REPORT

BUILDING DECONSTRUCTION
Foreword

This study forms part of the outputs of the author’s fellowship research project. The author was awarded the prestigious 7th CIB Gyula Sebestyen Young Researcher’s Fellowship 2001 by the International Council for Research and Innovation in Building and Construction (CIB). The fellowship was awarded for a research project called “Realising the full potential of the secondary construction materials market: an eye opener for South Africa”.

The study was conducted at the M.E. Rinker Sr. School of Building Construction, University of Florida, Gainesville, Florida, USA. It was conducted using three approaches viz. a desktop study of current information, interactions with members of the CIB Task Group 39 of which the author is a member and site visits.

This study provides a comprehensive summary of the concept of building deconstruction. The report has two main objectives i.e. to consolidate current knowledge in the field of building deconstruction into one short, but comprehensive document and to introduce the concept of building deconstruction to developing countries that may not be aware of it as yet.

The report is intended to be an easy reference document for decision makers in government, the construction industry particularly the demolition sector and waste management.
Acknowledgements

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Executive Summary

The advancement of humankind from the Stone Age, to the Iron Age and to the Information Age has improved our quality of life and has enabled us to live sophisticated lives with things increasingly becoming just a touch of a button away. Unfortunately with these advances came consequences. The construction industry has made a significant contribution to the current situation. Until recently, the use of natural resources and the abuse of the environment have been dismissed as “costs of development”. Many of the environmental costs of construction processes such as extraction, production, operation and maintenance, demolition and disposal have yet to be accounted for.

In recent years, the construction industry has realised a need to be environmentally responsible and has adopted activities and processes that minimise the negative environmental impacts. To the traditional criteria of performance, quality and cost for building systems (products or services) have been added a set of sustainability criteria that focus on the environmental and social aspects. This represents the concept of “green” or sustainable construction.

Building deconstruction can play a role in the drive towards environmental responsibility and can help mitigate some of the current problems. Deconstruction is a new technique that is based on the old practice of dismantling buildings to enable waste materials salvage for reuse and recycling. Deconstruction can help divert waste material from landfill sites, thereby saving landfill airspace. The salvaged waste can be converted to useful secondary materials and develop a new resource pool for the construction industry. This will ease the burden on virgin materials and help preserve natural resources. Furthermore, the use of secondary materials will conserve the embodied energy of those secondary materials and reduce the need for more energy consumption during virgin material extraction, production and supply.

Kibert developed a model that incorporates principles of sustainable construction in the traditional life cycle assessment model for construction. The model presents the sustainability principles that must be applied to the resources used in buildings at the various stages of a building’s life. This model can be used to locate building deconstruction in the theory of sustainable construction. The ease of deconstruction is determined by the flexibility of the building, which in turn depends on the initial design of the building elements. Design for deconstruction deals with the design of buildings for easy recovery of building components and materials for reuse and recycling during the operation & maintenance and the building removal stages.

To summarise the key aspects of building deconstruction:

- Building deconstruction is concerned with the dismantling of buildings to maximise material salvage for reuse. This technique can be easily located in the model for sustainable construction, which presents sustainability principles that need to be applied to the resources used in a building at the various stages of a building’s life.
- Building deconstruction is not only a technique for building removal that can be used to improve the performance of demolition contractors, but it can also be used as a waste minimisation strategy to reduce the waste generated by the construction industry, it can be used as an urban renewal tool to help dismantle, renew and reuse old and abandoned buildings, and it can also be used as a community economic
regeneration strategy to help create employment, local businesses and use local resources.

- Salvaged building materials can serve the low-end markets of low-income communities that are looking for affordable building materials as well as the high-end markets of discerning buyers that are looking for quality in salvaged materials. In addition, a new breed of markets are developing which consists of “green” clients and practitioners that want to develop “green” buildings out of commitment to environmental responsibility in construction.

- The process of deconstruction is simply ‘construction in reverse’ and predominantly uses labour intensive methods. This makes it a good tool for training workers in construction trades. This has two main spin offs for the construction industry, i.e. it creates a large resource pool for labour and can absorb excess labour from the construction industry.

- Because deconstruction is a labour intensive activity, labour issues, environmental issues and occupational health and safety issues require special attention.

- If feasible, building deconstruction can support a secondary construction materials market and guarantee the supply of secondary materials to meet the demand.

- Designers need to increasingly consider design for deconstruction during the design stage of a building because the decisions made during design affect the deconstructability of a building at its end-of-life. (Incorporating design for deconstruction will ensure that the subsequent building stages of remodelling, repair and removal are conducted more efficiently.)

- A feasibility study needs to be conducted before a decision to implement deconstruction can be made. The feasibility depends on physical conditions e.g. available building stock and the building condition and economic conditions e.g. local economic and construction activity and secondary markets.

- Deconstruction has economic and social benefits that can contribute to the economy and help improve people’s lives, but perhaps the most important are the often-unnoticed environmental benefits.

Government can develop various policies, in different sectors, that are driven by the common goal of achieving sustainability. Such policies can where appropriate, present a window of opportunity for the use of building deconstruction. For instance:

- Local economic development policy – deconstruction can play a significant role in the creation of employment, training of labour in construction trades, SMME development and in creating a new economic stream, i.e. secondary markets.

- Redevelopment/Preservation policy – deconstruction can find application in the restoration and renovation of historic and abandoned buildings.

- Environmental policy – deconstruction can be a preferred technique for environmentally responsible building removal (reduced pollution and energy conservation).

The feasibility of building deconstruction will vary with region, country and continent, mainly because different areas use different building methods and materials. If applicable, deconstruction can become a giant step in the construction industry’s quest to achieve sustainability in construction (in all three pillars i.e. economic, social and environmental).
Table of Contents

Foreword .................................................................................................................. 3
Acknowledgements .................................................................................................. 4
Executive Summary ................................................................................................ 5
Table of Contents .................................................................................................... 7
List of Tables .......................................................................................................... 8
1. Background and Introduction .............................................................................. 9
2. Context: Sustainable construction ........................................................................ 11
3. Definition ............................................................................................................ 14
4. Elements of building deconstruction .................................................................... 15
   4.1 Site assessment .................................................................................................. 15
   4.2 Environmental site assessment ........................................................................ 15
   4.3 Planning for deconstruction ............................................................................ 17
   4.4 Building removal permit .................................................................................. 17
   4.5 Site conditions .................................................................................................. 17
   4.6 Labour ............................................................................................................ 18
   4.7 Building disassembly ...................................................................................... 19
   4.8 Processing and materials handling ................................................................... 20
   4.9 Salvaged materials management ..................................................................... 21
5. Design for deconstruction .................................................................................... 23
   5.1 Definition ........................................................................................................ 23
   5.2 Why design for deconstruction ....................................................................... 23
   5.3 A look at the theory of building layers .............................................................. 24
   5.4 Useful hints for design for deconstruction ....................................................... 25
   5.5 Building component considerations ................................................................ 26
   5.6 Conclusions ..................................................................................................... 28
6. Feasibility of building deconstruction .................................................................. 29
   6.1 Physical factors ................................................................................................ 29
   6.2 Economic factors ............................................................................................. 31
   6.3 Policy and regulations ..................................................................................... 32
   6.4 Secondary materials markets ......................................................................... 33
7. Benefits of building deconstruction ..................................................................... 35
8. Deconstruction versus demolition ........................................................................ 37
9. Conclusions .......................................................................................................... 39
10. Case Studies ....................................................................................................... 40
   10.1 USA - Fort Ord Pilot Deconstruction Project, Reference [10] ......................... 40
   10.2 USA – Riverdale Deconstruction Project, Reference [7] .................................. 42
   10.3 Netherlands – Reuse of apartment buildings in Maassluis, Reference [18] .... 45
11. References ......................................................................................................... 48
Appendix A: Principles and a model for sustainable construction ......................... 51
Appendix B: Waste Management and End-of-life Scenario Hierarchies ................. 58
Appendix C: Building Site Assessment .................................................................... 63
Appendix D: Environmental Site Assessments – Hazardous Substances ............... 68
Appendix E: Useful Tools for Deconstruction .......................................................... 72
Appendix F: Building Layers ................................................................................... 74
Appendix G: Principles of design for deconstruction .............................................. 77
## List of Tables

