uses manufacturing experience as a reference point and maps the entire project process from the client's recognition of a new or emerging need through the operations and maintenance of a building (Kagioglou et al., 2000). It maps the design and construction process into eight activity zones namely: development, project, resource, design, production, facilities, health and safety, statutory and legal, and process management. These activity zones are multi-functional sub-processes, which facilitate communication and co-ordination, control and management of resources and the adoption of a common objective. It is divided into 10 phases, that are grouped into four stages: pre-project, pre-construction, construction, and post-construction (see Figure 6.3). The potential benefits (Sheath et al., 1996; Kagioglou et al., 1998a; Cooper et al., 1998; Lee, 2000) of using the Process Protocol are:

- a whole project view is taken;
- recognition of the interdependency of activities throughout the duration of a project;
- focuses on the 'front-end' activities through the identification, definition and evaluation of clients' requirements;
- provides the potential for adopting a standard approach to performance measurement, evaluation and control to facilitate continuous improvement in construction;
- facilitates concurrency and progressive fixity and/or approval of information throughout a project through the stage-gate/phase process review approach;
- enables co-ordination of the participants and activities in construction projects and identifies the responsible parties;
- encourages the establishment of multi-functional teams including stakeholders. This fosters a team environment and encourages appropriate and timely communication and decision making; and
- facilitates a legacy archive whereby all project information is collectively stored and can be used as a future learning vehicle.
Chapter 6: Development of Deconstruction Process Model

Figure 6.3: The Process Protocol High Level Map (kaloglou et al., 1998a)

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6.3.3 Other Construction Process Models

Other process models have been developed for various requirements in construction. These process models include:

1. **The Analytical Design Planning Technique (ADePT)** (Austin et al, 2000): This is a model that was devised as a data flow model to plan and manage the building design process. It uses computer tools to facilitate a more effective planning and management of the building design process. It takes account of the interdisciplinary iterative nature of the building design process to reduce time and cost. The first stage of the model represents design activities and their information requirements. The model links data via a dependency table to a dependency structure matrix (DSM) analysis tool. This is used in the second stage to identify iteration within the design process and schedule activities. The objective is to optimise the order of the task. The third stage of the model produces design programmes based on the optimised process sequence. The technique requires some iteration between the matrix and programming stages. The scope of the model is limited to the design process. It does not address the construction process.

2. **Walker’s Model** (Walker, 1985): This model is an input-output process of the project delivery process in construction. The construction process is viewed as a parallel function to the owner’s process. Each process transforms input into outputs, and interacts with the environment and each other. Walker also developed a hierarchical model of the construction process. The construction process is modelled as three sequential systems consisting of conception, inception and realisation. Each system is divided into subsystems and key decision and operational decisions serve as the boundaries of systems and subsystems. The construction process is seen as a transformation process with inputs and outputs which interacts with the environment. The processes involved are divided into tasks bounded by decision-making, which may be interpreted as a representation of information.

3. **Sanvido’s Conceptual Construction Process** Model (Sanvido, 1984): This model is a generic, time-independent representation of a project’s site operations. The model is divided into two parts. The first part defines three major functions in the construction process and identifies the major influences of each function. The second part of the model is a hierarchical description of the construction process.
The three major functions are defined as planning, resource acquisition, and output coordination. The planning and resource acquisition are governed by influences on planning and supply of resources respectively. The output coordination function exerts influences of project on participants and environment. Each group of these influences is divided into influences from or on 1) the external environment; 2) the owner; 3) the contractor, and 4) the resource and service suppliers. The hierarchical model identifies the hierarchy of management functions and the participants in the construction process. The interrelationships among the functions and their coordination are represented by the flow and feedback of resources and information. The scope of the model is limited to the management and control of the construction process. It does not identify the processes and information flow of actual activities.

6.4 Choice of Process Model

Process Protocol was used as a tool to develop the deconstruction process model. The choice of Process Protocol was based on its structured yet flexible methodology or approach in modelling and integrating different issues into the building process. In addition, its features make it the most applicable model for integrating deconstruction into the project delivery process because of the following (Cooper et al, 2005):

- recognition of the versatility of skills needed throughout a construction project's life cycle;
- provides a generic form for a context whereby the process of design and construction can be adapted to fit organisations' needs and working practices;
- allows the sub-division of activities and processes;
- encourages interrelationships, responsibilities and roles of the building team to have an influence in the building process in a seamless way; and
- the development was based on manufacturing process models and this makes it ideal for integrating DFD (which is similar to design for disassembly in manufacturing) into the building process.
6.5 Rationale for Deconstruction Process Model

The rationale for developing the Deconstruction Process Model (DPM) is as follows:

- emphasis from several studies (CIB, 1999; CRISP, 1999; DETR, 2000) on the need for the industry to implement sustainable construction practice;
- the findings and results from the questionnaire survey and case study (see Section 5.4) in this research indicate that for the industry to practically implement deconstruction into the project delivery process, there is a need to develop an appropriate mechanism;
- studies (Crowther, 2001; Pulaski et al., 2004) have suggested that through the principles of DFD the industry can facilitate some aspects of sustainable construction practice (such as reduction of waste, reuse and/or recycling of building materials); and
- previous studies (see Section 4.2.2) have primarily focused on the technical efficiency of implementing deconstruction rather than the effectiveness of integrating deconstruction into the building process.

In addition, the building process is complex and usually organised through a structured approach to meet the demands of each stage of a construction project (Sanvido et al., 1989). Through DFD the construction industry can adopt a new approach to the building process. This approach would involve integrating the concept of DFD into the project delivery process in construction. However, implementing DFD into this process requires a lasting strategy and a mechanism that can serve as the basis for the industry to realise sustainable construction practice through making adequate provision for deconstruction. Accordingly, Kagioglou et al., (1998) point out that one of the best ways to improve the building process is to provide a model process to ensure effectiveness. Thus, the most appropriate method for integrating deconstruction is using a prototype based on an existing process model.
6.6 The Development of the Deconstruction Process Model

The development process involved: (a) literature review on design for deconstruction and related concepts; (b) an investigation of current deconstruction practice (carried out through an industry survey and case study; (c) a review of existing process models in construction; and (d) reviews, discussions and feedback with academics and/or industry practitioners interested in the research. The Process Protocol and RIBA Plan of Work were also used as a benchmark to guide the development and potential effectiveness.

The DPM was developed from the perspective of assisting construction professionals to realise some aspects of sustainable construction practice (such as effectively reducing waste during the building process, encouraging the reuse and/or recycling of building materials and components) in a building project. This means that the tasks and activities potentially encourage deconstructability of a building. The DPM incorporates a framework that:

- encourage the implementation of reuse and recycling strategies from the inception of a building project;
- manage the dynamic process of designing for maximum adaptability and flexibility of a building to facilitate future reuse instead of demolition;
- consider some aspects of sustainable construction that could facilitate waste reduction during the building process;
- provide a practical framework to facilitate aspects of sustainable construction practice; and
- enable construction professionals to work concurrently on all aspects of the project delivery process to realise the benefits of integrating DFD.

The structure of the model is based on the project phases of the Process Protocol model. These include: pre-project phase; design phase; construction phase; and post-construction phase. An additional phase called the deconstruction phase is added to the construction project life cycle. It's purpose is to address the following: the end of a building's useful and the possible future reuse of a building. The detailed activities are presented in two levels at each process phase. The first four process phases correspond to the feasibility stage of RIBA Plan of work (see Figure 6.4). The next three process
phases fall within the design stage and the pre-construction period. Two process phases correspond to the construction stage, while a process phase falls within the post-construction phase. Lastly a process phase covering issues of building refurbishment, deconstruction and demolition is provided.

The DPM consists of major activities and sub-activities. The involvement of project actors (i.e. construction professionals) at each stage of the process phase of the DPM is established. The basic structure of the DPM comprises of a process stage, main activity and sub-activities of each process stage (see Figure 6.5). The process actors involved at each process stage are shown in the squares below the main activity. The process phases and stages of integrating deconstruction into the building process are described in the next sections.
Figure 6.4: The Demolition Process Model

Phase 1: Conceptual Design
Phase 2: Substantive Feasibility Study & Outline
Phase 3: Substantive Feasibility Study
Phase 4: Outline Design
Phase 5: Full Conceptual Design
Phase 6: Financial Authority
Phase 7: Substantive Feasibility Study
Phase 8: Full Conceptual Design
Phase 9: Financial Authority
Phase 10: Refurbishment, Deconstruction, Demolition,

Implementation Plan: Building Demolition

RIBA Outline

Chapter 6: Development of Demolition Process Model
Figure 6.5: Different components of the Deconstruction Process Model
6.6.1 Pre-Project Phase

The pre-project phase relates to the strategic considerations of any new construction project and corresponds to the generic Process Protocol and RIBA Plan of work stages A & B (see Figure 6.4). It is assumed that the client and/or developer is aware of the concept of sustainability and that the client is also keen to implement and give consideration to the different aspects of sustainability through the concept of DFD at the early stages of the building process. Therefore, there is a challenge to effectively and efficiently realise some practical aspects of sustainable construction through deconstruction practice. For example, the ease by which building components can be disassembled at the end of a building's life is taken up in addition to conventional pre-project phase activities. The pre-project phase for DPM includes: explore the scope of deconstruction, prepare deconstruction criteria for project, prepare deconstruction matrix for project and prepare deconstruction plan.

These four process stages have main activities at the first level and are further divided into a set of second level sub-activities. The main project actors at these process stages are the client, architect and project manager for phases zero to two and it is proposed that a deconstruction consultant should get involved from the preparation of the deconstruction plan, which is phase three. A description of each process phase and its activities is presented below:

Phase 0 Explore The Scope Of Deconstruction: This phase is a clear definition of the intention to implement deconstruction. It has three main activities (see Figure 6.6) which include:

- **Investigate Feasibility Of Deconstruction:** This activity involves identifying the relevant drivers associated with the three broad themes of sustainability (i.e. environment, social, and economic). This activity also deals with exploring the necessary standards and regulations that can encourage practical implementation of deconstruction. The Actors involved at this phase of the activity are the architect, project manager and the client.

- **Identify The Site Limitations:** This activity involves an initial assessment of the site limitations to establish a deconstruction brief. The activity also deals with
identifying initial waste management plan for site works that can encourage deconstruction implementation.

- **Identify The Extent Of Deconstruction:** This activity deals with defining and identifying the extent of deconstruction implementation by the project manager in consultation with the client. This can be undertaken through a preliminary investigation of the potential construction methods that will encourage the application of deconstruction principles in the project.

**Phase 1 Prepare Deconstruction Criteria For Project:** This phase involves producing documentation that sets out the criteria that should assist construction professionals to consider the deconstruction principles and issues. It has three main activities (see Figure 6.7) which include:

- **Identify The Drivers For Deconstruction:** This activity involves a further investigation into the drivers identified in phase 0 and providing documentation to highlight the potential implementation implications to the project.

- **Specify The Deconstruction Aim And Objectives:** This activity deals with specifying the aim and objectives of the project that are relevant in achieving and implementing deconstruction principles. The project manager and the architect should define the scope of deconstruction implementation in consultation with the client.

- **Identify How To Implement Deconstruction At All Stages:** This activity involves defining and identifying the necessary requirements (such as cost and durability of materials) that can encourage the implementation of deconstruction within the design and construction phases of the project.
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Figure 6.6: Phase 0: Explore Scope For Deconstruction

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Figure 6.7: Phase 1: Prepare Deconstruction Criteria for Project
Phase 2 Prepare deconstruction matrix for project: This phase involves using the deconstruction matrix template as a guide to preparing the deconstruction objectives of the project. It has two main activities (see Figure 6.8) that include:

- **Review Feasibility Studies:** This activity involves revising the initial project brief that was produced in phase 0. Thus, consideration is given to the design implications of deconstruction to the overall project execution plan. The architect is the main actor in this activity.

- **Review The Aim & Objectives Of Deconstruction:** This activity involves using the deconstruction matrix template plan to review the aim and objectives of deconstruction. The project brief is then updated with considerations such as design options that can encourage flexibility and adaptability of the building.

Phase 3. Prepare deconstruction plan: This phase involves clear definition of the DFD concept with the implementation plan for deconstruction. It has three main activities (see Figure 6.9) which include:

- **Consider DFD Design Concept:** This activity involves producing a documentation that would show how deconstruction will be implemented in the project. The main actors at this stage is the architect and a deconstruction consultant (i.e. an expert who has experience in designing buildings for disassembly)

- **Undertake Environmental Appraisal And Assessment:** This activity involves undertaking the necessary environmental appraisals and assessment that will enhance the waste management plan and reduce environmental impact. The assessment can include: the lifecycle impact of the building and the materials and technologies.

- **Undertake Cost Benefit Analysis (CBA):** This activity involves an initial cost benefit analysis of factors such as the additional cost of implementing deconstruction principles, estimating the cost of disposal and estimating the value of the recovered materials in future within the initial deconstruction management plan.
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Figure 6.8: Phase 2: Prepare Deconstruction Matrix for Project
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**Figure 6.9: Phase 3: Prepare Deconstruction Plan**
6.6.2 Design Phase

After completing feasibility studies and approvals with an initial deconstruction plan, the project progresses through to the design phase. The design phase is defined by the need to facilitate the deconstructability of a building. It is developed using the 'system of systems' approach to model the design of the building system. This phase is significant as the design decisions taken at these process stages determine the ease of a building's decomposition at the end of its life. The design phase has three main process stages:

Phase 4 Prepare DFD check list for outline conceptual design: This phase is intended to produce a checklist of factors which should enable the initial conceptual design to be assessed against the deconstruction plan. It has 3 main activities (see Figure 6.10) The main process actors at phase four are the architect, structural engineer and deconstruction consultant.

- **Prepare Design Approach (System of Systems):** This activity deals with implementing principles of design to encourage DFD. In this activity the architect, structural engineer and deconstruction consultant have to collaborate to produce initial sketches for the deconstruction conceptual design.

- **Identify Key Elements and Structure/Materials:** This activity deals with the design designs for the building elements and materials which can facilitate DFD. The Building Decomposition Model (see Chapter 7) is used as a guide for the decision making process.

- **Identify DFD Compatible Construction Methods:** This activity deals with assessing the compatibility of different building systems to enable deconstruction of the building. The suppliers and manufacturers can be appointed at this stage of the project.

Phase 5 Prepare DFD checklist for full conceptual design: This phase involves preparing a checklist of factors which should enable deconstruction the full conceptual design to be assessed against the deconstruction plan. It has 3 main activities (see Figure 6.11). At phase five it is proposed that the manufacturer and/ or supplier of building materials and components are included as process actors. This is necessary as
their expertise on the suitability of materials and components at the design phase is crucial to the integration of DFD.

- **Detailed Design Approach:** This activity involves modifying the sketches that were produce in phase four and updating the checklist of deconstruction principles that have been taken into consideration.

- **Propose Key Elements/Structures:** This activity deals with updating the structural report that was produced in phase four.

- **Propose Construction Methods:** This activity deals with assessing the bespoke and standard options of construction methods which can facilitate the deconstructability of a building. A report on the relevance of these construction methods to the project should be produced.
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Figure 6.10: Phase 4: Prepare DFD Checklist for Outline Conceptual Design
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Figure 6.11: Phase 5: Prepare DFD checklist for Full Conceptual Design
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Phase 6 Assess extent of DFD integration including assembly options etc. in final design: This phase is an assessment of the integration process of deconstruction for the production/construction stage (see Figures 6.12). The building services engineers designated as ‘Engineering Other’ in the DPM are included as process actors at this stage. It has 3 main activities which include:

- **Develop Strategic Integration Plan**: This activity deals with producing an integration plan report to ensure that all stakeholders in the project have an understanding of the full implication of implementing DFD.

- **Complete DFD Design Proposal**: This activity deals with finalising the conceptual plan for DFD in the project. The drawings that are produced at this stage should show different scenarios of sequence of assembly and disassembly of the building.

- **Finalise Cost Benefit Analysis**: This activity deals with updating the cost benefit analysis document produced in phase 3 and finalising the design options that reflect value for money in terms of deconstruction considerations.
Figure 6.12: Phase 6: Assess Extent of DFD Integration including assembly etc in Final Design
6.6.3 Construction Phase

The Construction phase is primarily focused on the actual on-site activities. The benefits of implementing DFD principles (such as design for prefabrication, preassembly and modular construction, simplified and standardised connections and details and separate building systems) which could facilitate building component assembly may be realised here. Other site related issues (such as methods and techniques for building assembly, co-ordination and communication of appropriate information of construction works) can be addressed by using the deconstruction methods and plans. The Construction phase has two process stages:

Phase 7 Produce deconstruction plans and methods statements: This phase is a production of working drawings and specification showing the construction and assembly methods that would facilitate deconstruction (see Figure 6.13). The three main activities include:

- **Schedule Of Deconstruction:** This activity involves providing a documentation and a set of drawings that are approved by the client and agreed by all actors for construction. The main output in this activity apart from the drawings is a revised integration plan for deconstruction.