**Table 1:** Waste management hierarchy .......................................................................................... 13
**Table 2:** Sequence of building disassembly .................................................................................. 19
**Table 3:** Processing and handling salvaged building materials .................................................... 20
**Table 4:** Types of salvaged building materials, source [7] ............................................................. 21
**Table 5:** Lifespan and replacement cycles of building materials and components, source [14] ..... 24
**Table 6:** Principles of design for deconstruction, references [4], [6], [15], [16] ............................ 25
**Table 7:** Building component considerations for design for deconstruction, references [12] and [16] .................................................................................................................................. 27
**Table 8:** Summary of issues relating to building conditions for residential buildings, source [17] .................................................................................................................................. 30
**Table 9:** NAHB Research Centre rating scale, source [17] ............................................................. 31
**Table 10:** Time required per building component (as percentage of total), source [7] ............... 44
**Table 11:** Time required per task category, source [7] ................................................................. 44
**Table 12:** Management of materials, source [15] ......................................................................... 44
**Table A1:** Principles of sustainable development .......................................................................... 56
**Table B1:** Levels of Hierarchy of End-of-life Scenarios ................................................................. 60
**Table C1:** Building (Material) Inventory Form ............................................................................... 64
**Table F1:** Life spans of building layers (and their sources) ............................................................ 75
**Table G1:** Principles of design for deconstruction and the Hierarchy of Recycling .................... 78
1. Background and Introduction

Global scale

The advancement of humankind from the Stone Age, to the Iron Age and to the Information Age has improved our quality of life and has enabled us to live sophisticated lives with things, increasingly, becoming just a touch of a button away. The Industrial Revolution gave birth to new processes, materials and products, and infrastructure that have completely changed the shape of the earth in both form and function. Unfortunately with these advances came consequences. The global population has increased more than eight times since the 1700s resulting in increased consumption rates. Even worse, the materials economy has increased by magnitudes of scale in comparison, e.g. the world production of pig iron increased 22 000 times in the same period [1]. The production processes use virgin materials as input to manufacture products. Increased production means increased materials extraction and inevitably increased generation of waste as a by-product. Our consumption has resulted in the annual destruction of 2% of forests, with 50% of frontier forests already destroyed. Every year, 24 000 million tons of topsoil are lost and up to 70% of biodiversity hotspots have been destroyed [2].

Impact of the construction industry

The construction industry has made a significant contribution to the current situation. The construction industry has been estimated to account for 30-40% of the total energy consumed in many countries. Up to 40% of virgin materials are extracted for use in construction activities. The construction industry generates up to 40% of the total waste stream in many countries with 15-30% of this waste ending up in landfill sites [3]. Until recently, the use of natural resources and the abuse of the environment have been dismissed as “costs of development”. Many of the environmental costs of construction processes such as extraction, production, operation and maintenance, demolition and disposal have yet to be accounted for.

Trends in international policy

In the past two decades, sustainable development has become an important part of national policy in most countries. There has been a trend in international policy towards environmental responsibility and nature preservation. For instance, Germany has passed legislation on Extended Producer Responsibility (EPR) whose aim is to ensure manufacturer responsibility for products from “cradle to grave”. The Netherlands has passed legislation that prohibits the disposal of reusable construction and demolition (C&D) waste in landfill sites, and many countries are promoting and supporting the reduction, reuse and recycling of waste e.g. the US has funded research and demonstration projects on building deconstruction [4]. The concept of resource efficiency calls for a new revolution that will revamp traditional construction practice and open up new economic opportunities by making more with less.

The role of deconstruction

Building deconstruction is a new technique that is based on the old practice of dismantling buildings to enable waste materials salvage for reuse and recycling. This technique found renewed interest in the last decade and is growing everyday. Deconstruction can play a role in the drive toward environmental responsibility and can help mitigate some of the current problems. Deconstruction can help divert waste material from landfill sites, thereby saving
landfill airspace. The salvaged waste can be converted to useful secondary materials and develop a new resource pool for the construction industry. This will ease the burden on virgin materials and help preserve natural resources. Furthermore, the use of secondary materials will conserve the embodied energy of those secondary materials and reduce the need for more energy consumption during virgin material extraction, production and supply.

This report will introduce building deconstruction as an innovative technique that can be adopted and incorporated into strategies that aim to achieve sustainability in construction and reduce the waste generated during construction activities.

Structure of the report

Section 2 looks at the bigger picture of sustainable construction and where building deconstruction fits in
Section 3 defines building deconstruction
Section 4 gives a detailed explanation if the various components of deconstruction
Section 5 looks at the concept of design for deconstruction
Section 6 highlights some factors to be considered when determining the feasibility of deconstruction in a given area
Section 7 gives some of the benefits of deconstruction
Section 8 compares deconstruction and demolition
Section 9 gives some concluding comments and
Section 10 presents some case studies
2. Context: Sustainable construction

Sustainable development is now an influencing factor of government policy in most if not all countries around the world. The fundamental reasoning behind this principle is to use resources (whether they are economic, social or environmental) in a manner that will not adversely affect the environment and the use of the same resources by future generations. The two main criteria that underlie this principle are preserving resources and preventing environmental degradation.

The construction industry has contributed to the disturbance of natural ecosystems through activities associated with virgin material extraction and has contributed to environmental degradation through pollution and waste generation. In recent years, the construction industry has realised a need to be environmentally responsible and has adopted activities and processes that minimise the negative environmental impacts. To the traditional criteria of performance, quality and cost for building systems (products or services) have been added a set of sustainability criteria that focus on the environmental and social aspects [5]. This represents the concept of “green” or sustainable construction.

Du Plessis defines sustainable construction to be an integrative and holistic process aiming to restore harmony between the natural and the built environments, and create settlements that affirm human dignity and encourage equity [2]1. This is a particularly interesting definition because it departs from the rugged nature that the construction industry has come to be known for and brings in the “soft” elements of harmony, dignity and equity that are easily associable with sustainability. In order to be relevant and have merit, sustainable construction needs to subscribe to the same goals of the overarching principle of sustainable development within the bounds of construction. For instance there should be movement towards preserving resources such as virgin material and energy in construction, there should be a move towards the prevention of environmental degradation e.g. cleaner production and C&D waste minimisation and the focus should be on human development and improved quality of life.

Life cycle assessment (LCA) has been used extensively to determine the environmental impact of buildings in their different phases of existence. The strength of LCA is that it considers all stages in a building’s life, from idea generation to building waste disposal, when determining its environmental impact (this results in a true representation of a building’s footprint taking into account the extraction, production and transportation, design and construction, operation and maintenance, demolition and waste disposal effects) [6]. Even though it is still difficult to convert environmental impacts to environmental costs, LCA has been able to reveal that the true cost of a building system (product or service) is not just capital, we start paying long before the construction stage and we keep paying long after the construction project team has reconciled its financial books.

Crowther indicates that the LCA, however falls just short of addressing what can be done to reduce or remedy the environmental burden of buildings, as per assessment [6]. This next step requires an understanding of the concept of sustainability in construction. A new dimension is introduced into the debate i.e. sustainability principles. These can be superimposed into the LCA axes to produce a three-dimensional model for sustainable construction. Kibert is one of

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the recent authors to dedicate effort into defining these sustainability principles [5]. His list of sustainability principles includes the following:

1. Minimise resource consumption (Conserve)
2. Maximise resource reuse (Reuse)
3. Use renewable resources (Renew/Recycle)
4. Protect the natural environment (Protect Nature)
5. Create a healthy, non toxic environment (Non-Toxics)
6. Pursue quality in creating a built environment (Pursue quality)

The three dimensional model for sustainable construction, as described by Kibert presents the sustainability principles that must be applied to the resources used in buildings at the various stages of a building’s life. (See figure 1)

This model can be used to define and locate building deconstruction in the whole theory of sustainable construction. Deconstruction is concerned with the dismantling of buildings to maximise material salvage for reuse. One of the key elements to successful building deconstruction is design. The ease of deconstruction is determined by the flexibility of the building, which in turn depends on the initial design of the building elements. So if we try and locate design for deconstruction in the model in Figure 1 we see that design for deconstruction deals with the design of a building for the reuse and recycling (non-reusable) of materials [6]. This demonstrates that for success to be achieved with deconstruction at the end of life of a building, the input must be at the design stage of the process. Once again, the life cycle of a building is emphasized.

**Note:** A detailed description of each of Kibert’s sustainability principles and the model for sustainable construction is presented in Appendix A – adopted directly from [5]. Kibert’s principles form part of (or conform with) the broader principles of sustainable development, also presented in Appendix A.
Building deconstruction supports the waste management hierarchy in its sequence of preferred options for the management of generated C&D waste materials. (See Table 1) If a building is still structurally sound, durable and flexible enough to be adapted for a different use (either in-situ or by relocation), then waste can be reduced by reusing the whole building. If components and materials of a building can be recovered in high quality condition, then they can be reused. If the building materials are not immediately reusable, they can be used as secondary feedstock in the manufacture of other products, i.e. recycled. The aim is to ensure that the amount of waste that is destined for landfill is reduced to an absolute minimum. This approach closes the loop in material flow thereby contributing to resource efficiency.

<table>
<thead>
<tr>
<th>Waste Management Hierarchy</th>
<th>Most Desirable</th>
<th>Least Desirable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Waste Avoidance</td>
<td>Prevention (cleaner production)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Demand management (human behaviour &amp; lifestyle)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Reduction (source control)</td>
<td></td>
</tr>
<tr>
<td>Waste Minimisation</td>
<td>Recovery (salvage)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Reuse (immediate use)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Recycling (reprocessing)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Composting (biological reprocessing)</td>
<td></td>
</tr>
<tr>
<td>Waste Treatment</td>
<td>Incineration: Energy recovery</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Incineration: Volume reduction</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Chemical treatment (neutralisation)</td>
<td></td>
</tr>
<tr>
<td>Waste Disposal</td>
<td>Landfill</td>
<td></td>
</tr>
</tbody>
</table>

Note: Other examples of waste and end-of-life scenario hierarchies are presented in Appendix B – adopted directly from [4] and [6].
3. Definition

Building deconstruction can be defined as a process of selectively and systematically dismantling buildings to reduce the amount of waste created and generate a supply of high value secondary materials that are suitable for reuse and recycling. Deconstruction can be conducted prior to traditional demolition, be an integral part of the demolition process or replace demolition as a preferred building removal technique. Also known as building disassembly, deconstruction is actually a new term used to describe an old process of selectively dismantling buildings to recover some of the building components for reuse elsewhere. It can be viewed as a sustainable alternative to mass demolition that seeks to close the loop of material flow thereby contributing to resource efficiency in construction.

The process of building deconstruction can be described as construction in reverse. The materials that were installed last are the first to go and so on. Whereas traditional mass demolition is a mechanical process, deconstruction is largely a labour intensive process. It is thus a great way to understand how buildings are constructed, how components are assembled and connected together and how the scheduling and sequencing of tasks on construction sites works. This presents a great opportunity for training labour for the construction industry.

There are two main types of building deconstruction viz. non-structural (also known as soft stripping) and structural deconstruction. Non-structural deconstruction refers to the removal of non-load bearing components of a building such as windows, doors, appliances, sanitary ware, cabinets and electric fixtures among others. This type of deconstruction can be accomplished with few tools, typical job safety considerations and unskilled labour. It will generally take anything between a few hours and a couple of days. Structural deconstruction on the other hand refers to the dismantling of the structural fabric of a building e.g. building frame, roof system and walls. It requires a range of tools, may require mechanical equipment and a mix of unskilled and skilled labour. It will generally take anything between a number of days and a few weeks. Structural deconstruction is affected more by environmental and occupational health and safety regulations than non-structural deconstruction.

Non-structural deconstruction can be described as a more mature market. The salvage and resale of windows, doors etc. is a common practice. It largely serves low-income communities and contractors who are involved in the secondary materials market. Structural deconstruction is an emerging market that has been in existence for a long time, but has not been widespread for various reasons. Salvaged structural materials will usually appeal to a high-end buyer who is generally in search of historical or architectural value in secondary materials e.g. old Douglas fir framing lumber in the US.

Building deconstruction is not only a technique for building removal that can be used to improve the performance of demolition contractors, but it can also be used as a waste minimisation strategy to reduce the waste generated by the construction industry, it can be used as an urban renewal tool to help dismantle, renew and reuse old and abandoned buildings and it can also be used as a community economic regeneration strategy to help create employment, local businesses and use local resources.
4. Elements of building deconstruction

Building removal using the technique of deconstruction is different from the traditional process of mass demolition. The demolition contractor will have to consider some issues in more detail and also incorporate new issues into the project plan e.g. the project emphasis will be on material salvage and not disposal. As deconstruction is predominantly a labour intensive activity, a building must be deconstructable with labour methods. Because of the labour bias, occupational health and safety issues will require special attention. The site assessment and planning stages of the project are very important and could determine the success or failure of the whole project.