- **Sequence Of Assembly And Disassembly:** This activity deals with finalising and updating the drawings for the sequence of assembly and disassembly of the building.

- **Construction Techniques And Method Applicable:** This activity deals with updating the initial construction method report. A final construction report is produced with the main actors (including the architect, structural engineer, manufacturer, deconstruction consultant and Engineer other) in this activity.
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Figure 6.13 Phase 7: Produce Deconstruction Plans and Method Statements
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Phase 8 Check compliance of construction method with deconstruction plans: This phase involves a check by all construction professionals to ensure that selected construction methods support deconstruction (see Figure 6.14). It has two main activities which include:

- **Monitor Construction Works:** This activity deals with the actual construction of the building. The main actors in this activity is the project manager and building contractor. The deconstruction consultant is also expected to ensure that construction works are carried out according to DFD plan.

- **Check Compliance Of Construction Method With Deconstruction Plans:** This activity deals with supervising the construction works to ensure that the assembly process would facilitate disassembly in future. A check list is used to monitor the construction work.
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Figure 6.14 Phase 8: Check Compliance of Construction Method with Deconstruction Plans

This process will show activities that may be undertaken during the phase. It is not intended to suggest a prescriptive sequence of events. This figure guide the reader on considering the steps for specific projects/organisations.
6.6.4 Post–Construction Phase

The DPM at the post-construction phase is concerned with activities that facilitate a building's operation and use. It focuses on providing appropriate manuals and documentation at the end of the construction phase. This can be used to effectively manage the building during its operation and maintenance. For example, maintenance and replacement of components are facilitated through building components and building systems which can easily be disassembled. Furthermore, lessons learnt through the use of the 'Deconstruction Plan' can be summarised and documented for a building's future reuse.

Phase 9 Post-construction review (summarise lessons learnt, update & maintain deconstruction plan): This phase entails preparing a document that summarises the lessons learnt and preparation of guide for carrying out deconstruction at the end of the building's life (see Figure 6.15). The three main activities include:

- **Check Documentation:** This activity involves checking all the necessary documentation that would facilitate deconstruction, maintenance and refurbishment are compiled.

- **Review the Process of DFD:** This activity deals with all the construction professionals giving a final feedback of integrating the concept of DFD in the building project. It is important to assess the DFD goals that were achieved and summarise the lessons learnt. This because it would assist with the future reuse of the building.

- **Strategy for Future Reuse:** This activity involves determining the benefits and drawbacks of integrating DFD in the project. A documentation showing the list of components and manuals for building disassembly should be produced in this activity.
Figure 6.15: Phase 9: Post-Construction Review – Summarize Lessons Learnt & Update Deconstruction Plan
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6.6.5 Deconstruction Phase

The deconstruction phase is the final phase of the DPM. This process phase is about predicting the future and the actual building decomposition process.

At this process phase it is also proposed that the building's materials and components which can be reused, recycled or disposed should be identified. This can be carried out through an iterative and feedback process to ensure effectiveness and future usefulness of each building material and component identified. The client and all the construction professionals are involved at this process phase. It is proposed as part of the sub-activities at this stage that a building decomposition plan is used. The suggested steps proposed for implementing the building decomposition plan are shown in Figure 6.17.

Phase 10: Implement plan for Building Decomposition: This phase involves the preparation of recommended new proposals with the identified components and sub-assemblies and the associated safety issues (Figure 6.16). The two main actives are:

- **Identify Elements for New Proposal:** This activity involves making new proposals for the reuse of the building and checking the list of components from documentation for possible ways to reuse components. A manual should be produced in this activity to assist plans for future reuse of the building.

- **Establish Safety Issues for New Proposal:** This activity deals with the actual building deconstruction. A final deconstruction plan should be produced with safety issues taken into consideration.
Figure 6.16: Phase 10: Implementation Plan for Building Decomposition
6.7 Guideline for Implementing the DPM

A guideline for using the DPM is shown in Table 6.3. The guide explains the key outputs from each phase of the DPM's main activities. The guide assumes a level of knowledge with those responsible for executing the project and designates roles and responsibilities. The main actor responsible at each process stage should consult other construction professionals in the main activity to undertake the relevant actions. The guide is designed to accommodate variations that could occur as a project develops (such as cost and changes in design). Thus, it is essential that the main actor at each phase understands the basic requirements at level 2 of the each process phase and consequently the activities that led to the expected outputs in the DPM. This understanding by the main actor of the requirements and matching appropriate contributions from key consultants in the phase should facilitate a robust and comprehensive output. This is the context in which the guide has been designed as it offers a structured approach for integrating DFD throughout the building process.
Table 6.2 Guideline for Implementing the DPM

<table>
<thead>
<tr>
<th>Phases</th>
<th>Level 2</th>
<th>Suggested Actions for Expected Outputs</th>
<th>Consult</th>
<th>Actor</th>
</tr>
</thead>
</table>
| 0. Explore Scope of deconstruction         | Investigate feasibility for deconstruction. | [0.1.1, 0.1.2] Deconstruction project brief (Initial)  
   a) Define the intention of implementing deconstruction and defining the deconstruction needs that the project can meet.  
   b) Assess of regulations and standards on sustainability that can encourage deconstruction.  
   c) Recognise and consider design standards that would encourage deconstruction. | Arch    | Arch or Proj |
|                                             |                              | [0.1.3] Stakeholder list  
   a) Ensure that appropriate consultants are appointed as early as possible to address deconstruction issues that relate to the project.  
   b) Appoint a specialist (that is deconstruction expert) depending on the complexity expected in the project and level of detail required | Proj    | Arch        |
| Identify the site limitations               |                              | [0.2.1, 0.2.2, 0.2.3] Site survey  
   a) Identify the site location, physical conditions, size and available infrastructure that would enable the deconstruction process.  
   b) Assess of the various options to encourage deconstruction such as possible storage facilities for materials and safety issues  
   c) Assess of possible solutions for waste minimisation. | Client  | Arch        |
| Identify the extent of deconstruction       |                              | [0.3.1, 0.3.2, 0.3.3] Deconstruction execution plan (Initial)  
   a) Define a structured approach to integrate the process of deconstruction into the project delivery process.  
   b) Assess of the type of structure with possible construction method.  
   c) Agree or find out from the developer or owner about the extent of deconstruction (that is full or partial) to be carried out as this can determine the design decisions. | Arch    | Proj        |
| 1. Prepare deconstruction criteria for project | Identify the drivers for deconstruction | [1.1.1, 1.1.2, 1.1.3] List all the drivers especially environment, social, economical and others  
   a) Prepare a written document that encompasses the drivers that are directly linked with the project. The content and level will vary depending on the extent of deconstruction that has to be achieved. This should be determined by the overall cost of the project and expected outcomes. | Proj    | Arch        |
|                                             | Specify the deconstruction aims and objectives | [1.2.1, 1.2.2, 1.2.3] Deconstruction execution plan (Update)  
   a) Update deconstruction execution plan based on agreed proposals in phase 0.  
   b) Scope the relevant design options that can be implemented.  
   c) Revisit each option based on aims and objectives of the project.  
   d) Consider the various options for building disassembly. | Arch    | Proj        |
<table>
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<th><strong>Chapter 6: Development of Deconstruction Process Model</strong></th>
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</table>
| **Identify how to implement deconstruction at all stages** | [1.3.1, 1.3.2, 1.3.3] Deconstruction process management Plan  
  a) Define DFD Design aspirations with relevant priorities such as cost and construction requirements.  
  b) Consider flexibility and adaptability with overall design plan of the project.  
  c) Consider structure of the deconstruction process plan  
  d) Prepare an organisational structure defining roles and responsibilities for the decision making process. | Proj  
  Client  
  Arch |
| **2. Prepare deconstruction matrix for project** | **Review feasibility studies** | Proj  
  Client  
  Arch |
| **a) Advise on alternative methods of implementing deconstruction.** | **b) Review regulations and standards on sustainability that can encourage deconstruction.** | **c) Analyse any implications of design standards that would encourage deconstruction.** | **d) Outline DFD design and construction requirements.** |
| **Review the aim & objectives of deconstruction** | [2.2.1, 2.2.2, 2.2.3] Deconstruction Matrix Plan | Proj  
  Client  
  Arch |
| **a) Use deconstruction matrix template as a guide to propose indicators for DFD (such as flexibility and adaptability of design options).** | **b) Identify criteria for implementation with template.** | **c) Assess any design proposals of project against the deconstruction project brief with template.** | **d) Develop an understanding of the relevant DFD options applicable to project.** |
| **3. Prepare deconstruction Plan** | **Consider DFD design concept** | Arch  
  Decon |
| **[3.1.1, 3.1.2, 3.1.3] Deconstruction process management plan (Update)** | **a) Develop deconstruction project brief into draft design and construction brief** | **b) Review the draft design and construction brief in terms of agreed project aims and objectives for deconstruction** | **c) Develop proposal for deconstruction design methodology concept** | **d) Review structure of the deconstruction process plan with roles and responsibilities** |
| **Undertake environmental appraisal and assessment** | **[3.2.1, 3.2.2] Site Plan and analysis report** | Decon  
  Arch |
| **a) Produce drawings and documentation indicating consideration for deconstruction on site with pre and post construction scenarios.** | **[3.2.3] Waste management plan** | Proj  
  Decon  
  Arch |
| **a) prepare a waste management plan especially with respect to deconstruction plan.** | **Undertake Cost Benefit Analysis (CBA)** | Proj  
  Client  
  Arch  
  QS |
| **[3.3.1, 3.3.2, 3.3.3] CBA report for deconstruction plan (Initial)** | **a) Develop a cost plan based on deconstruction project brief.** | **b) Evaluate cost in terms of future benefits to owner/end-user.** | **c) Undertake of CBA for deconstruction in terms of overall project cost.** |
| 4. Prepare DFD checklist for outline conceptual design | Prepare design approach ('system of systems') | [4.1.1, 4.1.2, 4.1.3] Building decomposition plan (Initial)  
   a) Produce check list with deconstruction principles taken into consideration  
   b) Produce sketches indicating possible deconstruction aspects of building design | Proj  
   Client  
   Decon or Arch |
|-------------------------------------------------|---------------------------------------------|--------------------------------------------------|
| Identify key elements and materials/structures | [4.2.1] Building material and component report (Initial)  
   a) Appraise materials and components that are suitable for disassembly  
   b) Determine components that have potential for reuse and recycling  
   c) Prepare a comparative assessments of building products | Struct  
   Decon  
   Arch |
| Identify DFD Compatible construction methods | [4.4.2.2, 4.4.2.3] Structural report (Initial)  
   a) Investigate structural options for the deconstruction plan  
   b) Analyse of proposed structural elements available for design proposal  
   c) Define the type of structural elements to be used and make recommendations  
   d) Evaluate the potential construction methods that would encourage deconstruction | Arch  
   Struct  
   Arch  
   Struct  |
| 5. Prepare DFD checklist for full conceptual design | Detailed design approach | [5.1.1, 5.1.2, 5.1.3] Full building decomposition plan (Revised)  
   a) Produce check list with deconstruction principles taken into consideration  
   b) Produce sketches indicating possible deconstruction aspects of building design  
   c) Consider design options in terms of value such as cost and waste reduction of materials | Decon  
   Arch |
| | Propose key elements/structures | [5.2.1, 5.2.2, 5.2.3] Structural report (Update)  
   a) Update the initial structural report based on changes in design proposal and drawings | Arch  
   Decon  
   Struct |
| | Propose construction methods | [5.3.1, 5.3.2] Report on construction method (Initial)  
   a) Make Information on both bespoke and standard options available for construction  
   b) Assess compatible methods for design proposals  
   c) Evaluate potential construction methods that can facilitate deconstruction | Arch  
   Manu  
   Decon  
   Struct |
| 6. Assessment of extent of DFD integration including procurement etc in Final Design | Develop strategic integration plan for DFD | [6.1.1, 6.1.2, 6.1.3] Integration plan report (initial)  
a) Consult with all stakeholders involved in the deconstruction plan and ensure full understanding of selected design and construction requirements.  
b) Undertake discussions with developer/occupier in respect of how the building will be used post-completion. | Arch Manu Struct Engr Decon Client Proj |
| --- | --- | --- | --- |
| Complete DFD design proposal | [6.2.1, 6.2.2, 6.2.3] Full building decomposition plan (Updated)  
a) Finalise conceptual design plan and ensure consultation on technical aspects are carried out with building contractor, supplier and manufacturer. | Arch Struct Engr Proj |
| Finalise cost benefit analysis | [6.3.1, 6.3.2, 6.3.3] CBA report for deconstruction plan (Final)  
a) Update full conceptual design and structural report (Final). | Decon Client Arch Struct QS Proj |
| 7. Produce Deconstruction Plans & Method Statements | Schedule of deconstruction | [7.1.1, 7.1.2] Integration Plan Report (Revised)  
a) Use feedback on all findings and conclusions to produce a report. This report should assist with implementing deconstruction principles in the overall design and construction of project.  
b) Devise strategy for management with co-ordination of information. This is a vital step to prevent and ensure appropriate communication during the construction process. | Decon Proj |
| Sequence of assembly and disassembly | [7.2.1, 7.2.2, 7.2.3] Deconstruction assembly and disassembly drawing plans  
a) Plan a suitable sequence for assembly and disassembly appropriate for the time of removal or reuse of building components and structures  
b) Agree communication for on site decision making with respect to assembly especially on schedule of DFD implementation process  
c) Ensure regular consultation with suppliers, manufacturers and building contractor on full design and construction progress. | Arch Manu Struct Engr Decon Arch/Struct |
| Construction techniques and method applicable | [7.3.1, 7.3.2, 7.3.3] Report on construction method (Final)  
a) Update and finalise all information on the construction method agreed. | Arch Manu Struct Engr Decon Arch/Struct |
| 8. Check Compliance of construction method with deconstruction plans | Monitor construction works | [8.1.1, 8.1.2, 8.1.3] Checklist of actual construction work  
a) Prepare a checklist of construction works to be carried out that relates with the implementation of deconstruction.  
b) Ensure appropriate co-ordination between key participants and the construction work is done in accordance with the design and construction requirements agreed for design. | QS Manu Decon Proj |
| 9. Deconstruction Review - Summarise DFD lessons Learnt | Check documentation | [8.2.1, 8.2.2, 8.2.3] Supervision of construction works with checklist  
| a) Ensure clear understanding of the assembly and disassembly strategy with regards to the project delivery process |  
| b) Produce supplementary design and construction advice as required in response to change requests or requests for information | BC Manu Decon Proj |
| a) Document actual construction carried out with respect to deconstruction  
| b) Provide a manual with instructions for every part of the building that can be dismantled |  
| c) Provide a guide on how building materials and components can be sorted and disposed of. | BC Arch Manu Struct Engr Decon |
| | [9.2.1, 9.2.2, 9.2.3] Final decomposition plan  
| a) Carry out a final survey of actual construction work carried out with respect to deconstruction.  
| b) Ensure that the building owner/developer has access to these documents.  
| c) Ensure that the building owner/developer understands and is aware that the building can be dismantled and reused.  
| d) Ensure documents contain appropriate information on the disassembly sequence of components. | BC Arch Manu Struct Engr Decon |
| | [9.3.1, 9.3.2, 9.3.3] A list of components and materials  
| a) Prepare a document with the list of components and materials that can be used for future construction. | BC Arch Manu Struct Engr Decon |
| a) Prepare a document with a list of elements that would be reused in the new proposal.  
| b) Specify method for disassembly. | BC Arch Manu Struct Engr Decon |
| | Establish Safety issues for new proposal | [10.2.1, 10.2.2] Documentation manual for deconstruction, refurbishment and/or demolition  
| a) Ensure documentation for building decomposition is accurate and meets with standards.  
| b) Define safety measures to carry out building decomposition. | BC Arch Manu Struct Engr Decon |
### [10.2.3] Building Decomposition Plan (Post-plan)

- **a)** Review changes of actual building decomposition with planned decomposition.
- **b)** Recommend building components and materials to reuse in another building proposal.
- **c)** Recommend materials and components for recycling.

### Abbreviations:

- Arch - Architect
- BC - Building Contractor
- Decon - Deconstruction Specialist
- QS - Quantity Surveyor
- Engr - Building services engineers
- Struct - Structural engineers
- Manu - Manufacturers and suppliers
- Client
Chapter 6: Development of Deconstruction Process Model

6.7 How the DPM Meets the Requirements for Integrating DFD

The development of the deconstruction process model was designed for integrating DFD into the building process. The requirements which were identified from literature review, the survey and case study is used to summarise how the deconstruction process model would facilitate the integration of DFD. These requirements and how the activities in the deconstruction process model incorporates them are presented in Table 6.3 below.