4.1 Site assessment

The most important part of assessing the feasibility of deconstruction for a structure is a detailed inventory of how and of what the building is made [7]. The building inventory is used to determine the extent to which a building can be deconstructed, particularly using labour intensive methods. The site assessment takes two forms, first a thorough visual, non-invasive inspection of the building and then an invasive inspection to assess the hidden layers of the building. The assessment is intended to identify each type of material used in the building, its condition, the way it is secured to the structure and the ease of its removal. Site assessment also includes an environmental assessment (next section) that is conducted to determine the extent of hazardous substances in the building. The site assessment must be conducted by individuals with construction experience and basic training in hazardous substance identification.

Note: An example of a Building Material Inventory Form and the Material Estimation Tool associated with it are given in Appendix C – adopted directly from the NAHB Research Center reports [7] and [17].

4.2 Environmental site assessment

Building and environmental regulations usually require that hazardous materials are identified and abated before a building can be removed. The main hazardous materials that create problems during building removals are asbestos and lead. Other potential problems include underground fuel tanks, electrical transformers and PCB containing components.

4.2.1 Asbestos-Containing Materials

Asbestos has been used extensively in buildings in the past. There is concern that much of the asbestos contained in buildings may be disturbed during building removal, thereby causing a health hazard. There are two main types of asbestos i.e. friable and non-friable. Friable asbestos is easily crumbled or pulverised by hand pressure and if disturbed it can easily be suspended in air and create a health hazard. Non-friable asbestos on the other hand is not easily reduced to dust and thus does not present much of a problem if undisturbed. Over many years however, previously non-friable asbestos can degenerate to a friable state and present health problems.

Activities related to demolition, by their nature, tend to disturb buildings resulting in large volumes of dust containing airborne particles that include asbestos. Deconstruction has two aspects in relation to asbestos. On the one hand deconstruction involves a thorough building
assessment that may uncover previously unnoticed asbestos containing materials (ACM) and help reduce the risk of worker exposure, on the other hand since deconstruction is labour intensive, it brings workers in close contact with ACM. The latter makes environmental and health and safety regulations more applicable to deconstruction compared to demolition [8].

There is no easy way to identify ACM in the field and contractors usually go by experienced judgement. The amount of asbestos can be determined in a certified laboratory using polarized light spectroscopy. Typical examples of building components that may contain asbestos include pipes, ducts, wall and ceiling insulation, ceiling tiles, roofing, siding, flooring, plaster, window caulking and finishing [9].

The proper removal of asbestos requires specialised equipment and training. For this reason, the abatement of ACM in the building removal process is usually contracted to a professional abatement firm. Safety measures that are used in the abatement include the use of full-mask respirators and negative air pressure systems [7].

4.2.2 Lead-Based Paint

Many old buildings were coated with paint finishes that had lead content. The identification of lead as a hazardous substance means that building removal is potentially a hazardous activity, particularly if labour intensive. Environmental regulations generally have a threshold of lead content that is used to ensure acceptable worker exposure. Building deconstruction, being labour intensive, may generally be required to incorporate worker safety measures. Normal safety measures for working in lead contaminated areas include the use of respirators, protective work clothing, change areas and hand washing facilities. All workers are required to attend lead awareness training and have biological monitoring of lead content in their blood [7].

Lead content in buildings can be determined using the following test methods [7]:

- LBP Test Sticks – the sticks are used in the initial determination of lead content in the field. Affirmative results suggest a need for a more detailed analysis while negative results are not accepted as conclusive evidence of lead absence
- X-ray Fluorescence and Atomic Absorption Spectroscopy – these tests determine the percentage concentration of lead in paint or other coatings
- Toxicity Characteristic Leaching Procedure (TCLP) – this determines the lead leaching potential of mixed C&D debris. It helps classify C&D waste as hazardous or non-hazardous.
- Air Monitoring – this method assesses the concentration of lead in the air to determine worker exposure

In order to thoroughly assess a building for lead and asbestos content, both visual and invasive inspections are necessary. An accurate environmental assessment can help determine the feasibility of deconstruction as a preferred technique for building removal. Failure to accurately determine all occurrences of these substances could result in danger to workers and high-unforeseen costs that might cause the project to register a net loss.

Note: A detailed description of asbestos and lead abatement is provided in Appendix D – adopted directly from the NAHB Research Center report [7].
4.3 Planning for deconstruction

Based on the outcomes of the building inventory and the environmental site assessment a decision can be made on whether deconstruction is a suitable technique for building removal. The results of the assessments will indicate the amount of building components and materials that can be salvaged. This information will help in deciding whether structural and/or non-structural deconstruction should be conducted. It will also be useful in the cost analysis of the project (costs and revenues). Generally, if the cost of salvaging materials is high and the salvage value\(^2\) of the materials is low, deconstruction may not be economically feasible (or the project may not be able to sustain itself without external financing).

Having decided on the type of deconstruction to conduct, activities and tasks can be planned. Careful consideration must be given to the scheduling and sequencing of tasks. The site layout should ensure smooth material removal from the building, processing and storage without conflict with respect to space and timing. As part of the planning process, the used building materials markets should be investigated to determine the demand and end use for salvaged materials. Also to be determined is the resale value of salvaged materials and the associated costs of storage and transportation.

4.4 Building removal permit

Land and building jurisdictions require a formal notification of intent to remove a building. Building deconstruction, like demolition, is a technique used in building removal and thus requires a permit. The approval process generally requires the satisfaction of the following requirements:

- The disconnection of electrical power
- The capping of all gas and sewer lines
- The abatement of asbestos, lead and other hazardous substances
- Pre payment for site inspection by building authority (or air pollution authority)

The third requirement links the permit process to the environmental site assessment process i.e. for a permit to be granted, all inspections relating to hazardous substances need to have been satisfactorily conducted by qualified personnel.

Since building deconstruction generally takes longer that traditional demolition (because of labour), many of the proponents of building deconstruction call for a mandatory waiting period between the granting of the permit and the commencement of new construction to allow enough time for building deconstruction and material salvage.

4.5 Site conditions

4.5.1 Security

Security on a deconstruction site is intended to protect the workers and the general public, as is the case with demolition. However, deconstruction has an added aspect i.e. the protection of salvaged components and materials. Salvaged materials are carefully stripped from buildings and processed to ensure good quality for resale purposes. The salvaged materials become susceptible to theft as labour and the public begin to realise the true value of the salvaged

\(^2\) Salvage value may be determined by the quality of the material or the resale value as dictated by the market.
materials (resale value and reuse potential). Simple security measures that can be implemented include the erection of a perimeter fence with a lockable gate, lockable storage areas and the monitoring of the staff upon entry and exit of the site to prevent the smuggling of salvaged materials. Other items such as electrical equipment and tools should also be stored in lockable storage areas.

4.5.2 Site safety

Site safety refers to the protection of workers from potential operational hazards. The deconstruction of a building involves the stripping of both structural and non-structural components. In the case of structural components, the workers should be aware of critical building supports and ensure that structural collapse is prevented at all times [7]. Workers generally need protection from falling while working in elevated parts of the building, protection from falling objects in the building, fire protection and protection from the collapse of the whole building.

4.6 Labour

Since building deconstruction is a labour intensive activity, labour related issues need special attention. The workers need to be protected from physical and environmental hazards e.g. through the use of protective equipment (hard hats, eye protection etc), provision should be made for compensation in the event of an accident and workers should be remunerated according to prevailing wage rates.

Insurance

Contractors involved in building deconstruction need to provide general liability insurance for the project. In addition, they need to provide worker compensation insurance for their workers. Since deconstruction is currently not widely practiced (compared to demolition), worker classification for compensation insurance purposes is sometimes unclear. Deconstruction contractors need to clearly define the different tasks that are performed by the workers and in conjunction with insurance companies arrive at agreeable premiums for insurance cover.

Training

Deconstruction workers will need basic training in construction trades. All workers need to be familiar with construction vocabulary, the use of tools, materials handling and basic safety requirements. All workers have to undergo lead awareness training and blood lead level testing to monitor the lead content (before and after the project). A portion of the workforce will need to undergo lead worker training to be able to remove building components coated with lead based paint. Asbestos abatement is considered a specialised activity, therefore it is contracted out to a professional abatement contractor.

Wages

The department of labour generally determines the wage rates for construction industry activities such as new construction, demolition, remodelling and repair. Deconstruction is somewhat unclear because it does not appear in the traditional definition of construction industry activities. Prevailing wage rates for construction and demolition can be used as
benchmarks when determining wage rates for deconstruction. Some of the factors that influence deconstruction wages include the skill level of workers, the tasks performed and the value of salvaged materials.

4.7 Building disassembly

The process of deconstruction is simply ‘construction in reverse’. The materials that were installed last in the building are the first to go and so on. Throughout the stripping process, the structural integrity if the building should be monitored to prevent the building from collapsing on its own. When structural components are stripped, it is advisable to erect scaffolding to ensure stability, worker access, mobility and safety. In addition, some building sections may need bracing to maintain rigidity. It is suggested that wherever possible, elevated building components e.g. the roof be brought down to ground level for stripping. This is because it is safer and quicker to work on the ground.

Table 2 gives a typical sequence for the disassembly of building components during building deconstruction.

<table>
<thead>
<tr>
<th>Item</th>
<th>Component</th>
<th>Comments</th>
</tr>
</thead>
</table>
| 1    | Fixtures  | -Typical fixtures that are removed include doors, windows, shelving, cabinets, appliances, HVAC systems, wiring, water heaters, boilers etc.  
|      |           | -Stripping typically by hand tools  
|      |           | -The materials are stored indoors e.g. warehouse |
| 2    | Roof      | -Typical roof material includes sheeting, rafters, truss system, chimney top, ceiling joists, gypsum board, gutters etc.  
|      |           | -Stripping typically by hand tools  
|      |           | -Useful materials go to processing and the rest is stored in dumpsters and recycling containers |
| 3    | Walls     | -Typical wall components include exterior wall, interior wall, framing material, chimney, tiles etc.  
|      |           | Typical materials include timber, brick, gypsum drywall, steel etc.  
|      |           | -Stripping typically by a combination of hand tools and mechanical equipment  
|      |           | -Useful materials go to processing and the rest is stored in dumpsters and recycling containers |
20

4 Floor 3

-Typical components include floor finishing e.g. tiles and carpeting, and floor layers e.g. floor bed and foundation. Typical materials include timber, concrete, ceramics etc.

-Depending on the floor material, stripping can be done by hand tools or mechanical equipment

-Useful materials go to processing and the rest is stored in dumpsters and recycling containers

5 Other

Special features such as stairs, basements, elevated floors, etc. should be given special attention with due consideration of site-specific conditions

Note: Typical tools that are used by deconstruction workers are listed in Appendix E – adopted directly from [10] and [7].

4.8 Processing and materials handling

Material removal from a building needs to be coordinated with material processing and material storage to avoid pile-ups, blockages, double handling and potential hazards on site. The site layout should allow the stripping and processing (i.e. de-nailing, cleaning, sorting, sizing, bundling and stacking) of different types of materials in separate locations without conflict. All recyclable materials should have a designated route that does not interfere with materials salvaged for reuse. Customers have shown willingness to buy salvaged materials that have been accurately sized, neatly stacked and stored in a manner that prevents further damage. Furthermore, customers have indicated that material sales would increase if materials were cleaned and trimmed to remove defective areas e.g. split ends and nail holes in timber [10]. Table 3 gives a list of typical building materials and some comments on their processing.

<table>
<thead>
<tr>
<th>Component</th>
<th>Typical material</th>
<th>Processing</th>
<th>Storage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fixtures</td>
<td>Timber e.g. doors&lt;br&gt;Metal e.g. window frame, wiring&lt;br&gt;Ceramics e.g. sanitaryware</td>
<td>Cleaning and packing</td>
<td>Indoors</td>
</tr>
<tr>
<td>Roof</td>
<td>Timber e.g. rafters, truss&lt;br&gt;Asphalt e.g. roof tiles&lt;br&gt;Metal e.g. sheeting, gutters&lt;br&gt;Gypsum e.g. ceiling board</td>
<td>De-nailing, sizing, stacking</td>
<td>Indoors – timber stored in stacked bundles&lt;br&gt;Outdoors – metals in recycling containers, gypsum and asphalt will either be stored in recycling containers or disposed in dumpsters depending on the</td>
</tr>
</tbody>
</table>

Note: In some cases wooden floors can be easily removed after the removal of fixtures.
Building Deconstruction                                                                                      CIB/CSIR 2001

| Walls | Timber e.g. framing, exterior walls  
|       | Bricks e.g. exterior walls, interior walls, chimneys  
|       | Gypsum drywall e.g. interior walls | De-nailing, sizing, stacking Cleaning | Indoors – timber stored in stacked bundles  
|       | Outdoors – bricks stored in stacked piles, gypsum will either be stored in recycling containers or disposed in dumpsters depending on the economics and markets |

| Floor | Timber - floor  
|       | Concrete - floor  
|       | Ceramics - finishing | De-nailing, sizing, stacking Crushing Cleaning | Indoors – timber stored in stacked bundles  
|       | Outdoors – Concrete stockpiled for recycling and ceramics stored in recycling containers or disposed in dumpsters |

4.9 Salvaged materials management

The resale of salvaged building materials is expected to offset the main cost of deconstruction i.e. labour. If managed properly, salvaged materials can save costs and generate revenue for the project. Producing high quality secondary materials is only half of the challenge; the other half is finding end use markets for the salvaged materials. There are three basic types of salvaged building materials viz. low value, good quality and high value materials. (See Table 4)

Table 4: Types of salvaged building materials, source [7]

<table>
<thead>
<tr>
<th>Material type</th>
<th>Price range as % of retail price</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low value</td>
<td>10 - 25</td>
<td>Materials whose value is a small fraction of new materials. The low value is a function of their condition or original value.</td>
</tr>
<tr>
<td>Good quality</td>
<td>50 - 85</td>
<td>Materials whose value is a significant portion of new materials. These materials can substitute one-for-one with readily available new materials. The previous use does not affect the way they can be reused.</td>
</tr>
<tr>
<td>High value</td>
<td>100+</td>
<td>Materials whose value may equal or exceed that of new materials. The value of these materials has increased over time because of scarcity, similar qualities currently expensive to acquire and their reprocessing adds value.</td>
</tr>
</tbody>
</table>
There are several ways of handling salvaged building materials. The owner can store salvaged building materials for future use on the same site or on other projects. This would save the client procurement costs related to acquiring new materials. Alternatively, the owner can donate the salvaged materials to charity if no use can be found for them. Another option is to sell salvaged materials and generate income from them. There are a number of different approaches that can be used to market secondary building materials [11]. These include:

- **Direct marketing to retailers and end users** – this is a yellow pages approach, which involves direct contact with potential buyers usually through telephone (and word of mouth). This method may consume a lot of time and thus have significant costs.