<table>
<thead>
<tr>
<th>Requirements</th>
<th>How it was Satisfied in the Deconstruction Process Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Include building techniques and methods that would facilitate deconstruction</td>
<td>• Assess possible construction and structure type&lt;br&gt;• Evaluate possible construction methods available&lt;br&gt;• Prepare sequence for building disassembly&lt;br&gt;• Evaluate DFD design &amp; structural details with suppliers and manufacturers</td>
</tr>
<tr>
<td>Include options for materials and components</td>
<td>• List of components and materials for reuse&lt;br&gt;• Consider materials that would facilitate DFD&lt;br&gt;• Prepare feedback of the possible materials and components for adaptable reuse</td>
</tr>
<tr>
<td>Provide a catalogue of different solutions to encourage adaptable reuse of buildings</td>
<td>• Deconstruction Matrix template.&lt;br&gt;• Define the Criteria to facilitate DFD in the design process&lt;br&gt;• Review architectural and structural elements</td>
</tr>
<tr>
<td>Use a tailored-made guide to illustrate the building process</td>
<td>• Prepare manual for the reuse of the different building elements&lt;br&gt;• Manage and co-ordinate the off-site assembly and delivery of prefabricated components</td>
</tr>
<tr>
<td>Ensure on-site revisions during the production of the building</td>
<td>• Verify the technique and methods with the deconstruction matrix&lt;br&gt;• Monitor the assembly of building subsystems to ensure compliance with deconstruction plan</td>
</tr>
</tbody>
</table>

The DPM was based on the process protocol to provide a strategic framework for integrating the concept of DFD into the building process. Some of the potential advantages of adopting the DPM are:

- It maintains a focus on sustainable building requirements throughout the building process;
• It encourages the co-ordination of information flow throughout the project delivery process;
• It identifies the project participants that are responsible at each process phase;
• It specifies activities that can facilitate the appropriate integration of DFD into the conventional building process;
• It recognises the role of the manufacturer at the conceptual stage to facilitate building assembly and/or disassembly of building elements and components; and
• It provides a process model that construction professionals can use to plan the future reuse of a building and potentially the building's components.

6.8 Summary

This chapter has reviewed process modelling in construction and highlighted the need to use it as an effective and appropriate approach for the integration of deconstruction into the building process. The rationale for developing a deconstruction process model was also discussed and a detailed description of the Deconstruction Process Model presented. The next chapter describes the building decomposition model which is part of the DPM.
CHAPTER 7 DEVELOPMENT OF DECOMPOSITION MODEL

7.1 Introduction

This chapter describes the building decomposition model. It is part of the DPM described in chapter 6 and should assist in the implementation process from Phases 4 through to 10. The aim of the model is to facilitate the process of integrating deconstruction into the project delivery process. The systems thinking approach (through the concept of a 'system of systems') is used to illustrate the building decomposition model. The building is analysed as a product made up of different sub-systems which includes construction professionals as part of the building system.

7.2 The System of Systems Approach

7.2.1 Defining a System

To understand the System of Systems approach it is important to explore the meaning of a system. There are as many definitions of the term 'system' as there are academics researching this area (see Table 7.1). Also, the concept of a system is a very fundamental idea used by various researchers and studies in different industries to illustrate an objective or purpose for an entity or an organisation. Consequently, a system must have a purpose or a reason for its existence. For example, the human body is a system consisting of many different parts and organs, each acting separately, yet all working together and affecting each other (O'Connor and McDermott, 1997).

There are several dichotomies which exist to classify systems (Gideon et al., 2005). These classifications include: Open versus closed, physical versus conceptual, static versus dynamic, and natural versus artificial systems. The differences in these classifications are based on how the system is created and the way it operates, functions, and interacts. For example, open systems exist within an environment which they interact with whilst closed systems exist without any outside influence.
### Table 7.1: Definitions of a system.

<table>
<thead>
<tr>
<th>Authors</th>
<th>What</th>
<th>How</th>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Singleton (1974)</td>
<td>A system is a set of interconnected or related objects or entities.</td>
<td>Information and energy are shared or exchanged between them and they change with time</td>
<td>the entities are dynamic in their behaviour (i.e. can exist in more than one state); the collection has a purpose or reason for existence</td>
</tr>
<tr>
<td>O'Connor and McDermott, (1997)</td>
<td>Something that maintains its existence</td>
<td>It functions as a whole by interacting with its parts</td>
<td>It consists of many different parts and organs, each acting separately, yet all working together and affecting the other.</td>
</tr>
<tr>
<td>Haines (1998)</td>
<td>A set of components</td>
<td>Works together for the objective of the whole</td>
<td>Processes, patterns and relationships.</td>
</tr>
<tr>
<td>Daellenbach &amp; McNickle (2005)</td>
<td>An organised assembly of components</td>
<td>By exhibiting behaviours that are unique to the system</td>
<td>Its components, the relationship between components, the behaviour or activities of the system, its relevant environment, the inputs from the environment, the outputs to the environment, and the special interest of the observer</td>
</tr>
<tr>
<td>Gideon et al (2005)</td>
<td>A combination of dependent elements operating together to accomplish a single common goal</td>
<td>The system cannot be expected to operate in the designed manner without its components and the components serve no useful purpose when separated from the system</td>
<td>It has to be coordinated, have an ordered assemblage or set of correlated members and interaction has to be within a set boundary.</td>
</tr>
<tr>
<td>Blanchard &amp; Fabrycky (2006)</td>
<td>An assemblage or combination of elements or parts forming a complex or unitary whole, such as a river system or transportation system;</td>
<td>There must be unity, functional relationship and useful purpose.</td>
<td>A system must be made of components. There must be a hierarchical structure within the system. A system must have specific limits, boundaries and scope. The total system, at whatever level of the hierarchy, consists of all components, attributes, and relationships needed to accomplish an objective.</td>
</tr>
</tbody>
</table>
Chapter 7: Development of Decomposition Model

A system may also be described as dynamic, synthetic and holistic, as it provides a superior rationale to the traditional approach of carrying out activities. In its very nature a system accepts non-measurable elements and is capable of dealing with dynamic behaviours. In addition, it focuses on the interrelationships between all the parts rather than individual parts (Emery, 1981).

Clearly, a system is a conceptual framework, for defining a specific set of functions and activities. It can serve as a unifying framework for understanding and modelling the organisational, technical, and other complexities of the building process. Therefore in conceptualising the building decomposition model, the key objective is to ensure a systems approach whereby the integration of construction professionals, processes, problem-solving mechanisms and information merge together.

7.2.2 System of Systems

The 'system of systems' (SoS) concept draws on similar definitions and characteristics as that of a system. However, a SoS is a more complex system as its parts are made up of independent systems, which are autonomous in nature, forming their own connections or links, whilst being able to respond to change more rapidly (Gideon et al., 2005). It has been described as an assembly of components, where each component is complex enough to be regarded as a system assembled together to form a larger system (Maier, 1996). Kasser (2002) points out that it should be viewed as a set of interdependent systems each at a different phase of its individual system life cycles (SLC) and is evolving at a different rate from the other. Crossley (2003) describes a system of systems as a mix of multiple systems, each of which is capable of independent operation but must interact with one another to meet a need or a set of needs to fulfil a purpose or mission.

For the purpose of this research, a 'system of systems' is defined as a complex system designed or developed from separate systems which are independent in purpose and function from the overall system. However, these different systems (which make up the overall system) must typically interact with each other and the environment to maintain a collaborative system collectively and independently (see Figure 7.1). The SoS approach has been used extensively because of the unique performance that can be obtained through its influence in developing a complex system (Keating et al, 2003; Gideon et al 2005; Sharawi et al., 2006). The description of a complex system through the SoS approach must have certain characteristics to realise its full potential. Sauser and
Boardman (2006) suggest that these characteristics should provide the fundamental building blocks for realising and managing a SOS.

A number of such characteristics have been identified by different researchers (Crossely, 2003, Keating et al., 2003). However the five characteristics identified by Maier (1998) will be discussed here, as they would be used to illustrate the building system through the SOS approach. These characteristics include: operational independence of the components, managerial independence of the components, emergent behaviour of the system, geographic distribution of the components and evolutionary development of the system.

**Operational independence of the components.** This is a system characteristic that shows that each of its components is capable of performing independent of other components, and that the function and operation of the component remains different and useful. For example, a building comprises a roof, walls, floors and a foundation. The walls often provide support to the roof but can be designed independently from the roof, so that the roof supports itself. These components of a building can be designed to be open and dynamic in nature. They are not fixed rigidly within the overall system (the
building system). This characteristic of the components of a building system can influence and facilitate a building to be deconstructed.

**The managerial independence of the elements.** This is a system characteristic that shows that each component has its own independent purpose and is separately managed for its independent purpose. These components are acquired separately and assembled together to maintain a continual operational existence independent of the system of systems. For example, the floor system can be subdivided into various parts (such as floor slab, floor layout, floor finish) which are independently managed through separate professional expertise (that include: structural engineer, architect, building service engineer) to ensure an effective building deconstruction.

**Evolutionary development.** This is a system characteristic that shows the system is not fully formed or finished but in a constant state of change. Its development and existence is evolutionary with functions and purpose added, removed and/or modified as information is gathered. For example, the building system continues to evolve as needs change and new technology becomes available. This means that a building should be designed to easily adapt to different changes and requirements. This ensures that a building adapts to change over time involving different stages of its life, with the functions and purpose of use changing to meet new technological requirements.

**Emergent behaviour.** This is a system characteristic that shows the capability of each component adapting easily to any unexpected changes and requirements to meet effective system performance and optimisation. Thus, in a building system the way each component is assembled in the system should facilitate effective building deconstruction. This unique behaviour of the components ensures that the functional aspect of deconstructing a building is carried out effectively.

**Geographic distribution.** This is a system characteristic that shows the capability of each component part having a wide geographic distribution that dictates, primarily, the exchange of information and ‘not substantial quantities of mass or energy’. In this case, the building system is implemented and controlled or managed by the constructional professionals who are often geographically dispersed from the actual location of the building.

Therefore to facilitate building deconstruction, the building system should exhibit all the five characteristics described above. This recognition of these characteristics to influence
and encourage building deconstruction through the SOS approach provides a basis to explore the requirements of the building decomposition model. These requirements are discussed below.

7.3 Requirements for a Building Decomposition Model (BDM)

The previous section discussed the five characteristics of a system of systems from the perspective of a building system. These characteristics have provided a way to conceptualise the Building Decomposition Model (BDM) and identify the sub-systems of the building system. Accordingly, Keating et al., (2003) points out that there are five dimensions in developing a 'system of systems'. These include: technology, context, operation, geography and conceptual framework. The five dimensions are used as a guide to describe each criterion for the building decomposition model.

**Technology:** A building is made up of several component parts and sub-systems. The technical requirements for assembly differ for each component and sub-system. As technology changes and improves, it is often necessary to change different parts of a building. This means that the building decomposition model should provide a clear analysis of the building decomposition process, in order to meet changing technological requirements.

**Context:** Contextual issues such as human, organisational, policy and political systems can ultimately change decision making and feasible solutions for developing any technical system (Keating et al, 2003). In the same way, a building system is designed with a preconceived context of use based on a client's brief. However, the context of use for a building over a period of time changes due to changes in such factors as user requirements, technology, ownership, legislation and regulations. The development of the BDM should reflect these contextual issues so as to facilitate decision making for building decomposition.

**Operations:** The functional integration of each component of a building should ultimately contribute to how the building will be assembled, and its capability for future reuse and the reuse or recycling of its components and materials. Thus, In order to respond to changes more efficiently and to meet the functional performance of various components, the building decomposition model should accommodate different design requirements for
the future. This means designing the building to make provision for different operational levels of the building element for the future.

**Geography:** It is not uncommon for professionals involved in a building project to be working from different locations. Similarly, the assembly and co-ordination of the various elements of a building can be particularly complex as the location of building components are usually geographically dispersed. The BDM through an integrated approach of visualising the tasks and activities involved in the design and construction of buildings should influence issues (such as the location of building elements and construction professionals) to facilitate the deconstruction of buildings.

**Conceptual frame:** Each construction professional has a different view of the final product (building), and of how the building system and subsystems should fit together to ensure decomposition. Hence a conceptual frame of these views aimed at resolving the various processes and mechanisms should be defined and developed by each construction professional. This conceptual frame should include: details, styles, elements, and sub-systems of the building. It should be set as a guide by each construction professional to facilitate building decomposition.

### 7.4 Building Decomposition Models in Construction

The decomposition of a building is a complex process that requires a systematic approach for evaluating and understanding the best way to implement it. Consequently, a number of theories and models have been developed by various researchers and practitioners to address its complexity. A selection of these models is discussed below. The presented models are those that are relevant to the concept of DFD.

#### 7.4.1 Theory of Levels

The theory of Levels or 'building layers' assumes that a building is a system made up of different parts or sub-systems called layers. Various studies suggested that the building layers should have different rates of change and different interpretations of time levels (see Table 7.2). In addition, the studies have used various factors that can influence building design to develop different expected service life spans of building layers. These factors include:
Chapter 7: Development of Decomposition Model

- users' changing demands for functional space and the need to upgrade equipment and furniture in buildings;
- consideration of technological and social changes and their impact on buildings and the environment;
- sustainable design to reduce the environmental consequences of constructing and operating buildings;
- life cycle costs of building in terms of its future maintenance and operation;
- reducing environmental burdens by designing buildings that account for the different life spans of various elements; and
- reducing embodied energy in buildings through reduced material use and encouraging the recycling of materials.

**Table 7.2 Life Spans of Building Layers (in years)**

<table>
<thead>
<tr>
<th>Structure</th>
<th>Layer</th>
<th>Skin</th>
<th>Services</th>
<th>Space plan</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
<td>Skin</td>
<td>50</td>
<td>15</td>
<td>5-7</td>
<td>Duffy 1989</td>
</tr>
<tr>
<td>30-300 (typically 60)</td>
<td>Services</td>
<td>20</td>
<td>7-15</td>
<td>3-30</td>
<td>Brand 1994</td>
</tr>
<tr>
<td>40</td>
<td></td>
<td>15</td>
<td>3</td>
<td>5-8</td>
<td>Cook 1972</td>
</tr>
<tr>
<td>25-125</td>
<td></td>
<td>25</td>
<td>5</td>
<td>5</td>
<td>Kikutake 1977</td>
</tr>
<tr>
<td>60-100</td>
<td></td>
<td>15-40</td>
<td>5-50</td>
<td>5-7</td>
<td>Curwell 1996</td>
</tr>
<tr>
<td>60 (assumed maximum life of building)</td>
<td></td>
<td>20</td>
<td>7-15</td>
<td>3-5</td>
<td>Storey 1995</td>
</tr>
<tr>
<td>65</td>
<td></td>
<td>65</td>
<td>10-40</td>
<td>5</td>
<td>Howard 1994</td>
</tr>
<tr>
<td>50 (assumed maximum life of building)</td>
<td></td>
<td>30-50</td>
<td>12-50</td>
<td>10</td>
<td>Adalberth 1997</td>
</tr>
<tr>
<td>40 (assumed maximum life of building)</td>
<td></td>
<td>36</td>
<td>33</td>
<td>12</td>
<td>McCoubrie 1996</td>
</tr>
<tr>
<td>-</td>
<td></td>
<td>15-30</td>
<td>7-30</td>
<td>-</td>
<td>Suzuki 1998</td>
</tr>
<tr>
<td>40 (for brick veneer house)</td>
<td></td>
<td>12-30</td>
<td>30-40</td>
<td>8-40</td>
<td>Tucker 1990</td>
</tr>
</tbody>
</table>

Source: Crowther, (2001)

In an earlier study Habraken (1961) suggested that there are three levels in the built environment. He described these as the levels of decision making within the built
environment. They include: urban fabric or tissue, base building or support, and fit out or infill. The development of these levels is based on a pattern of responsibility and control. That is, the building and its inhabitants interact at the infill level (Inhabitants define the infill level), the tenant organisation is responsible for the support level, while the whole community is responsible for the tissue levels. The support level enables the infill level to be assembled, altered and taken down independently, whilst the support level remains constant during these changes. Figure 7.2 below shows the three independent horizontal level of decision making that provide a flexible framework for future modifications of the infill level.

![Diagram showing three independent levels of decision making](Image)

**Figure 7.2: Three Independent Levels of Decision Making**

Source: Durmisevic, (2006)
Furthermore, Habraken (1998) expanded on his theory to classify the building into two distinctive layers: the permanent support (structural frame) and the temporary dwelling (internal spaces). The ‘Supports’ should provide access to common mechanical systems and accommodate a variety of dwelling unit plans. These ‘Supports’ can also facilitate detachable dwelling units to be installed independently from the base building that supports it.