- **Site sale and auction** – the sale is generally advertised in local media such as the radio, newspapers, billboards etc. On the selected day all materials are displayed and the customers submit bids for materials they are interested in buying.

- **Using a broker** – an individual or firm with knowledge and information about end users and markets can be employed to handle all matters relating to salvaged materials at a negotiated fee.

- **Regional/Periodic auctions** – auctions that are common in the area can be used to sell material to the highest bidder. The seller is usually responsible for transport costs, not the auctioneer.

- **The Internet** – the Internet sale of materials can open up the sale of reused materials to a national customer base. This method is more useful for high value materials because of the shipping costs involved.
5. Design for deconstruction

5.1 Definition

Design for deconstruction (DFD) refers to the design of a building with the intent to manage its end-of-life more efficiently. The process is intended to ensure the easy disassembly of buildings in order to reduce waste generation and maximise the recovery of high value secondary building components and materials for reuse and recycling. This innovative approach encourages designers to incorporate DFD principles at the design stage of construction projects to ensure that the subsequent stages of remodelling, repair and building removal are conducted efficiently (DFD views end-of-life scenarios for building systems, products and services in a holistic manner that includes both asset management and building removal processes). This approach reinforces the need to consider the life cycle of a building as presented in the model for sustainable construction.

A new perspective that is increasingly being debated is that of perceiving buildings as a future resource pool for building materials. Instead of demolishing old buildings and disposing of the C&D waste and extracting virgin materials from finite natural resources to construct new ones, many environmentally inclined construction practitioners are beginning to consider buildings as one of the preferred sources4 of building materials. The reasons for this include reduced energy and emissions associated with material supply and the conservation of embodied energy contained in secondary materials. When considering buildings as a future source of raw materials DFD5 is a key element in material retrievability [12].

5.2 Why design for deconstruction

The longevity of a building is determined by the building’s ability to maintain structural integrity for a long time, as well as its desirability in terms of function and style. The structural integrity of a building is determined by the durability of materials and the quality of construction. Desirability is determined by the building’s ability to adapt to change over time. Striking a balance between durability and adaptability in the design of a building results in building flexibility – an important quality in buildings that are constructed according to the principles of sustainable construction.

Bowes and Golton indicate that obsolescence is the dimension that determines the timing of the demolition of a building [13]. Buildings are not demolished only when they have reached the end of their technical design life, quite commonly they are demolished because those who control them have no further use for them. The reasons that lead to buildings having no further use include economic perspectives e.g. financial aspects and location, utility perspectives e.g. function and the environment, social perspectives e.g. style and regulatory control and of course structural perspectives e.g. structural decay [13] and [14].

Designing a building for durability can save costs and reduce the negative environmental impacts related to operation and maintenance i.e. the consumption of materials during renovations and the resultant waste generation. On the other hand, if a decision to demolish a building is made long before the expected end of life, the above can be reversed i.e. the incurred costs of durable materials, which may have cost more, may not be recovered because

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4 Other preferred sources include renewable resources and recyclable waste from other industries.
5 DFD is used synonymously to refer to design for disassembly.
of the building’s short life [15]. This emphasises the salient point that if a building is intended to have longevity, then durability must be balanced with adaptability.

Adaptability in buildings refers to both the shell and interior of a building. Incorporating adaptability in building design enables the building to adapt to changing demands of the intended use as well as the ability to adapt to a different use. This flexibility in building design introduces a fresh perspective of looking at buildings, i.e. as a series of layers that can be configured in various ways to meet the changing demands of the user and the surrounding environment.

5.3 A look at the theory of building layers

Buildings have for a long time been thought of and designed as “eternal entities”. Part of the reason for this is that designers and contractors perceive buildings as entities that should last forever (designers are not prepared to invest in structures that will not last and no contractor believes that his structure will be torn down) [12]. Buildings have also generally been perceived to be “complete entities” that are designed to perform as a whole i.e. hence the use of “a building” in singular [6]. Craven et al point out that such buildings lack inherent flexibility and are likely to generate more waste when modified, in extreme cases their inflexibility can leave no option but for them to be demolished under the pressures of changing demands that are placed upon them [14].

Crowther takes the argument further by pointing out that the notion of “a building” in the singular may be a misconception resulting from the reading of a building in a limited timeframe [6]. Few, if any buildings actually remain in their initial state for more than a few years or a couple of decades at most. Building remodelling, repair, expansions and maintenance continually change the building. These changes occur both on the exterior and interior of the building in response to the demands of the user and the surrounding environment. This means that the exterior and interior of a building should be able to respond to the criteria determined by the economic, utility, social and structural perspectives mentioned earlier for the building not to be obsolete.

Table 5 gives some of the elements of the building exterior and interior and their estimated lifespans.

Table 5: Lifespan and replacement cycles of building materials and components, source [14]

<table>
<thead>
<tr>
<th>Building Component/Material</th>
<th>Estimated lifespan (years)</th>
<th>Replacement*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paint, awnings, solar collectors etc.</td>
<td>15</td>
<td>Replaced 9 times in the average life of a structure</td>
</tr>
<tr>
<td>Flooring, plumbing fixtures</td>
<td>30</td>
<td>Replaced 4 times in the average life of a structure</td>
</tr>
<tr>
<td>Plaster, windows, piping systems</td>
<td>60</td>
<td>Replaced at least twice in the average life of a structure</td>
</tr>
<tr>
<td>Primary structures</td>
<td>150</td>
<td>-</td>
</tr>
</tbody>
</table>

* Replacements according to the estimated life of the primary structures in row 4
Note: A detailed table of building layers and lifespans is shown in Appendix F – adopted directly from [6].

The theory of building layers enables the designer to incorporate flexibility into building design. This allows a building to be easily disassembled into components. It also allows the selective removal and replacement of specific components without affecting the rest of the structure. Without a doubt, this theory will be useful in the design of buildings with intent to deconstruct at the end. However, an understanding of the building design i.e. finite or eternal, material type e.g. virgin, recycled content or composite, reusability, recyclability, the various lifespans of chosen materials, component connectivity and the changes in user and environmental demands will be key to its use.

5.4 Useful hints for design for deconstruction

Design for deconstruction is still not used extensively in practice. There are a number of reasons for this, the two of which are:
- The benefits of using the principles of design for deconstruction take anything between 30 to 150 years before they are realised. This means that the designers may not live to see the benefits of their designs, which is not a good incentive.
- There are no official guidelines yet on how to design buildings for deconstruction.

Not much can be done about the first constraint, except for the construction industry to target the services of environmentally inclined designers, “the converted” or “green designers”, for construction projects. The second constraint limits the use of DFD principles during building design.

A number of researchers in the field of building deconstruction internationally have realised this among other shortcomings and are currently dedicating their efforts into the integration and consolidation of recurring themes, principles and experiences that have come out of previous research efforts and deconstruction projects. It is expected that some of these efforts will contribute to the formulation of a set of ‘guidelines for building deconstruction’ that can be used by building designers. In addition, other industries e.g. the automotive industry are more advanced in terms of design for disassembly and lessons could be learned from their experiences and adopted to the construction industry.

Table 6 presents a list of principles that can be used as a guide when considering design for deconstruction in projects.

<table>
<thead>
<tr>
<th>Item</th>
<th>Principle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Information</td>
<td>- Keep the records of all information relating to the design and construction of a structure, for example: Architectural plans Engineering designs Components used Materials used Photographs of connections, location of wiring system etc.</td>
</tr>
<tr>
<td>Building design</td>
<td>- Incorporate flexibility into the design (durability, adaptability and</td>
</tr>
</tbody>
</table>
building layers), for example:
Consider using modular design (standardisation, prefabrication)
Consider preparing designs for the disassembly of the building
Design buildings that can be easily converted to a different use
Consider designing demountable buildings
Choose materials based on life cycle costs and salvageability (not just capital cost)

| Materials                  | - Use a minimum of different materials  
|                           | - Reuse secondary materials            
|                           | - Use renewable, recyclable and recycled content materials    
|                           | - Avoid materials containing hazardous substances     
|                           | - Choose materials with low embodied energy       
|                           | - Avoid composite materials                

| Connections                | - Use a minimum of connections          
|                           | - Use a minimum of different types of connections    
|                           | - Avoid adhesives and nails                
|                           | - Use standardised connections i.e. connection points, connectors and building components 
|                           | - Use easily removable, reusable connectors     
|                           | - Use building components designed for repeated use 

| Material salvage           | - Always consider the end-use hierarchy when designing for deconstruction, i.e.: 
|                           | **Reuse** – Building Components Materials 
|                           | **Recycling** – Upcycling Recycling Downcycling 
|                           | **Incineration** – Energy recovery Volume reduction 
|                           | **Disposal** – Landfill                    

**Note:** A detailed table of principles of design for deconstruction and the hierarchy of recycling is included in Appendix G – adopted directly from [6]

5.5 Building component considerations

When designing buildings for deconstruction, care should be taken in the selection of building materials. The material selection process should be guided by the principles of sustainable construction (see Figure 1). The quality of each building component and the performance of the structure, as a whole, should not be compromised.

In some cases, conflict will be inevitable for example:
The use of “green” materials vs. their usefulness at deconstruction stage  
Cost and embodied energy vs. durability
In such cases decisions will have to be made by evaluating the priorities of the project e.g. resource reuse or renewable resources and by analysing the life cycle costs of the project e.g. using expensive durable materials or cheap replaceable materials.

The main aim of designing buildings for deconstruction is to ensure that at the end-of-life the building can be disassembled relatively easily, the waste generated is minimised and the salvaged materials are maximised. Thus for buildings to be the resource pool of the future, designers should use materials and construction methods that will yield a high percentage of salvaged materials that are fit for reuse and recycling.

Table 7 gives a summary of some building component considerations for design for deconstruction.

Table 7: Building component considerations for design for deconstruction, references [12] and [16]

<table>
<thead>
<tr>
<th>Component</th>
<th>Elements</th>
<th>Materials</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Foundation and floor</td>
<td>Foundation, Floor bed, Floor finish</td>
<td>Concrete, Timber, Ceramics, Carpets</td>
<td>Concrete – cannot be reused immediately, but can be recycled into secondary materials. Timber – can be reused immediately and recycled into various products. Ceramics – durable, cannot be reused immediately, but can be recycled. Carpets – recyclable, but process complicated, small market.</td>
</tr>
<tr>
<td>Walls</td>
<td>Frame, Siding, Wall finish</td>
<td>Timber, Steel, Concrete, Brick, Gypsum drywall</td>
<td>Timber as above. Steel – needs extra care if immediate reuse is considered, most recycled material. Concrete as above. Brick – high reuse potential, can be recycled into secondary materials. Gypsum drywall – highest percentage of generated construction waste, recyclable if not contaminated, small market.</td>
</tr>
<tr>
<td>Roof</td>
<td>Frame, Sheeting, Ceiling</td>
<td>Timber, Metal, Asphalt, Concrete, Polymers, Gypsum</td>
<td>Timber – as above. Metal – durable, costly initially but cheaper in long term, most recycled category of materials, established secondary market. Asphalt – affordable, not reusable initially, can be recycled to road materials depending on prevailing policy. Concrete as above. Polymers – usually composite, not reusable or recyclable. Gypsum as above.</td>
</tr>
</tbody>
</table>
5.6 Conclusions

Design for deconstruction can contribute to the construction industry’s quest to achieve sustainable construction, particularly through natural resource conservation, waste reduction and waste recovery for reuse and recycling. It is important that designers learn to consider design for deconstruction during building design because the decisions made during design influence the deconstructability of a building at its end-of-life.

The main elements to consider when designing for deconstruction are:
- Using the model for sustainable construction as a guide during design
- Designing for flexibility i.e. balancing durability and adaptability and using building layers
- Using principles of design for deconstruction
- Selecting the right materials for building components
6. Feasibility of building deconstruction

The feasibility of building deconstruction refers to the assessment of the conditions under which the disassembly of buildings to maximise material salvage for reuse and recycling purposes is likely to be successful. The feasibility of deconstruction can be determined using two main criteria viz. the physical potential and economic potential of a given area. The assessment of an area for deconstruction potential depends on the availability of baseline information about the prevailing conditions in that area. Useful sources of information include public housing authorities, building authorities, statistical services, finance and revenue services, health departments and existing secondary material businesses.

In addition to being used as a preferred option to mass demolition for building removal, deconstruction can be used to address other national and local problems. These include the following:

- Deconstruction can be incorporated into strategies to minimise waste from the construction industry
- Deconstruction can be used in urban renewal plans to rehabilitate dilapidated buildings, abandoned buildings and unhealthy buildings
- Deconstruction can be used as a community economic regeneration tool to create employment and business development opportunities using local resources and circulating the money within the community

It is thus important that deconstruction feasibility be assessed with due consideration of all these aspects.

There are a variety of factors that influence the feasibility of building deconstruction. These factors present both the opportunities and the barriers to deconstruction. Many of the factors will vary in different areas, but some commonalities can be drawn on a broad scale. Some examples of the factors that influence the feasibility of building deconstruction include the availability of buildings to be deconstructed, the physical condition of the buildings, local construction activity and practice, the local economy, secondary markets, prevailing policy, labour issues, environmental concerns, tipping fees, time constraints, government support, prevailing codes and specifications, and public perceptions of secondary materials.

This section will attempt to describe the role of some of these factors by looking at some broad issues viz. physical factors, economic factors, policy and regulations and secondary markets.

6.1 Physical factors

Building stock

Building deconstruction, like demolition, depends on the availability of buildings that will form the feedstock for the industry. However, for deconstruction it is not only the amount of available buildings that is the concern, but also the amount of deconstructable buildings. Building types vary locally, regionally and nationally. In addition buildings also vary by function i.e. residential, commercial or industrial. Buildings can be dismantled using structural and/or non-structural deconstruction. A decision between the two types will usually be determined by the physical conditions of a building and the cost-benefit analysis of each option.
The text box below gives examples of the kind of building stock that could present an opportunity for the use of deconstruction.