Duffy and Henney (1989) defined four layers (see Figure 7.3) for the building decomposition which are different from the two layers suggested by Habraken (1961).

![Figure 7.3: Building Layers](source:Duffy and Henney, 1989)
Chapter 7: Development of Decomposition Model

Habraken concept is based on ensuring that over a period of time, the internal parts of a building's functions and space layout are adaptable to the users requirements and changing needs over a period of time. Duffy's and Henney's (1989) concept focused mainly on the interior fit-out of an office and commercial buildings. A description of the four layers is presented below:

- **Shell** – this is the supporting structure of the building. It consists of the foundation, the architectural and the structural elements (the walls, floors and roof) which supports the building. These parts are assumed to last the lifetime of the building.
- **Services** – these include the electrical, mechanical, plumbing, air conditioning and elevators.
- **Scenery** – these include the internal partitions and non-load bearing walls, finishes, and fixed equipment and/or furniture.
- **Set** – these include movable furniture that building occupants can easily move and rearrange.

The four layers concept was further developed by Brand (1994) who suggested a more general six layers concept for the decomposition all building types (see Figure 7.4). He replaced the shell layer with a structure layer and a skin layer. The site which represents the location of the building and its environs was added as a new layer. He also replaced the scenery layer with a space plan layer.

![Figure 7.4 Sharing Layers of Change](source: Brand (1994))
A description of these layers is presented below:

- **Site** — this is the geographical setting, the urban location, and the legally defined plot of a building. The site is ‘eternal’ and often outlasts generations.

- **Structure** — the foundation and load bearing elements of a building. It is often two expensive and difficult to change. The structural life is about 30+ to 300 years although most buildings are demolished after 60 years.

- **Skin** — exterior surfaces of a building such as the cladding and roofing system (excluding the interior parts). These last for about 20 years and are changed mostly because of fashion, new technology and wholesale repair and maintenance.

- **Services** — This is the working guts of a building. It includes: communications wiring; electrical wiring; plumbing; sprinkler systems; HVAC (heating, ventilating, and air conditioning) and moving parts such as elevators and escalators. They wear out more frequently and are changed every 7 to 15 years. Most buildings are demolished as a result of these services being embedded in too deeply into the structure.

- **Space Plan** — that is, the interior layout — walls, ceilings, floors and doors. It changes every 3 years or so for commercial buildings but for residential homes, it may last for up to 30 years.

- **Stuff** — furniture; kitchen appliances; all the things that are moved around on a daily or monthly basis.

The theory of layers have used the different rates of change of building components and the functional levels to describe and highlight the potential of a building to be decomposed into various parts. Furthermore, Brand (1994) pointed out that the variable rates of change with some building components having a faster-cycle (space plan elements) than the structure of the building which has a slower-cycle, should be considered in the building process especially in design. Other studies related to the theory of layers focused (see Table 7.2) on the environmental sustainability of buildings, considering the rate of change of each layer and its impact on the natural and built environment. It should be noted that while the number of years estimated by each of these studies is different, there is a common acceptance that different parts of a building have different life spans and that these parts must be considered as different layers.
in conclusion, the implication of the theory of layers is that parts of a building with short service life span, should be separated (through design, construction and assembly) from those parts of the building with long service life. This means that there is no need for demolishing the whole building at the end of its life, in order to replace or upgrade building services or components as affected by factors such as new technological advancement and changes in users’ requirements.

7.4.2 Life Cycle Approach (LCA)

In this approach a product (building) or a service (process) is assessed from inception and throughout all phases of its life-cycle up to its disposal. It is usually used where it may assist with the decision making process in order to optimise the design and construction process to effectively address issues such as the environment, use of recycled components and energy use in buildings. Therefore, the use of this approach should potentially be able to provide information on the environmental performance of different building concepts in an accessible format. However, its use has been limited due to the inconsistency of studies carried out on building related products and issues. Kibert (2003) pointed out that the notion of carrying out the LCA of a building would assist the industry to effectively address the end-of-life scenarios of a building and facilitate DFD. This means that the LCA is an important concept to consider in designing buildings to deconstruct.

Durmisevic and Brouwer (2002), suggested that the potential of a building structure to be disassembled, is strongly related to the different life-cycles of each element and component. In addition, (Durmisevic, 2006) assumed that a structure represents a functional assembly with hierarchical levels and that every hierarchical level should be linked to the integration of the functional and technical life cycle of each building element, material and component. This means that the building may be decomposed through any of the different life-cycles of materials and elements. Furthermore, Durmisevic (2006) pointed out that the decomposition characteristics of each building element, material and system that comprises a building system has to be evaluated separately to ease building decomposition. This implies that in order to facilitate building decomposition, consideration should be given to the technical and use life-cycle of materials and elements, during the design and construction process.

In assessing the suitability of the two theories considered above it should be noted that the theory of layers focused on the durability of the component parts, technological
changes and social changes. The life-cycle approach considered the different lifecycles of building materials and components.

Table 7.3 shows a comparison of these existing models with the criteria of the proposed building decomposition model. It shows that the different concepts have focused on different criterion (see Table 7.3). However, none of these models have completely given consideration to some of the criterion (see Section 7.3 for description of each criterion). In addition, the basis by which the concept of the building decomposition model has been described (see Section 7.2.2) in this research, also shows these models do not fully satisfy the criterion. Nevertheless, these models have provided useful contributions in the need to design a building in such a way that deconstruction can easily be implemented at the end of a building’s useful life. Thus, the building decomposition model proposed in this research can be seen as a hybrid of these models. Essentially, It focuses on the operation (such as tasks and activities) and context (such as human, organisation, policy system) requirements with the technology and conceptual frame requirements to potentially ensure a more effective deconstruction of the building.

<table>
<thead>
<tr>
<th>Model Criteria</th>
<th>Habraken</th>
<th>Duffy</th>
<th>Brand</th>
<th>Durmisevic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technology</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Context</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Operations</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Geography</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Conceptual frame</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

7.5 The Building Decomposition Model

7.5.1 Overview

The building decomposition model describes the building symbolically using the System of Systems (SoS) approach. According to Sharawi et al (2006), in order to implement a system of systems approach it is important to accurately identify each component to be modelled as well as to establish the degree of flexibility that the SoS has to offer. In
addition, to ensure an effective building decomposition, it is important to show that all the systems that make up the building system are interconnected and functioning as a whole system. Accordingly, Agger, (2002) suggests that to model the building system, representation should be given to the collection of interrelated spatial elements that contains constructions or functions and the operational organisation of the building process.

In general, a building may be seen as an assembly of building elements which include the walls, foundation, interiors, floors, and roof. In describing the building decomposition model the building is represented as a system. The system is made up of the followings systems: the professional system, building system, parts system and details system. Two methods of decomposition is considered in describing how the building is decomposed. They include: a hierarchical decomposition (see Figure 7.5) which relates to the decision-making aspects of designing a building and a functional decomposition which is the generic description of a building system with the subsystems.

![Diagram](image-url)  
*Figure 7.5 An Illustration of levels used in the BDM*

### 7.5.2. The Professional System

The professional system comprises all the construction professionals that usually participate in the building process. From a hierarchical point of view they are at the top of the decomposition model taking responsibility from the early stages of a building project. In particular, from phase 4 (prepare DFD checklist for outline conceptual design) of the DPM the role of each construction professional is to recommend the necessary inputs (guidance and expertise) that would enable a building to be easily disassembled in...
factors such as change of use and end-of-life scenarios. For example, a floor system which is a sub-system of the building system is divided into four or more parts with each part assigned to a construction professional, who then defines the level of decomposition (see Figure 7.6). Therefore, the professional system is primarily concerned with exploring and capturing the knowledge prescribed by construction professionals to facilitate a building’s deconstruction.

![Diagram of the decision making process of the floor subsystem](image)

**Figure 7.6 Illustration of the decision making process of the floor subsystem**

### 7.5.3 The Building System

The building system consists of the generic parts of a building that collectively support the building’s structure, that is walls, the floors, roofs and foundation. The complexity involved in erecting a building system and how each sub-system (building element) interacts is assumed to be dynamic. That is, each building element is able to change to accommodate different end-of-life scenarios (Durmisevic, 2006). In other words, the fact that a system and sub-systems can be changed in a variety of ways means that there is almost an infinite number of configurations of a building. Each building configuration would have emergent properties that would be appropriate to assist building decomposition.

### 7.5.4 Parts System

The parts system is the sub-system of the building system. It consists of large number of interacting building elements and materials (such as wall partitions, windows and doors
openings, and floor slabs). The interrelationships and interdependencies of all the sub-systems are understood, evaluated, appropriately applied, and coordinated concurrently by different construction professionals according to their responsibility and expertise.

7.5.5 Details System

The details system is a further sub-system of the parts system and a system in its own right. The arrangement of the interdependent systems of the building elements and how they are connected to provide the capability for building decomposition is the basis of the details system.

7.6 The Objectives of the Building Decomposition Model (BDM)

The development of the BDM was designed to facilitate the process of decomposing a building. To achieve this, each construction professional is assigned a ‘parts system’ of the generic building sub-system (see Figure 7.6). The construction professional should then give a clear idea of the essential requirements (information and data) to facilitate building decomposition. A decision making flow chart is proposed for implementing the building decomposition model (see Figure 7.7).

---

**Figure 7.7 Decision Making Flow Chart**

| Step 1: Scope Extent of Decomposition Based on the 5 Requirements of BDM |
| Step 2: Define and/or Design Alternative Scenarios |
| Step 3: Select Appropriate Scenario |
| Step 4: Design Units of Assemblies, Subassemblies with Disassembly and the Specifications of Components and |
| Step 5: Complete Set of Drawings and/or Documentation |
| Step 6: Evaluate and Check Documentation |
| Step 7: Release of Documentation for Deconstruction Production/Construction |
Chapter 7: Development of Decomposition Model

Its purpose is to provide a step by step guide for construction professionals on making decisions that should ensure an effective outcome at the end of a building’s life-cycle. The context of implementing the BDM is based on providing a decision support system to enhance the process of building decomposition. The intention is to enable the effective integration of the principles of deconstruction at the design stage within which preliminary conceptual design decisions are usually formulated and conceived. This is significant because the expertise of each construction professional is exploited as early as possible through the various parts of the building system. This process should start at phase 4 (prepare DFD checklist for outline conceptual design) of the DPM through to phase 10 (Implementation plan for building decomposition) with each construction professional expected to consider and provide expertise how best to effectively assemble and deconstruct a building.

7.7 The Potential Benefits of the BDM

It is intended that the building decomposition model will facilitate improvements in the construction process, particularly with respect to: collaborative design, project coordination, reduction of design and construction waste, reuse and recycling of building elements.

Table 7.4 Summary of How the BDM can Facilitate Deconstruction

<table>
<thead>
<tr>
<th>Principles of Design to Facilitate Design for Deconstruction</th>
<th>How it can facilitate deconstruction</th>
</tr>
</thead>
<tbody>
<tr>
<td>design to accommodate deconstruction logistics.</td>
<td>the decomposition process should be an approach that works properly in a technical sense and satisfies the need of the client.</td>
</tr>
<tr>
<td>design to accommodate deconstruction logistics.</td>
<td>to encourage a unified and systematic analysis of the design issues amongst all construction professionals.</td>
</tr>
<tr>
<td>reduce building complexity</td>
<td>to improve the interface between building technologies, construction professionals who control the different technologies and an operational objective during the building process.</td>
</tr>
<tr>
<td>consider worker safety.</td>
<td>to encourage the arrangement of independence and interdependence between different building subsystems and systems to achieve reuse and recycling capabilities.</td>
</tr>
<tr>
<td>design for prefabrication, preassembly and modular construction.</td>
<td>simplifying and standardise connections and details. simplify and separate building system. design to incorporate reusable materials. select fittings, fasteners, adhesives and sealants that can facilitate the removal of reusable materials.</td>
</tr>
</tbody>
</table>
The model will be applicable to different types of buildings and hopefully reduce the fragmented approach used in most construction projects. Table 7.4 presents a summary of how BDM can facilitate the integration of the DFD within the building process particularly at the design, construction and deconstruction phase of the Deconstruction Process Model.

7.6 Summary

In this chapter, the concept of the building decomposition model has been described. The need to design a building in such a way that deconstruction can easily be implemented at the end of a building's useful life is the key issue addressed through the building decomposition model. The model is part of the deconstruction process model presented in chapter 6. It should be used from phases four to ten in the DPM to simplify the decision making process for facilitating building deconstruction. The next chapter presents the evaluation process of the DPM.


CHAPTER 8 EVALUATION OF THE DECONSTRUCTION PROCESS MODEL

8.1 Introduction

For a given model, the choice of an appropriate evaluation approach is important as it will influence the quality of the results obtained (Stufflebeam and Shinkfield, 1985). In addition, it is also important to consider the purpose of the evaluation findings (Smith 1975) as it will facilitate the understanding of the model and will assist in identifying the features to be measured (Pidd, 2003).

A Deconstruction process model (DPM) for integrating the process of deconstruction into the building process was developed in chapter 6. A complimentary building decomposition model associated with using the DPM was described in chapter 7. This chapter describes the evaluation of the deconstruction process model (DPM). The aim and objectives, the methodology and an analysis of the evaluation results are presented.

8.2. Aim and Objectives of the Evaluation Procedure

The aim of the evaluation procedure is to explore the suitability and practicality of using the DPM as a framework to integrate the concept of DFD into the building process. The specific objectives are to:

- assess how well it facilitates the integration of deconstruction into the building process;
- assess the effectiveness and practicality of DPM's coverage of issues (such as ease of building component disassembly and reuse/recycling of building materials and components);
- identify any appropriate and relevant activities or sub-activities which have not been addressed by the DPM; and
- assess the applicability and usability of the DPM as an adequate tool for encouraging sustainable construction practice.
8.3 Evaluation Methodology

Focus groups were used to evaluate the proposed DPM. These were conducted through a number of workshops. The format adopted for each workshop involved a short presentation introducing the background to the research, a brief summary of DPM and its potential benefits to industry practice, a description of how DPM may be used in practice, and participants' evaluation using a questionnaire. Each workshop lasted for about one hour.

8.3.1 Questionnaire Design

A questionnaire for evaluating the deconstruction process model for integrating deconstruction into the project delivery process was designed (see Appendix E). The questionnaire comprised two main parts. Part A which covered the background information about the participants. The second part, part B, consists of 11 questions which focused on the relevance of the DPM in addressing some aspects of sustainability especially as it relates to the process of deconstruction and finally questions about the respondents' general opinion on the DPM. The questions were grouped into several subsections:

- section 1 – effectiveness of DPM;
- section 2 – functionality;
- section 3 – coverage and scope of DPM;
- section 4 – ease of use/user friendliness; and
- section 5 – open-ended questions about the DPM.

Sections 1 to 4 were based on a five-point Likert rating scale ranging from 1 (poor) to 5 (excellent). Section 5 had open-ended questions with space provided for written responses and suggestions for improvements.

8.3.2 Evaluation Approach

The model was presented to a group of architects, a group of sustainability consultants and to other industry practitioners (see Table 8.1). The selection of the participants was based on the feedback from the survey and case study (see Chapter 5) and their roles and responsibilities during a construction project. The workshops were designed to elicit
feedback and discussions from participants on the appropriateness of the model. The details of the workshops are described below.

Table 8.1 Details of Participants

<table>
<thead>
<tr>
<th>S/No</th>
<th>Background of Participant</th>
<th>Organisation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Workshop#1 (Architects)</td>
</tr>
<tr>
<td>1</td>
<td>Architect (Retail design)</td>
<td>AEDAS Architects Ltd</td>
</tr>
<tr>
<td>2</td>
<td>Architect (Healthcare design)</td>
<td>AEDAS Architects Ltd</td>
</tr>
<tr>
<td>3</td>
<td>Architect (Educational design)</td>
<td>AEDAS Architects Ltd</td>
</tr>
<tr>
<td>4</td>
<td>Architect (Sustainability design)</td>
<td>AEDAS Architects Ltd</td>
</tr>
<tr>
<td>5</td>
<td>Architect (Educational design)</td>
<td>AEDAS Architects Ltd</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Workshop#2 (Sustainability Consultants)</td>
</tr>
<tr>
<td>6</td>
<td>Construction resource efficiency</td>
<td>BRE Ltd</td>
</tr>
<tr>
<td>7</td>
<td>Quantity surveyor</td>
<td>BRE Ltd</td>
</tr>
<tr>
<td>8</td>
<td>Sustainability consultant</td>
<td>BRE Ltd</td>
</tr>
<tr>
<td>9</td>
<td>Quantity Surveyor</td>
<td>BRE Ltd</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Other Industry Practitioners</td>
</tr>
<tr>
<td>10</td>
<td>Site/Construction management engineer</td>
<td>P.C.Harrington</td>
</tr>
<tr>
<td>11</td>
<td>Structural engineer/project manager</td>
<td>Arup</td>
</tr>
<tr>
<td>12</td>
<td>Site/Project manager</td>
<td>Willmott Dixon</td>
</tr>
<tr>
<td>13</td>
<td>Construction Management</td>
<td>Loughborough University</td>
</tr>
<tr>
<td>14</td>
<td>Civil engineer/Demolition expert</td>
<td>Dorton Demolition &amp; Excavation Ltd</td>
</tr>
</tbody>
</table>

Workshop #1 (Architects)
The first evaluation workshop was held at the Aedas architectural firm in Leeds. The participants comprised 6 architects who specialise in the design of different types of buildings including educational, healthcare, and retail buildings. The presentation was followed by a discussion session where copies of the DPM and the evaluation questionnaire were distributed. The participants provided feedback on the various phases and activities of the DPM.

Workshop #2 (Sustainability Consultants)
This validation workshop was held at Building Research Establishment (BRE) in Watford. The participants were 4 consultants from BRE with a speciality in design and costing as well as in sustainable design. A description of the process model was provided and a discussion session was carried out for about 20 minutes. A copy of the DPM was
Chapter 8: Evaluation of the Deconstruction Process Model

distributed along with the evaluation questionnaire to the participants to provide feedback on the DPM.

Other Industry Practitioners
The evaluations were also carried out as individual sessions. They started with a presentation of the research and an explanation of how DPM could encourage construction professionals to integrate DFD. The DPM was presented to 5 participants, who included a site project manager, a researcher, a project manager/structural engineer and a structural engineer. Participants were given a one-page summary (see Appendix F) of the DPM which included definition, description and potential benefits of the DPM to the industry. This provided a guide to ensure that participants had a common understanding of the context of the evaluation process. A detailed description was given on DPM and participants were invited to complete the evaluation questionnaire.

8.4 Evaluation Results

8.4.1 Overview of the results

In general, all the participants in the workshop gave positive feedback regarding the suitability of integrating deconstruction into the building process. The responses were analysed under the following 5 categories (see Appendix E): Effectiveness; Functionality; Coverage and Scope; Ease of use/User friendliness; and general questions on DPM. The distribution of the scores (as percentages) and the mean scores (or average ratings out of 5) of the 14 participants are presented below.

8.4.2 Effectiveness

54% of the participants felt that the DPM was a very good representation of sustainable construction issues, 31% thought it was good and 15% felt it was a fair representation (see Table 8.2). Other aspects of the effectiveness of the DPM include: 38% of the participants indicating that it related effectively to the design issues of reuse and recycling of building materials and components and 69% indicating it was a good or very good mechanism for integrating deconstruction into the project delivery process. The average mean score for effectiveness was 3.49 suggesting that the participants viewed DPM as a framework that is good in its suitability and practicality for industry practice.
8.4.3 Functionality

46% of the participants felt that the model has a good functionality in terms of the sustainability agenda. The other 46% felt it had a very good or excellent functionality with respect to the sustainability agenda (see Table 8.2). 77% of the participants felt it had good or very good functionality in terms of facilitating the planning and implementation of DFD into construction practice. In addition, 93% of the participants felt the functionality of the DPM could assist in reducing design and construction waste. The average mean score of 3.77 for functionality suggests that the participants felt that the DPM had good features in the designated activities and sub-activities to facilitate deconstruction practice.

8.4.4 Coverage and Scope of DPM

The average mean score of 3.72 from the responses shows that the DPM had a good coverage and scope (see Table 8.2). Furthermore, 77% of the respondents felt that the coverage and scope of the DPM was good or very good in addressing the different stages of the project delivery process. 15% felt it had an excellent coverage and scope. Another 73% and 8% indicated it was good or very good respectively and excellent in capturing the various stages/activities necessary to integrate the concept of deconstruction into the building process. Finally, 15% thought it fully captured the overall essence of sustainability while 61% indicated that it was good or very good.

8.4.5 Ease of use/User friendliness

75% of the participants indicated that the DPM had a good or very good format to understand, while 8% thought it was in an excellent format. 69% of the participants indicated that it was easy to use the DPM while 17% thought it was excellent (see Table 8.2). With a mean score of 3.49, the participants' ratings indicate an overall good practicality of the DPM in terms of ease of use/user friendliness.
<table>
<thead>
<tr>
<th>Key Features</th>
<th>Level of Suitability and Practicality</th>
<th>Equivalent (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td><strong>1. Effectiveness</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>15%</td>
<td>31%</td>
</tr>
<tr>
<td>B</td>
<td>8%</td>
<td>38%</td>
</tr>
<tr>
<td>C</td>
<td>15%</td>
<td>38%</td>
</tr>
<tr>
<td><strong>2. Functionality</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>D</td>
<td>8%</td>
<td>46%</td>
</tr>
<tr>
<td>E</td>
<td>15%</td>
<td>31%</td>
</tr>
<tr>
<td>F</td>
<td>8%</td>
<td>62%</td>
</tr>
<tr>
<td><strong>3. Coverage and Scope</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>G</td>
<td>23%</td>
<td>62%</td>
</tr>
<tr>
<td>H</td>
<td>31%</td>
<td>62%</td>
</tr>
<tr>
<td>I</td>
<td>23%</td>
<td>23%</td>
</tr>
<tr>
<td><strong>4. Ease Of Use/User Friendliness</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>J</td>
<td>15%</td>
<td>54%</td>
</tr>
</tbody>
</table>

**8.4.6 General Questions**

The responses from the open-ended evaluation questions (see Appendix E) provided additional valuable insights into the suitability and practicality of the DPM. To identify the strengths and weakness of the DPM, a SWOT analysis was used. The use of SWOT analysis was deemed necessary because it helps to identify the participants' perception of the DPM as a strategic framework for integrating deconstruction into the building.
process. SWOT analysis is a business management tool that is used for measuring a proposition or an idea. It allows data to be put into a logical order that helps the understanding, presentation, discussion and decision-making (Armstrong 1982; Hill and Westbrook, 1997). The analysis is done under four main headings, these are Strengths, Weaknesses, Opportunities, and Threats (see Table 8.3). The analysis of the responses is presented in a grid format. This consists of four sections each representing one of the four SWOT headings. The responses were edited to facilitate the analysis and to allow for better understanding. Furthermore, the four dimensions of the SWOT were used to identify and summarise the participants responses into two headings: Benefits and Limitations of the DPM (see Section 8.5.2).
Table 8.3: Participants responses to the evaluation questions

<table>
<thead>
<tr>
<th>Strengths</th>
<th>Weaknesses</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Good framework structure and strategy</td>
<td>• Needs to differentiate between reuse and recycling,</td>
</tr>
<tr>
<td>• The early phases are very useful towards implementation</td>
<td>environmental building impact and different construction methods</td>
</tr>
<tr>
<td>• The details in the sub-activities would help in identifying the</td>
<td>• Needs to to be linked to existing building regulation requirements</td>
</tr>
<tr>
<td>importance of deconstruction methods and techniques</td>
<td>in the industry</td>
</tr>
<tr>
<td>• A useful tool to encourage whole life cycle perspective particularly</td>
<td>• Needs more consideration of sustainability issues such as</td>
</tr>
<tr>
<td>in the feasibility and pre-construction phases</td>
<td>environmental valuation materials using LCA that can include</td>
</tr>
<tr>
<td>• Each phase diagram is very detailed and has a good description</td>
<td>deconstruction options for reuse and recycling</td>
</tr>
<tr>
<td>of activities required to be considered to meet deconstruction</td>
<td>• Needs more coverage at the construction phase (such as an</td>
</tr>
<tr>
<td>requirements</td>
<td>illustration of a building project). This would make the DPM more</td>
</tr>
<tr>
<td>• Easy to understand</td>
<td>tangible for users to comprehend</td>
</tr>
<tr>
<td>• Phase 4 of the DPM which describes the decomposition of the building</td>
<td>• Needs a case study/example to demonstrate the implementation</td>
</tr>
<tr>
<td>into its generic parts (that is roof, wall, floor, etc)</td>
<td>of the framework. This will help highlight the benefits, clarify any</td>
</tr>
<tr>
<td>• Guidance is in line with RIBA Plan of Work</td>
<td>gaps and reasons for using DPM</td>
</tr>
<tr>
<td>• Very well structured approach</td>
<td>• Needs to emphasise the drivers in Phase 1</td>
</tr>
<tr>
<td></td>
<td>• Needs in-depth requirements for design developments</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Opportunities</th>
<th>Threats</th>
</tr>
</thead>
<tbody>
<tr>
<td>• More consideration of deconstruction design and</td>
<td>• Insufficient differentiation between reuse and recycling aspects</td>
</tr>
<tr>
<td>building ownership</td>
<td>• Insufficient examples of the building's environmental impact</td>
</tr>
<tr>
<td>• Less waste and less use of new products</td>
<td>• Links to existing building requirements, legislation and standards on sustainable construction</td>
</tr>
<tr>
<td>• Creates more awareness of sustainability issues in future</td>
<td>• No current legislation on end of life of building</td>
</tr>
<tr>
<td>• Assist in a more sustainable building specification such as feedback</td>
<td>• Legislation is essential for designers/contractors to be committed to the idea/theory</td>
</tr>
<tr>
<td>data into resource &amp; waste planning and possibly increase reuse rates</td>
<td>• Looks daunting from the number of stages and issues</td>
</tr>
<tr>
<td>• Easy and safe deconstruction</td>
<td></td>
</tr>
<tr>
<td>• It brings the key issue of deconstruction to the forefront in</td>
<td></td>
</tr>
<tr>
<td>construction</td>
<td></td>
</tr>
<tr>
<td>• Green buildings</td>
<td></td>
</tr>
<tr>
<td>• Protection of natural resources, reduction of waste to</td>
<td></td>
</tr>
<tr>
<td>landfills, construction technologies (processing) and</td>
<td></td>
</tr>
<tr>
<td>reuse of materials</td>
<td></td>
</tr>
</tbody>
</table>
8.4.7 Comments from Participants

The comments from the participants during the discussion sessions at the workshops are summarised below:

- Retail buildings (such as supermarkets and department stores) are most likely to be deconstructed as they generally have an interior fit-out cycle of 2 to 5 years with a refurbishment rollout.

- The strategic and technical aspects of integrating deconstruction into the project delivery process should consider:
  - ensuring the flexibility and adaptability of building components and not just a modular layout and related techniques, which can both become obsolete with time;
  - implementing a take-back strategy for product manufacturers by setting a minimum percentage of the project value;
  - introducing legislation for deconstruction, especially for buildings that have short life spans;
  - using dry construction methods where appropriate;
  - providing simple ways to encourage deconstruction practice; and
  - convincing developers to take responsibility for perceived extra costs to facilitate ease of building disassembly in the future;

- Introducing an end-of-life directive for EU buildings, similar to the one used in the car industry, to encourage manufacturers to take back products; the possibility of leasing building components and developers to take responsibility.

- Legislation and additional building regulations to be the main driver for developers/clients to consider the possible benefits of deconstruction.

- The usefulness of benchmarking the DPM with other initiatives in the construction industry (such as the various guidance provided by WRAP and the Sustainability Task Group) with respect to sustainable construction practice.

- The possible difficulty in having a construction (site) personnel involved from the early phases such as phase 3. This is because the companies already have dedicated professionals who should produce the appropriate documentation for the construction phase.
8.5 Discussion

In the following section the results of evaluating the collected responses will be discussed. The homogeneity of the results and the overall rating of good or very good (see Figure 8.1) of most of the key features of the DPM indicate that the evaluation was reliable and appropriate in obtaining responses from industry practitioners.

8.5.1 Summary of the Evaluation Results

This section is a discussion showing how the evaluation results meet the objectives set out in section 8.2.

Achieving Objective One

The first objective was to assess how comprehensively the process of deconstruction was integrated into the building process. Therefore, the DPM was evaluated based on three questions to find out how well it rated in terms of:

- its suitability for integration into the project delivery process;
- the extent to which it would facilitate planning and implementation of DFD; and
- the number of stages/activities captured and the integration of the concept of deconstruction into construction practice.

The overall rating of 3.46 (69%) for suitability of integration, 3.46 (69%) for the extent to which it facilitates integration and 3.77 (75%) for capturing the stages/activities indicate that DPM can effectively be used for integrating deconstruction into the building process (Figure 8.1). However, the participants thought that if an illustrative example of implementation was given and DPM's activities were linked with other frameworks and standards (such as CDM regulations, BREEAM) developed in the industry then the DPM would be more practical and effective.
Achieving objective Two

The second objective was to assess the effectiveness and practicality of the DPM’s coverage of issues such as ease of building component disassembly and reuse and/or recycling of building materials and components. This was assessed by the addressing the following points:

- the relation of the design phase of the DPM to reuse and recyclability; and
- the functionality of the DPM in reducing design and construction waste.

Several comments were put forward by participants (see section 8.4.7), and suggestions for improving the guide and deliverables were also made (see table 8.4). Average ratings of 3.62 (72%) and 4.23 (85%) indicate that DPM is considered both effective and functional in addressing this objective.

Achieving objective Three

The third objective was to identify other appropriate and relevant activities or sub-activities. With an overall rating of 3.62 (72%) and 3.46 (69%) for functionality the comments received from the participants (see Table 8.3) indicate that to some extent the activities and/or sub-activities were relevant and appropriate. However, the participants suggested the following sub-activities: a registry of materials, differentiating between materials that can be recycled and reused and relating these sub activities to standards (such as ISO14201).
Achieving objective Four

The fourth objective was to assess the applicability and usability of the DPM as an adequate tool to encourage sustainable construction practice. This was assessed by addressing the following points:

- The model's representation of sustainable construction issues.
- Its contribution to the sustainable construction agenda.
- The extent to which it captured the overall essence of sustainability.

With the overall ratings of 3.39 (68%); 3.62 (72%) and 3.46 (69%) on these questions it can be deduced that DPM can assist the practice of sustainable construction. However, it is important to recognise that the subject of sustainability is very wide and far-reaching, therefore, suggestions were put forward for improving the DPM (see section 8.6).

8.5.2 The Benefits and Limitations of the DPM

The evaluation exercise provided a good indication of how suitable and practicable the DPM would be if implemented in a real project. Therefore, the benefits and limitations as suggested by the participants are summarised below.

Benefits of implementing the DPM include:

- It helps to ensure that, at the feasibility stages of a building project, consideration is given to sustainable construction issues and drivers.
- DPM may serve as a strategic framework for effectively and systematically approaching the extent by which buildings can possibly be adapted for reuse at the end of their useful life.
- DPM should help increase designers' awareness so that they may reconsider their traditional approach to building design especially the initial design phase.
- DPM has the potential to assist in sustainable design and innovation of the building process.
- DPM should assist in future resource planning in construction. The proposed activities (such as 'strategy for future reuse' and 'identify elements for new proposal') in phase 9 and 10 would encourage this.
- DPM provides a good framework for professionals to give consideration to the process of deconstruction and its benefits to sustainable construction practice.
- The expected outputs/deliverables of the DPM (which include a report on construction method for deconstruction, a report for future reuse of building, and
a documentation plan for deconstruction) is similar to CDM requirements for building contractors. This makes it a practical framework to implement.

- The activities of the design phase are good as they are critical in considering the disassembly of components in the future.

Limitations of the DPM include:

- The perceived extra cost and time involved in using the DPM is seen as a barrier to implementing deconstruction practice.
- Some of the activities (such as identifying key elements and structure of materials) need an exact estimate of the percentages to realise the potential benefits of the DPM.
- Some of the activities and outputs should be linked with existing sustainable construction frameworks and tools (such as BREEAM) currently available in industry practice.
- The DPM needs to be made more clear by showing an illustration of a building project to support the activities and outputs.

8.5.4 Constraints in the Evaluation

A major constraint in the evaluation process was that the DPM was developed as a paper-based framework. However, to instigate interest, it was sent out electronically to participants. This led to organising workshops through the format of a focus group to obtain appropriate feedback. Thus, the evaluation process of the DPM was limited to describing the potential integration of the DPM into the building process. Nevertheless, the participants had the opportunity to explore the potential of the DPM as a suitable framework to guide construction professionals in integrating DFD into the project delivery process.

Another constraint was that there was no specific example (that is a building project) associated with the possible implementation or use of the DPM. This limitation was as a result of the findings in this research (see Chapter 5). The findings indicated the need to develop a strategic framework to guide the integration of deconstruction into the project delivery process. Therefore the proposed framework mainly focused on strategic aspects instead of linking it to a specific project. Nonetheless, the participants felt that the framework was clear and practicable enough for them to provide adequate feedback.
8.6 The Modified DPM

Following the feedback obtained from the evaluation process, the DPM has been revised and is presented in Appendix 6. In addition, the suggestions for improvement are divided into two categories: (a) Improvements that address the structure of the DPM and (b) suggestions addressing the activities.

The highlights of the revised DPM include the following:

- The outputs of each phase are now included in the mapping structure of the DPM
- The order of the criteria in the deconstruction matrix template has been changed (see Table 8.4).
- The facilities manager role has now been included from phases 7 to 10
- Some phases and activities have been renamed to provide clarity of activity and output required (see Table 8.5).
- Some elements of the DPM are illustrated through a practical example
### Table 8.4: Suggestions for improving DPM

<table>
<thead>
<tr>
<th>S/No</th>
<th>Recommendations for Improving the DPM</th>
<th>Reasons for including or not including Recommendations</th>
<th>Incorporated</th>
<th>Not Incorporated</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Structure of the DPM</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Change order of deconstruction matrix in phase 2</td>
<td>Yes, it was logical to do.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Change names of activities and outputs, and include activities and outputs in phases 4 to 7, Phase 9 and Phase 10</td>
<td>Yes, the change of names would better reflect the activities (see Table 8.5)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Include the outputs of each activity in the mapping of DPM</td>
<td>Yes, it would enable easy understanding of the outputs.</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>General suggestions for the activities</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Consider the percentages of materials and components that can be recycled or reused in the DPM activities.</td>
<td>It will be a useful addition to the activities but will greatly depend on the type of project and level of implementation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>It would be useful to consider the building system in the following ways: (a) the characteristics that would enable each building sub-systems to decompose; (b) the percentage of the materials and components to be used.</td>
<td>NO This is covered to some extent in the complimentary building decomposition model</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>In Phase 9 of DPM, consider the following: environmental evaluation; registry of materials; differentiate between recycling and/or reuse of materials and components; impacts of CO$_2$; and the value of materials (for example, the value of brick is infinite, and steel has a high recyclability value)</td>
<td>It would be a useful addition to the guide so as to facilitate reuse and/or recycling of a building and its components</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Consider the roles of Facility Manager (FM) from phases 7 to 9 especially at phase 9 and if possible include relevant activities</td>
<td>Included FM as part of the Actors responsible.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Consider economies of scale in terms of housing replication and different building types</td>
<td>Not necessary within the scope of research but important for future research work</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Consider linking the phases and activities of DPM to existing standards and tools developed to assist sustainable construction practice in the industry such as CDM regulations</td>
<td>Not necessary within the scope of research but important for future research work</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Consider how DPM will interact with different buildings' life spans, i.e. commercial, retail, listed building</td>
<td>Not necessary within the scope of research but important for future research work</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Consider focusing on refurbishment as opposed to complete deconstruction and possibly modular refurbishments</td>
<td>The DPM allows for both partial and full deconstruction</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 8.5 Suggested changes in the names of activities in DPM

<table>
<thead>
<tr>
<th>Proposed Name</th>
<th>New Suggested Name</th>
<th>Adopted</th>
</tr>
</thead>
<tbody>
<tr>
<td>Report on construction method</td>
<td>Report on construction method for deconstruction</td>
<td>Yes</td>
</tr>
<tr>
<td>Strategy for future use</td>
<td>Strategy for future reuse</td>
<td>Yes</td>
</tr>
<tr>
<td>Post-Construction Review-</td>
<td>Post-Construction Review-</td>
<td>Yes</td>
</tr>
<tr>
<td>(Summarise Lessons Learnt, Update Deconstruction Plan)</td>
<td>(Summarise Lessons Learnt, Update Final Deconstruction Plan)</td>
<td></td>
</tr>
<tr>
<td>Include output name in phase 9 and 10</td>
<td>Building decomposition (final) and Full Building decomposition (post-plan)</td>
<td>Yes</td>
</tr>
</tbody>
</table>

8.6.1 Practical example

A practical example is presented here to illustrate some of the activities and outputs at various stages of the DPM within the context of a building project. It is considered infeasible to present a detailed and complete practical example. This is because a full practical implementation of the model would involve a collaborative input by all the members of a project team. The following assumptions are made to illustrate these activities and outputs of the DPM:

- A client or developer has given a consortia of construction professionals a brief with the following requirements:
  - a 4 bedroom semi-detached house that can be converted into independent one bedroom apartments;
  - make provision in design for alternative reuse options that would reduce waste and encourage flexibility and adaptability; and
  - encourage the reuse of the building elements for future use of the building.

The practical example illustrates some elements of the DPM. These include:

**Phase 2.** Prepare deconstruction matrix for project (see table 8.6). The deconstruction matrix template is used to illustrate how each criteria can be identified in terms of the five main requirements. For example, in the four bedroom project, the design concept, the planning and function of spaces, the technology used for the materials is ‘high priority’.
These choices indicate that design options can include flexibility and adaptability to facilitate deconstruction.

### Table 8.6: Deconstruction Matrix Template

<table>
<thead>
<tr>
<th>Requirements Criteria</th>
<th>User</th>
<th>Design</th>
<th>Structure</th>
<th>Material/Component</th>
<th>Function of Spaces</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concept</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Process</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Strategy</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Planning</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Technology</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Method</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cost</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Durability</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sustainability</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- Medium priority
- High priority

**Phase 4. Prepare DFD checklist for outline conceptual design**

The output in this process phase is illustrated by showing the ground floor and first floor plan of the four bedroom with alternative layout options and change of use as the house can be converted into three independent one bedroom apartments (Figure 8.2 for the original plans and Figures 8.3 and 8.4 for alternative layouts). The approach and side elevations are shown in Figure 8.6 with bricks used as a finish. Bricks have a high recycling value and are reusable.

In addition, the panels used to fit-out the interior space are moveable and can be reused (see Figure 8.5). The materials used and the method used to fix the panels would facilitate deconstruction. Figure 8.7 and 8.8 show a detail of a typical panel with the grooves for easy assembly and disassembly. Typically building components (such as walls and floors) are manufactured with a standard dimension that relates to the horizontal and vertical layouts of a building. In this case, the wall partition is made up of several panels where the width and length of each panel is assumed to be measuring 900mm by 2100mm with the grooves indicating how the panels are clipped together.
Chapter 8: Evaluation of the Deconstruction Process Model

Figure 8.2 Sketch Plans of Four Bedroom House

Ground Floor Plan

First Floor Plan
Figure 8.3 Different Layout Options Showing Flexibility of the Design Approach
Chapter 8: Evaluation of the Deconstruction Process Model

Figure 8.4 Different Layout Options Showing Flexibility of the Design Approach
Figure 8.5 Three Dimensional illustration of movable panels
Chapter 8: Evaluation of the Deconstruction Process Model

Figure 8.6: Front and Side Elevations

(proprietary single ply membrane roofing with profiles @ 600mm c/c.)

brick finish
Figure 8.7: Details Showing the Panels

Figure 8.8 'A'Details Showing the Grooves for Joining the Panels
8.7 Summary

This chapter has presented the results of the evaluation of the DPM. The evaluation procedure sought to establish the suitability and practicality of integrating the process of deconstruction throughout the project delivery process. For this research, the evaluation approach used (as discussed in section 8.3.2) can be considered appropriate. It helped to examine all aspects of the DPM identified in the evaluation objectives and was successful in drawing out important issues (such as linking the DPM with other building requirements for sustainability). The highlights of the evaluation process can be summarised as follows:

- The evaluation questionnaire covered all aspects of the DPM that needed to be appraised. In addition, it encouraged participants to provide very useful and essential feedback.
- It used different approaches to suit different professional groups which meant gathering a wide range of opinions for verifying the understanding and acceptance of the DPM.
- Participants actively took part in the discussion sessions. This ensured a detailed feedback on the suitability and practicality of DPM in the project delivery process (see section 8.4.7).
- It provided a realistic assessment of the DPM by gathering feedback from participants with different background (particularly their considerable industrial experience and knowledge of the deconstruction process (see table 8.1).

Furthermore, the fact that most participants gave different suggestions on improvement and appreciated the possible benefits of the DPM was testament of the balanced feedback obtained and the appropriateness of the evaluation process. Thus, DPM as a framework can potentially be part of the available tools in industry practice to integrate the process of deconstruction into the building process. However, some of the limitations identified by the participants (such as the extra cost of using the DPM, adequate links to other tools) are valid but beyond the scope of this research. In addition, the suggestion for improvement and positive feedback has led to the development of an improved version of the DPM.
CHAPTER 9 SUMMARY AND CONCLUSIONS

9.1 Introduction

This chapter summarises the research findings and discusses how the aim and objectives of the research were achieved. The conclusions and limitations of the research are also presented. Finally, the chapter presents recommendations and suggestions for future research work.

9.2 Summary

The research aim was to develop a mechanism to integrate deconstruction into the project delivery process (see Section 1.5). The specific objectives based on the research questions (see Section 1.3) were:

- to review the concept of sustainable development and identify the current issues and implications for the construction industry;
- to review the concept of design for deconstruction (DFD) and related concepts in the construction industry;
- to obtain a broad-based knowledge from the construction industry in the UK on the awareness and practice of sustainability with respect to deconstruction;
- to undertake a case study of a practical example of implementing sustainable construction which reflects deconstruction principles in conventional building practice; and
- to propose a mechanism for the integration of deconstruction principles into the project delivery process.

The specific tasks undertaken during this research, to achieve the research objectives, are summarised below:

Objective 1: To review the concept of sustainable development and identify the current issues and implications for the construction industry.

The objective was realised through a broad-based review of the term 'sustainable development' from academic journals and conference articles, the Internet and government policy documents. The review focused on the following: the framework for
sustainability with respect to the three broad themes of social, environmental and economic issues; the definition and principles of sustainable construction; sustainable construction in the building process; and tools for implementing sustainability in construction practice.

Firstly, the review provided background knowledge and understanding of the requirements and goals for achieving sustainable development in any given industry. It discussed the issues that the construction industry is most likely to address within the framework of sustainability (see Section 3.3), vis-à-vis the three broad themes of sustainability, which are: social, environmental and economic dimensions.

Secondly, the application of sustainability principles in construction known as sustainable construction was reviewed. The definition and principles of sustainable construction were investigated. The review also focused on how the construction industry is implementing sustainable construction practice.

Lastly, the review discussed sustainable construction in the current building process and tools that the industry have developed to assist sustainable construction practice. The basis for using these tools to achieve, address and meet the requirements of sustainable construction was also appraised.

Objective 2: To review the concept of Design for Deconstruction (DFD) and related concepts in the construction industry.

The objective was realised through a review of journals and conference publications on deconstruction practice from both academic and quasi-regulatory organisations such as BRE and CIRIA.

Firstly, the various definitions of the term 'deconstruction' as suggested by researchers and practitioners in the construction industry were identified. The definitions provided the basis of exploring the role of deconstruction in sustainable construction practice. Specifically, the review on deconstruction highlighted the following: the benefits of deconstruction as against demolition practice; deconstruction as a strategy to minimise waste; and the opportunities and barriers of implementing deconstruction within the current building process.
Secondly, the review discussed the concept of design for deconstruction (DFD). The key issues discussed were the possibility of applying deconstruction through the design process, consideration of design principles that can facilitate DFD, assessment of the potential of DFD to encourage waste minimisation and reuse and recycling of building components and materials, and DFD as an aspect of building design that would facilitate sustainable design. The review also discussed existing concepts (such as offsite construction, open building approach) in construction practice that are related to DFD. Design for Disassembly in manufacturing was also discussed as it provided the basis to examining other industry practices on sustainable development practices.

Lastly, the enablers and barriers of integrating DFD into the project delivery process were discussed. The drivers for implementing DFD into the current building process were discussed with a view to identifying how to facilitate the integration process in conventional construction practice. The requirements for applying DFD in the design and construction process were also highlighted and discussed. Specifically, the potential benefits offered by DFD to achieve some aspects of sustainable construction (such as minimising waste and reducing the environmental impacts of buildings) and the most likely effective ways to integrate DFD were considered.

Objective 3: To obtain a broad based knowledge from the construction industry in the UK on the awareness and practice of sustainability with respect to deconstruction.

This objective was realised through a questionnaire survey with a cross-section of construction professionals (including architects, demolition contractors, engineers and project managers) in the UK. The overall results from the survey indicated that there was a general awareness of deconstruction and the possible benefits it offers the construction industry in achieving some aspects of sustainable construction practice. The key findings can be summarised as follows:

- construction professionals are aware of deconstruction principles and have used it on specific building projects on an ad-hoc basis;
- the decision to demolish and/or deconstruct a building mostly depends on the building owner’s decision rather than the building type and/or the structural form;
- there is insufficient information and knowledge currently available to facilitate the integration of DFD into the project delivery process; and
- the viability of integrating deconstruction into the project delivery process would depend mostly on legislation, additional building standards and cost implications.

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Objective 4: To undertake a case study of a practical example of implementing sustainable construction which reflects deconstruction principles in conventional building practice

The objective was realised by carrying out a case study of a building demonstration programme known as Industrial, Flexible, and Demountable (IFD) building which had integrated principles similar to DFD into the design and construction process. The aim was to investigate the implementation issues that are relevant to integrating deconstruction. From the investigation the following findings were made:

- to effectively integrate the principles of deconstruction throughout the project delivery process, it is necessary to formulate an underlying concept;
- in order to facilitate the integration of deconstruction principles into the building process, it is important to involve all construction professionals at the early stages of the design process;
- effective collaboration and planning between the construction professionals and developers (client) of a building project should ensure the implementation of deconstruction practice;
- it is important to provide a mechanism to guide the implementation of DFD into the project delivery process;
- legislation and standards are essential for ensuring participation and increased awareness of implementing a concept such as DFD into the building process; and
- through demonstration projects and other exemplar case studies, industry-wide interest and awareness can be stimulated regarding the possible advantages of deconstruction practice.

Objective 5: To propose a mechanism (with guidelines) for the integration of deconstruction principles into the project delivery process.

In meeting objective 5 of this research, a process model was proposed for integrating deconstruction into the project delivery process. The objective was realised from the following: literature review on process modelling and other existing construction process models; and using the findings from the questionnaire survey and the case study to structure and develop the model. The model called the Deconstruction Process Model (DPM) was intended to facilitate the implementation of DFD throughout the project delivery process. The key objective of the model was to provide guidance on how to
implement deconstruction principles at each stage of the design and construction phases of a building project. Thus, it is expected that the use of the DPM should offer an effective mechanism for the industry to integrate deconstruction throughout the project delivery process. This, in turn, would encourage sustainable construction practices such as the reuse and recycling of building materials and components and waste minimisation during the building process.

Finally, focus groups were organised through workshops to assess the suitability and practicality of using the DPM as a mechanism for integrating deconstruction into the project delivery process. The proposed model was modified based on the feedback from participants.

9.3 Conclusions

The following conclusions can be drawn from the research:

- review of existing literature in sustainable construction and deconstruction indicated that a number of factors (such as types of materials and components used, type of building foundation used, techniques and methods used to connect and assemble building components and the decision making process) can determine how best to integrate the concept of DFD into the building process;
- review of various concepts in construction similar to DFD (i.e open building, offsite construction and prefabrication) established that there is a body of knowledge available in construction practice that can facilitate the adoption of DFD principles into the building process;
- articulation of the requirements, drivers, enablers and barriers to integrating DFD into the building process in this research, provides further understanding and guidance on how building deconstruction can serve as a suitable option to building demolition that often generates construction waste.
- the results of the survey and the case study implied that developing an effective mechanism can potentially enhance and facilitate the integration of deconstruction principles into the building process;
- the feedback gathered during the evaluation process showed that there is a potential in the industry to explore the benefits of deconstruction practice if additional building regulations and legislation are established;
• integrating the concept of DFD into the building process can provide an effective means for the construction industry to realise sustainability principles such as reduction of waste generation and reuse of materials and building components;

• the Deconstruction Process Model (DPM) developed in this research, opens up new possibilities for leveraging the tools (such as BREEAM and LEED) that are already available in construction practice to implement sustainable building design;

• the Deconstruction Process Model (DPM) offers the industry a mechanism and the opportunity to further explore the process of facilitating building component reuse and recycling of building materials in construction practice; and

• the use of Deconstruction Process Model can assist construction professionals to take into consideration the design of buildings that can easily be disassembled and (as most existing buildings are not designed to be disassembled) take into account the possibility of their future reuse.

9.4 Contribution to Knowledge

This research has contributed to knowledge in three key areas. Firstly, it presented the context of sustainable construction in achieving sustainability, by showing the significance of considering deconstruction as one of the possible solutions to facilitate and promote the reuse and recycle of building materials and components. Some of the key issues identified include:

• there are a number of barriers and enablers of adopting design for deconstruction in current practice. These barriers (such as the fragmented nature of the construction process and the general attitudes of people to buildings would need to be address) in order to encourage adoption of DFD;

• existing concepts in construction (such as prefabrication, offsite construction and open building approach) provide a case for the possible adoption of deconstruction into the current building process; and

• the current information and data (that is methods and techniques) available on building materials and components would need to be improved to encourage the adoption of design for deconstruction.

Secondly, The Deconstruction process model was developed as a mechanism to integrate deconstruction into the project delivery process and demonstrated through a process model how best to implement DFD throughout the building process. The process
model added a ‘deconstruction stage’ to the conventional life cycle of a building project. The processes, sub-processes and activities and tasks were identified at this stage, can assist decision making at the end of buildings useful life. Thus, it provides an approach to assist (designers and building owners) on how best to address the difficulty in predicting the future reuse of a building and the options of recycling and reusing building materials.

Lastly, this research has implications for all the stakeholders in the construction industry that are involved in the continuous improvement (especially in the area of sustainability) of the building process. These include:

- **Clients, planners, and developers**: It raises the awareness of the benefits of sustainable design and the whole life cycle cost of a building. This can be seen as an additional value for reselling a building in future and reducing the environmental impacts of buildings when renovation or refurbishments are essential.

- **Designers (architects and engineers)**: It provides guidance towards careful considerations of the functionality of spaces and the buildability of a building in terms of it’s future reuse, operation, maintenance and how best to dispose of building materials and components to reduce environmental impacts.

- **Property Agents**: it provides the opportunity to promote the flexibility and adaptability of a building to meet potential tenants’ and buyers’ changing requirements of functional spaces in the future. For example, the owner can carry out quick conversions of a living room into a bedroom with minimal cost and disruption.

- **Facility Managers**: it provides the opportunity to manage a building in a sustainable way and could assist in developing action plans that enable best practice of measuring building performance in terms of its value for future use.

- **Government**: it can provide guidance on how best to formulate additional building regulations and standards that can promote sustainable design and encourage effective initiatives on how best to legislate for building components to be reused in new construction projects.

- **Manufacturers/suppliers**: it can promote and encourage a process whereby manufacturers are willing to ‘take back’ building components and materials and possibly facilitate the design and manufacture of components that can easily be reused and recycled.

- **Educational institutions**: the way in which most architectural and engineering curriculum are designed could be changed to reflect and encourage designers to
think of designing a building were its future reuse and disassembly is a priority at the conceptual stage of building design. For example courses in architecture can include sustainable design and deconstruction.

- IT tool developers: the development of a software tool, which can facilitate the implementation of deconstruction in the project delivery process so as to: predict the future scenarios of how a building can effectively be disassembled for reuse; recognise and illustrate different parts of a building system and manage the complexity of assessing the information and data stored by different construction professionals.

### 9.5 Limitations of this Research

This research, like any other, has limitations in terms of scope, the choice of research methodology and the generalisation of the findings. Its key limitations include:

- the Deconstruction Process Model (DPM) was developed in a paper-based format and its practicability described through a presentation to industry practitioners. The key focus of the evaluation process was to ascertain the relevance of the DPM in addressing some aspects of sustainability especially as it relates to deconstruction. However, an IT-enabled format may have facilitated a wider industry exploration of the potential benefits of the DPM;
- the evaluators of the Deconstruction Process Model (DPM) had different suggestions on how best to practically implement the DPM. Their interest was reflected in their desire to see additional sub-activities that link DPM with existing sustainable building design tools. However, this expectation from the participants should be seen against the background that the DPM is essentially ‘a model process’ developed as a mechanism to effectively assist in integrating the concept of DFD within the building process.
- It was not feasible to implement the DPM in a real building project in this research due to time constraints. However, the evaluation of the DPM provided a good platform to explore how practicable the DPM can be used to provide a strategic mechanism for integrating deconstruction principles throughout the project delivery process; and
- in order to explore the complete integration of deconstruction principles throughout the project delivery process in construction practice, there is a need for the industry to adopt new approaches to designing buildings. For example,
providing additional legislation with building standards to support deconstruction practice and providing training that can change the existing perception of how buildings are designed.

9.6 Recommendations for Further Work

There are several elements of further work that can be undertaken based on this study. These include:

- Assessing further the effectiveness and appropriateness of the DPM proposed in this research by using it to implement a life building project from inception, through design and construction, and including operation and maintenance. This is essential in generating empirical confirmation of its benefits, enhancing its validity and suggesting further improvement for practical use.
- Developing and adopting the DPM from a paper-based format into an IT based format. This will provide an effective means to store data and capture knowledge that can be used to further explore various aspects of deconstructing different types of buildings. The components of the IT based format can include:
  - An email software to facilitate communication such as Ms outlook
  - A database software for storage and retrieval of information such as Ms Access
  - A link to computer-based drawing tools such as Autocad to facilitate revision and storage of drawings
- Using the principles and requirements of the Building Decomposition Model (BDM) to explore the effectiveness of collaborative work amongst construction professionals in facilitating building deconstruction.
- Assessing the potential of DPM as a mechanism to encourage the basis of a broad based standardisation of implementing building deconstruction:
  - by exploring new additional sub-activities to facilitate a link to existing tools such as BREEAM; and
  - enhancing the guidelines for DPM by associating it with existing regulations such as CDM regulations and BS8900 (2006) sustainable development guidance.
- Using the DPM to explore the potential of engaging manufacturers and suppliers of building materials at the early stages of the project delivery process (especially at phase 4 to phase 6). This is essential in assessing the following:
Chapter 9: Summary and Conclusions

- the design and development of building materials and components that can easily be disassembled;
- exploring the potential of reusing 'the same building materials' in a building during refurbishment and change of use in the future and
- recycling building materials for new building projects.

Addressing the barriers that would prevent design for deconstruction to be adopted as a mainstream concept in building design. This because it can facilitate and assist the design of sustainable buildings. Thus, more research can be undertaken to investigate and understand the barriers and ways to overcome them.

9.7 Closing Remarks

The design of buildings that can easily be deconstructed at the end of their useful life is not normally part of conventional construction practice. Through the emerging concept of Design for Deconstruction (DFD), the construction industry is beginning to take account of building deconstruction. This is essential as it offers the industry the potential benefit to reuse and recycle building components and materials. This benefit would facilitate waste minimisation and reduce extraction of resources, which are part of sustainable construction practice. This research has made a fundamental contribution to the sustainability agenda in construction by developing a deconstruction process model for facilitating the integration of deconstruction principles into the project delivery process in construction. Adoption of the models, guidelines and recommendations made in this thesis will enable the construction industry to address a key aspect of sustainable construction.
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References


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http://www.civil.ubc.ca/~tfroese/pubs/fro95b_process_models/fro95b.html (Accessed April 2006)


Appendices

Appendix A: Interim publications from Research


## Appendix B: Sustainability Issues in the Construction Industry

<table>
<thead>
<tr>
<th>SOCIAL</th>
<th>ENVIRONMENT</th>
<th>ECONOMIC</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>User Comfort/Satisfaction</strong>&lt;br&gt;The term 'user friendly' is often associated with the design of products and services that are acceptable to users. This acceptance by users can be translated to the comfort and satisfaction they get from using these products/services. In building design, the room temperature and the interior layout could determine the level of comfort and satisfaction of the occupants.</td>
<td><strong>Design and Operation</strong>&lt;br&gt;A significant sustainable challenge is to minimise the ecological pressure imposed by urbanisation while meeting people's living, working and recreational needs and enhancing the quality of urban life. Incorporating environmental conscious design through energy saving measures (such as natural lighting and ventilation) can reduce operating costs of buildings.</td>
<td><strong>Appropriate Employment</strong>&lt;br&gt;Through construction activities, employment opportunities are often created. This employment if appropriate to the neighbourhood boosts the economy of the area.</td>
</tr>
<tr>
<td><strong>Public Amenity</strong>&lt;br&gt;Public amenities in cities provide a pleasant or useful feature of a place. For example, design considerations which include parks and open spaces, creates a great atmosphere in the city, where people can relax and avoid the stress of cities. This encourages socialising and gives a sense of community.</td>
<td><strong>Transport Impact</strong>&lt;br&gt;The transportation of goods and people is very energy-intensive. This has a negative impact on the environment. With the growing demand for mobility, alternatives have to be sought. Rethinking the design of transportation systems and alternative sources of fuel for vehicles may facilitate a sustainable environment.</td>
<td><strong>Ethical and Equity Issues</strong>&lt;br&gt;Ethical and equity issues are dependent on the moralistic thinking of sustainable development. For example, ensuring that all neighbourhoods have a relatively equal standard of living, promoting equality in access to facilities and services, good environmental quality and social justice.</td>
</tr>
<tr>
<td><strong>Crime Prevention</strong>&lt;br&gt;Crime within cities has become increasingly a great concern to governments' and residents'. Thus, the importance of building design in crime prevention cannot be underrated, as poorly designed and unplanned areas in cities are often associated with high crime incidents. In addition, design considerations that involve proper planning and security features within a building could discourage crime and bad behaviour.</td>
<td><strong>Visual Impact</strong>&lt;br&gt;The visual impact of a building in the built or natural environment is significant. It may influence the way people perceive an area. It then becomes necessary to construct and arrange buildings, in such a way that it visually enhances a neighbourhood or city.</td>
<td></td>
</tr>
<tr>
<td><strong>Planning Issues</strong>&lt;br&gt;Existing planning policies and regulations within cities often determine the layout of buildings and locations of various building types. Building play a significant role in the overall structure of a city. Thus, incorporating planning policies and regulations that promote social interaction through building design would enhance sustainability.</td>
<td><strong>Noise Impact</strong>&lt;br&gt;Traffic congestion within cities and towns create considerable noise. This can affect the well-being of residents. Construction sites tend to generate noise. Thus, it is essential for designers to minimise congestion and noise through building design.</td>
<td></td>
</tr>
<tr>
<td><strong>Archaeology and Heritage</strong>&lt;br&gt;Most archaeological findings during excavation are unique and constitute a historical heritage of a place. It is an important source of information, which can determine the level of construction activity carried out within that area.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Community Involvement

The community in every society could play a vital role in the building of cities if consultation is carried out during the development process. Community inclusion in the design process will involve responding and respecting the opinions of those who live in the community or use the building on a daily basis. This means that local residents and employees of a company are consulted during the design and construction process.

Social Inclusion

Social inclusion involves recognition of people's values and behaviour. A social approach to building design would influence the way people conduct their lives, the duration of their lives and social behaviour.

Health and Welfare

The spatial planning of a building's interior and the ventilation system can affect the health and welfare of its occupants positively or negatively. Thus, incorporating design considerations (such as landscaping with trees for clean air and open spaces for opportunities for bicycle or walk) would provide a healthy atmosphere for building occupants.

Access

Access into buildings is a very important aspect of the design and construction process. Provision of easy access for occupants would add to the comfort and effective ingress to buildings. If properly planned could influence and contribute to effective building use.

Land Use

Most construction activities are carried out on land and materials used to build are extracted from the earth. There is a constant need to provide adequate infrastructure by the construction industry to support population growth within cities. This demand for buildings or infrastructure poses a threat to the environment. Sustainable development is about ensuring a cautious use of land and the natural resources whilst carrying out construction activities.

Ecology

Wildlife and flora are seen as resources that need to be conserved, as most of it is not renewable. The impact of construction on ecology is enormous. To minimise pollution and destruction of wildlife and flora, renewable and non-renewable resources should be utilised more efficiently in the built environment during construction activities.

Air Quality

The construction industry is one of the major energy consumers. Energy use during construction activities such as production of materials and transportation of materials to construction sites, generates pollution. This pollution damages the quality of air in the environment.

Water Quality

Rainfall every year produces adequate clean water. However, uneven distribution and pollution threaten to create serious water crisis in most cities. Producing portable water and treating wastewater creates a challenge of balancing activities within the environment. This relates to the provision of infrastructure, which would enable a clean and affordable water system. Thus, it is essential to design for increased water efficiency in buildings and water conservation in the built and natural environment.

Social Benefits/Costs

The construction industry through its activities can boost the economy of a local area. For example building refurbishment can save the cost of constructing a new building. Reuse benefits are seen as not only in potentially lower costs for typical end-user, but also in the value of retaining the style and character (heritage features) of buildings, in solid build qualities, and in the appropriateness of their location (Ball, 1999).

Transport (Infrastructure)

An efficient and good transport system in any nation will contribute to the economic prosperity. Economic growth and activity can also be recognised through the development and demand on the transportation systems. The various interest groups (such as urban planners, architects, engineers and the government) would need to take into consideration population growth and sustainability of the transportation system.

Employment/Skills Base

Construction activities are known to bring about significant economic growth (investment) and create considerable employment opportunities. The multiplier effect is such that one job in construction gives rise to two further jobs in any given economy. Also, adequate training of construction workers may contribute to good economic development, since skilled workers can help reduce costly mistakes that occur on construction sites. They can also carry out the amount of work required in a shorter period of time.

Visibility

Designing and constructing buildings that is useful for the present and the future. This will generate economic opportunities within a local area.
Appendix C: Guide for Questionnaire Survey

**Survey on design for deconstruction (DFD) in the construction industry**

**General Guidance**

This independent survey is part of a research programme at Loughborough University. The purpose of the survey is to establish the current industry practice on DFD. For the purpose of this research, "Deconstruction" is defined as selective dismantling or disassembly of building materials and components in order to encourage the efficient reuse or recycling of building materials and components, and to assist in waste minimisation in the construction and demolition (C & D) process. Please indicate your response to most questions by ticking or filling the box. There is also the opportunity for you to add your comments. Your response to this questionnaire is highly valued and will be treated with the strictest confidence. The information provided will be used for academic purposes only. Please address any queries to: Ms Chinwe Isiadinso; E-mail: isiadinso@lboro.ac.uk; Telephone: 01509 223 780

**Part A - BACKGROUND INFORMATION**

Provide contact details if you wish to receive a report/paper on the survey results.

Name (Optional): 

Company Name and Address (Optional): 

Tel: 

E-mail: 

Date: 

I. What was/is your designated role in a building project? (Choose only one)

- [ ] Architect
- [ ] Civil engineer
- [ ] Contractor
- [ ] Structural engineer
- [ ] Quantity surveyor
- [ ] Building services engineer
- [ ] Other (please specify)

II. How long have you worked in the construction or demolition industry? □ Years

**Part B - THE PROCESS OF DECONSTRUCTION**

1. To what extent do you consider deconstruction as an alternative to demolition?

- [ ] Not at all
- [ ] To some extent
- [ ] To a great extent
- [ ] Always

Please explain why this is so:

2. In the last 5 years have you specified or used any recyclable material in new construction or refurbishment projects?

- [ ] Yes
- [ ] No

If yes, please state what type of recyclable material or component. If no, please suggest what has prevented you from doing so:

...
3. Considering the following types of buildings and materials, please specify the number of projects in the last 5 years for which you witnessed or carried out partial demolition or refurbishment. (Please indicate the type of material used for construction from the following: Brick, timber, concrete, steel, glass and any other).

<table>
<thead>
<tr>
<th>Type of building</th>
<th>No. of Projects</th>
<th>Construction materials used</th>
</tr>
</thead>
<tbody>
<tr>
<td>Residential &amp; Housing</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Commercial Retail</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Public</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Office</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Institutional</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Industrial</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Leisure</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other Specify</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

4. Please indicate the 3 most likely building types to be deconstructed (Rank from 1 to 3)

5. Considering the following principles of deconstruction, which principles have you employed in your projects?

<table>
<thead>
<tr>
<th>Principles of deconstruction</th>
<th>Scale 5=Always, 4=Very often, 3=Fairly often, 2=Sometimes, 1=Never</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design for flexibility and adaptability</td>
<td>5 4 3 2 1</td>
</tr>
<tr>
<td>Design to facilitate disassembly logistics</td>
<td></td>
</tr>
<tr>
<td>Design using prefabricated, preassembled and modular units</td>
<td></td>
</tr>
<tr>
<td>Design with the intention for materials and components to be reused in future building projects</td>
<td></td>
</tr>
<tr>
<td>Minimizing the use of building components and materials</td>
<td></td>
</tr>
<tr>
<td>Recommending connection details that are simple and standardised</td>
<td></td>
</tr>
<tr>
<td>Specification of fittings, fasteners, adhesives and sealants that enable ease of disassembly</td>
<td></td>
</tr>
<tr>
<td>Using simplified and separate building system</td>
<td></td>
</tr>
</tbody>
</table>

6. Does your role in a building project allow you to influence the adoption of deconstruction principles in conventional design and construction practice?

☐ Yes  ☐ No

If yes, please state how, if not what are the constraints?
Part C - THE DESIGN PROCESS

7. Please rate the importance of each of the following criteria as they apply to design for deconstruction. (Please tick \( \Box \) in order of importance)

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Scale: 5=Definitely important; 4=Probably important; 3=Probably unimportant; 2=Not important; 1=No opinion/don’t know.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Internal Criteria</td>
<td></td>
</tr>
<tr>
<td>Type of building</td>
<td></td>
</tr>
<tr>
<td>Legislation and Standards</td>
<td></td>
</tr>
<tr>
<td>Structure of the building (Shape, size, volume)</td>
<td></td>
</tr>
<tr>
<td>Space layout</td>
<td></td>
</tr>
<tr>
<td>The materials and components available</td>
<td></td>
</tr>
<tr>
<td>Technology (Building technology, Information technology)</td>
<td></td>
</tr>
<tr>
<td>Client</td>
<td></td>
</tr>
<tr>
<td>Other (Specify)</td>
<td></td>
</tr>
<tr>
<td>External Criteria</td>
<td></td>
</tr>
<tr>
<td>Location of a Building</td>
<td></td>
</tr>
<tr>
<td>Quality of information (construction drawings, maintenance drawings)</td>
<td></td>
</tr>
<tr>
<td>Time and cost</td>
<td></td>
</tr>
<tr>
<td>Markets for reusable, recycled materials and components</td>
<td></td>
</tr>
<tr>
<td>Skills of workers</td>
<td></td>
</tr>
<tr>
<td>Other (Specify)</td>
<td></td>
</tr>
</tbody>
</table>

8. The choice of a structural form (volume, size, shape) at the design stage of a building project could influence the adoption of deconstruction principles?

- [ ] Strong Influence
- [ ] Influence
- [ ] No Influence
- [ ] Uncertain

Please explain why this is so:

9. Considering the list of materials below, please rate its potential in facilitating the adoption of DFD into the building design process (Please tick \( \Box \) in order of potential)

<table>
<thead>
<tr>
<th>Material</th>
<th>Scale: 5=Definite potential; 4=Probably potential; 3=Probably not potential; 2=Not potential; 1=No opinion/don’t know.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concrete</td>
<td></td>
</tr>
<tr>
<td>Bricks</td>
<td></td>
</tr>
<tr>
<td>Timber</td>
<td></td>
</tr>
<tr>
<td>Sheel</td>
<td></td>
</tr>
<tr>
<td>Glass</td>
<td></td>
</tr>
<tr>
<td>Other (Specify)</td>
<td></td>
</tr>
</tbody>
</table>

Comments:
10. Considering the typical parts of a building, please rate in order of importance, which part of the building if designed differently could facilitate the ease of deconstruction? (Please tick (v) in order of importance)

<table>
<thead>
<tr>
<th>Typical parts of a building</th>
<th>5</th>
<th>4</th>
<th>3</th>
<th>2</th>
<th>1</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roof</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Walls</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Floors</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Services</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Doors and windows</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other (Specify)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

11. Is your organisation currently making any provisions during the design process to incorporate deconstruction principles?

☐ Yes ☐ No

If yes please explain how. If no please suggest what factors are hindering this?

12. What are the key issues that your organisation would need to address to facilitate the better integration of DFD into the building design process?

Please explain below

13. Do you have adequate access to appropriate tools/techniques/methods (such as BREEAM, LEED) for incorporating deconstruction principles into the design process?

☐ Yes ☐ No

If yes, please state the tools/methods/techniques
14. What incentives (for example building technology, legislation) would you require to adopt deconstruction principles in the design process?

15. Have you received any feedback from building or demolition contractors on the 'ease of disassembly' of your building design?  
   Yes  No  
   If yes, please state in which area of design.

16. If a tool is developed to facilitate the adoption of DFD in the design process, what kind of features would you like included? (Please rank in order of importance)
1.  
2.  
3.  
4.  

17. If you have any further thoughts or comments please use this box below.

Your co-operation in completing the above questionnaire has being greatly appreciated. Please send the completed questionnaire in the stamped addressed envelope provided to: Ms Chinwe Isiadinso, Department of Civil & Building Engineering, Loughborough University, Loughborough, Leicestershire, LE11 3TU, UK or if you received it by e-mail send it to c.isiadinso@lboro.ac.uk. Thank you.
Appendix D: Guide for Case study

<table>
<thead>
<tr>
<th>Name</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Position</td>
<td></td>
</tr>
<tr>
<td>Experience in years</td>
<td></td>
</tr>
<tr>
<td>Company Details</td>
<td></td>
</tr>
<tr>
<td>Name</td>
<td></td>
</tr>
<tr>
<td>Address</td>
<td></td>
</tr>
<tr>
<td>Contact</td>
<td></td>
</tr>
<tr>
<td>Office</td>
<td></td>
</tr>
<tr>
<td>Fax</td>
<td></td>
</tr>
<tr>
<td>Mobile</td>
<td></td>
</tr>
<tr>
<td>Date</td>
<td></td>
</tr>
</tbody>
</table>

A. ROLE, PROJECT GOALS & OBJECTIVES
1. How long have you been involved in the IFD programme and when did it start?
2. Is there a designated time frame for completion?
3. Describe your day to day tasks?
4. What are the expected targets and results?
5. What are the major drivers for implementation?
6. What were the initial barriers encountered during execution?
7. What measures have been taken to overcome these barriers?

B. DESIGN CONSIDERATIONS
1. What are the main design principles utilised?
2. What specific design approaches have been applied?
3. What structural elements have been integrated in the design?
4. Did the conventional design process have to be changed to achieve specific design principles?

C. STRUCTURAL REQUIREMENTS
1. What specific structural considerations were applied to achieve the overall objectives of the project?
2. Can the structural form used ensure disassembly or deconstruction?
3. What measures are in place to ensure structural stability to during disassembly?
4. Describe the process in place to dismantle the structure at the end of its useful life.

D. CONSTRUCTION METHOD
1. Describe the construction method used;
2. What is unique or significant about this construction method?
3. Describe how this unique construction method would assist in achieving the overall objectives of this project.
4. Describe the difference between the method of construction used and conventional construction methods.
5. What safety measures have you adopted?

E. BUILDING COMPONENTS AND MATERIAL REQUIREMENTS
1. What specific steps have been taken to ensure the flexibility and adaptability of the building materials and components?
2. What building components and materials can be reclaimed or reused in a new design
3. What provision has been made in the design to ensure reuse of components and materials?
4. How has the disassembly potential of building components and materials been assessed in this project?

F. THE FUTURE AND SUSTAINABILITY CONSIDERATIONS
1. What provisions have been made in the project to achieve sustainable construction principles?
2. What are the benefits of this project to the future of DFD in the construction industry?
3. What are the lessons learnt in the method of construction that can be transferred to future construction projects?
4. What measures have you put in place to capture and sustain best practice?
5. What systems are in place to ensure ease of disassembly in the future?
Appendix E: Guide for Evaluating the Deconstruction Process Model

Evaluation Questionnaire

Part A - Background Information
Name of respondent (Optional):
Company Name and Address (Optional):
Tel:
E-mail:
Background of Respondent

Part B. Evaluation of Deconstruction Process Model

Please tick the box that best represents your opinion of the question, where:

1: Poor 2: Fair 3: Good 4: Very Good 5: Excellent

1. Effectiveness
(a) How well does the DPM represent sustainable construction issues?
(b) How effective is the DPM in the design process relating to reuse and recyclability of building materials?
(c) How suitable is the DPM for integrating deconstruction into the project delivery process?

2. Functionality
(a) To what extent does the DPM represent a contribution to the sustainable construction agenda?
(b) To what extent do you think the DPM would facilitate planning & implementation of DFD in construction practice?
(c) Do you think the DPM can help in reducing design and construction waste in construction projects?

3. Coverage and Scope of the DPM
(a) How well does the DPM cover the different stages of the project delivery process?
(b) How well have the stages/activities captured and integrated the concept of deconstruction into the building process?
(c) To what extent has DPM captured the overall essence of the sustainability issue?

4. Ease Of Use/User Friendliness
(a) Is the format easy to understand
(b) How easy is it to use the DPM

Page 1 of 2
1. Would you use or recommend using the DPM? YES/NO
   If yes, at what stage and during what activities

2. Which parts of DPM impressed you most and Why?

3. Which parts of the DPM did not meet your expectations? Why

4. In your view what are the potential benefits of DPM?

5. What new activities need to be added and how can DPM be improved?

Thank you for completing the Questionnaire
Appendix F: Summary of the Deconstruction Process Model

Deconstruction Process Model

Background

Title of Research Project - Design for Sustainable Construction: Integrating Deconstruction Into the Project Delivery Process.

Sponsor: Engineering and Physical Sciences Research Council (ESPRC).

Definition: Within the context of this project, 'Deconstruction' is defined as the selective dismantling or disassembly of building materials and components to encourage the efficient reuse or recycling of building materials and components, and to assist in waste minimisation in the construction and demolition (C & D) process. It has been identified as one of the possible alternatives to 'building disposal' instead of demolition.

Scope of the model

The main focus of the model is on new construction. However, the model can be utilised in facility management, operation and maintenance, and refurbishment of buildings. It can be adapted to different building types and use activities (relating to the appropriate functional units). It should also serve as a unified approach that would guide practitioners on how best to assess each stage of the project delivery process. This should assist in facilitating the reuse or recycling of building components and materials. (see attached for the first level of the Deconstruction Process Model).

Why use “Deconstruction Process Model” in Construction Management?

To facilitate the consideration of a building's adaptability and reuse or recycling of building materials/components by practitioners at the early stages of the design process and throughout the project delivery process.

Potential Benefits of Using the Model

- Allow practitioners to manage and co-ordinate the process of design for deconstruction (DFD) in a construction project from the early stages
- Provide guidance for practitioners to effectively focus on aspects of the building process that would encourage adaptable reuse or recycling of building components and materials.
- Assist practitioners in managing and integrating the complex and dynamic nature of sustainable construction practice.
Implement Plan for Building Dom:omlK'sition

Phase 0: DEMONSTRATING THE NEED

Phase 1: CONCEPTION OF NEED

Phase 2: OUTLINE FEASIBILITY STUDY & OUTLINE FINANCIAL AUTHORITY

Phase 3: CONCEPTUAL DESIGN

Phase 4: FULL CONCEPTUAL DESIGN

Phase 5: COORDINATED DESIGN, PROCUREMENT & FULL FINANCIAL AUTHORITY

Phase 6: CONSTRUCTION

Phase 7: OPERATION & MAINTENANCE

Phase 8: COORDINATED DESIGN, PROCUREMENT & FULL FINANCIAL AUTHORITY

Phase 9: CONSTRUCTION

Phase 10: Rebuilding, Restoration, Construction
Appendix G: Modified Version of the Deconstruction Process Model

<table>
<thead>
<tr>
<th>Pre-Project Phase</th>
<th>Design Phase</th>
<th>Construction Phase</th>
<th>Post-Construction Phase</th>
<th>Deconstruction Phase</th>
</tr>
</thead>
</table>

**Process Sequence:**
This process map shows activities that may be undertaken during the phase. It is not intended to suggest a prescriptive sequence of events. (See PPD Guide for details on customising the maps for specific projects/organisations.)

**Lexicon:**
- Level 1
- Logical dependency between activities (Suggested - not prescriptive)

[Diagram and detailed text not included in this format]
Phase 1: Prepare Deconstruction Criteria for Project

**Lexicon**

**Process Diagram**

**Deliverable**

**Legend**

**Summary**

This process diagram illustrates the steps involved in preparing deconstruction criteria for a project. It includes the following activities:

1. **Deconstruction Management**
   - Identify the drivers for deconstruction
   - Specify the deconstruction aim and objectives
   - Identify how to implement deconstruction at all stages

2. **Deconstruction Planning**
   - Define the deconstruction need/function specific to your project
   - Consider the design approach for deconstruction (influence design sequence to be used)
   - List the principles of deconstruction that are applicable to the project (e.g., specification of modular units)

3. **Deconstruction Execution**
   - Identify opportunities to implement a deconstruction plan
   - Identify the criteria to facilitate PFD in the design process
   - Identify criteria to facilitate DFD in the design process

4. **Deconstruction Management Plan**
   - List objectives of deconstruction (e.g., propose extent of deconstruction: partial or full)
   - List the drivers, especially environmental, social, economic, and others

**On-Going Phase Activities**

- See separate guide for details

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Appendices
Phase 3: Prepare Deconstruction Plan

- Prepare DFD concept design brief with overall project design criteria
- Define the design methodology to be used in the project
- Check design methodology is consistent with deconstruction matrix
- Define the environmental aspects that are significant
- Review site limitations with environmental benefits
- Site Plan and Analysis Report
- Waste Management Plan
- Prepare CBA and Advice sheet about the issues that relate to project
- Plan CBA
- Identify the CBA of deconstruction
- CBA Report for Deconstruction Plan Outline
- Undertake Cost Benefit Analysis (CBA)
- Undertake Environmental Appraisal and Assessment
- Consider DFD Design Concept
- Deconstruction Management

Lexicon

- Process Overview:
  - Present Objective of the Process
  - Process Overview
  - Process Activities
  - Input/Output
  - Data Flow Diagram
  - Activity Diagram
  - Process Sequence

- Resources:
  - Human Resources
  - Material Resources
  - Financial Resources

- Diagrams:
  - Control Chart
  - Flowchart
  - Logic Diagram

- Data:
  - Input Data
  - Output Data

- Glossary:
  - Key Terms

- Notes:
  - Additional Notes

- References:
  - Bibliography
  - Further Reading

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Phase 5: Prepare DFD checklist for Full conceptual design

Select design approach for project

Incorporate design approach with DFD concept options

Define criteria for selection of each DFD concept option

Review architectural and structural elements considered

Assess architectural and structural element stability issues

Evaluate the benefits and drawbacks of architectural/structural elements chosen

Structural report (update)

Consult with suppliers/manufacturers and establish communication methods

Review and identify construction methods available with project targets & goals

Draft Construction Method for Construction (Initial)

Appendices

Lexicon

Level 1

Level 2

Analysis

Design

Construction

Operation

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Appendices

Phase 6: Assess extent of DFD Integration including assembly etc in Final Design

- Develop Strategic Integration Plan For DFD
- Complete DFD Design Proposal
- Finalise Cost Benefit Analysis (CBA)
- Finalise DFD Design options plan
- Assess deconstruction costs of design options
- CBA Report for Deconstruction Plan (Fine)
- Full Building Demolition Plan (updated)
- Identify benefits of deconstruction options
- Finalise CFA for design options
- Evaluate DFD Design options with suppliers and manufacturers
- Final report for deconstruction plan
- Ensure all stakeholders agree and approve plan (including experts)
- Review all issues for implementation scoping site limitations, environmental benefits/requirements
- Check the proposed DFD option with the overall design objectives for the project

On-Going Phase Activities - See separate guide for details

Lexicon

Process Control
- Work Sequence
- Revised
- DFD - Data Flow Diagram
- DFDC - Deconstruction Consultant

Notes
- The process map shown indicates that change undergone during the phase. It is not intended to suggest a prescriptive sequence of events. See PCI Guide for details on supervising the implementation for specific projects/organizations.

References

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Appendices

Phase 7: Produce Deconstruction Plans & Method Statements

Deconstruction Management
- Schedule Of Deconstruction

Deconstruction Management
- Sequence Of Assembly And Disassembly

Deconstruction Management
- Construction Techniques And Method Applicable

Prepare final drawings for approved EPC design option
7.1.1

Organise and facilitate the techniques and methods to be used for construction
7.2.1

Propose sequence of deconstruction for approval
7.3.1

Verify the feasibility of joints and ease of deconstruction
7.3.2

Verify the technique and methods with the deconstruction matrix
7.3.3

Prepare the construction method for deconstruction (final)
7.3.3

Propose construction methods and techniques to be used
7.2.2

Deconstruction assembly and disassembly drawing plan
7.2.2

Prepare sequence of assembly for elements
7.2.1

Coordinate any last-minute changes to ensure accurate implementation
7.1.2

Integrate Risk Assessment (baseline)

Deconstruction Management

Lexicon

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Phase 8: Check Compliance of Construction Method with Deconstruction Plans

Deconstruction Management
Monitor Construction Works

Management
Manage The Assemble Process

Verify agreed method of construction is implemented

Ensure any changes to construction works/methods are in line with deconstruction goals and plan

Ensure that check list for DMS is implemented according to plan

Check List of Actual Construction Work

Monitor the assemblage of building subsystems to ensure compliance with deconstruction plan

Manage and coordinate the off-site assembly and delivery of prefabricated components

Ensure feasibility of interfaces between building subassemblies

Appendices

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