Building stock examples

1. In the US, an estimated 200 000 public housing units have been slated for demolition as a result of HOPE VI, a program of the US Department of Housing and Urban Development (HUD). This program was initiated to provide funding to local authorities for the demolition and construction or rehabilitation of public housing units across the US [12].

2. The US Department of Defence has ruled that hundreds of military bases across the country be closed or realigned and converted to civilian use [12].

3. Many local authorities in the UK are facing increasing numbers of undesirable dwellings, which are proving to be very difficult or impossible to let. Some local authorities are incorporating demolition into their overall strategy for tackling this problem [13].

Building condition

The physical conditions of a building that influence its feasibility to be deconstructed include:

- Building type
- Building status
- Building location
- Neighbourhood context
- Building physical condition
- Building materials
- Property access

Table 8 gives a summary of the issues that relate to each of the building conditions for residential buildings.

<table>
<thead>
<tr>
<th>Building condition</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Building type</td>
<td>High rise multi-family, Low rise multi-family, attached (row) housing, semi-detached, single dwellings</td>
</tr>
<tr>
<td>Building status</td>
<td>Condemned, abandoned, for sale, under renovation</td>
</tr>
<tr>
<td>Building location</td>
<td>High density residential area, residential suburb, inner city</td>
</tr>
<tr>
<td>Neighbourhood context</td>
<td>High or low income area, high or low crime rate, old or new neighbourhood, derelict neighbourhood</td>
</tr>
<tr>
<td>Building physical condition</td>
<td>Structurally unsafe, fire damaged, gutted, overgrown, water damaged, weathered, vandalised</td>
</tr>
</tbody>
</table>
Building materials | Timber, concrete, steel, aluminium, brick, gypsum etc.
---|---
Property access | Site access, mobility

These physical conditions can be used to assess and rate building deconstruction potential according to an agreeable rating scale. For instance, the NAHB Research Centre used a rating scale as presented in Table 9 to assess the deconstruction potential of buildings in DC, USA.

<table>
<thead>
<tr>
<th>Rating</th>
<th>Meaning</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>No deconstruction potential</td>
<td>Buildings in good condition, suitable for renovation.</td>
</tr>
<tr>
<td>AA</td>
<td>Some potential</td>
<td>Buildings have been fire damaged and gutted, deconstruction may not be cost effective. Maybe demolition is a better option.</td>
</tr>
<tr>
<td>AAA</td>
<td>High potential</td>
<td>Buildings with high value materials, suitable for deconstruction.</td>
</tr>
</tbody>
</table>

Generally, concrete and steel structures (e.g. high rise buildings) are not suitable for structural building deconstruction⁶. However, after mechanical demolition the concrete and scrap steel can be recovered for recycling. Brick buildings can be structurally deconstructed⁷. The decision to deconstruct will be determined by the cost of material salvage compared to its resale value. Timber structures are by far the most attractive buildings for structural deconstruction because of the quality and immediate reusability of the salvaged materials.

Non-structural deconstruction can be conducted in all of the types of buildings presented above. Typical items that can be salvaged include cabinetry, water heaters, boilers, windows, doors, sanitary ware, appliances etc.

**Note:** Different countries use different building methods and materials. For instance timber construction is used extensively in the US while South Africa mainly uses brick and concrete. This will have significant impact on the feasibility and type of deconstruction as well as the secondary materials markets.

6.2 Economic factors

The economic potential of building deconstruction depends mainly on the relationship between the availability of buildings with salvageable materials and the market demand for salvaged materials [17]. Some of the factors that influence this relationship include the local economy and construction activity in the area, the salvaged materials infrastructure, government programs and incentives.

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⁶ Unless mechanical processes will be used for deconstruction and local policy allows the reuse of recovered beams and slabs after testing, as was the case in Maassluis, Netherlands [18].
⁷ One example is the Riverdale case study [7].
**Local economy and construction activity**

A strong (growing) economy and a growing population stimulate activity in the real estate market [19]. This increases the demand for land for both business and residential purposes. The land earmarked for development may be occupied or unoccupied. In the case of occupied land, obsolete buildings may have to be removed to make space for new ones. This presents an opportunity for the use of building deconstruction.

** Salvaged materials infrastructure**

The supply and demand of salvaged building materials can determine the success or failure of building deconstruction. The salvage and collection of secondary building materials is only half the effort, the other half is being able to distribute the materials to end markets. The latter requires investment into used building material businesses and material storage facilities in order to ensure distributions points for material supplies. Also, the end markets rely on the consumer demand for secondary materials, which in turn depends on the perception of secondary materials.

**Government programs**

Government initiatives play a significant role in the promotion of building deconstruction. For instance:

- The Canadian government has implemented what is known as the Adaptive Reuse Conversions (ARCs), which is basically the refurbishing of old buildings [20].
- The District of Columbia in the US has implemented the Homestead Housing Preservation Program aimed at redeveloping existing buildings in the area [19].
- A number of cities in the US have implemented programs that link deconstruction training with other job training initiatives. This initiative has been successful in developing the skills of the unemployed, the youth and ex-offenders in construction trades while supplying the construction industry with low-cost labour [21].

All of these initiatives have the potential to stimulate deconstruction activity.

**Incentives**

Building deconstruction can be promoted by the introduction of incentives. This is a proactive approach of ensuring environmentally responsible construction practice while benefiting those involved. Some examples of incentives that have been introduced to stimulate deconstruction include:

- The technical and financial support of secondary material businesses that distribute and/or manufacture products from salvaged C&D waste.
- The provision of tax deductions for salvaged material and other tax relief measures.
- The provision of affordable prices and loans for the acquisition and redevelopment of abandoned or old houses [19].

6.3 Policy and regulations

Building deconstruction requires a lot of support from government if it is expected to succeed. One such support is the development of policy that promotes deconstruction activity. Policy support can take one of two forms:
Direct support for deconstruction

Local authorities can formulate policies aimed specifically at the promotion of deconstruction and material salvage. For instance the city of Portland, Oregon in the US undertook a program to aggressively support deconstruction, salvage, reuse and recycling. Driven by C&D waste statistics, Portland set targets for waste diversion from landfill sites, demanded recycling programs from construction projects, increased landfill tipping fees and enforced regulations.

Indirect opportunities for deconstruction

Government can develop various policies, in different sectors, that are driven by the common goal of achieving sustainability. Such policies can where appropriate, present a window of opportunity for the use of building deconstruction. For instance:
- Local economic development policy – deconstruction can play a significant role in the creation of employment, training of labour in construction trades, SMME development and in creating a new economic stream, i.e. secondary markets.
- Redevelopment/Preservation policy – deconstruction can find application in the restoration and renovation of historic and abandoned buildings.
- Environmental policy – deconstruction can be a preferred technique for environmentally responsible building removal (reduced pollution and energy conservation).

Sometimes all that may be required are minor changes to existing policies and regulations in order to stimulate deconstruction activity e.g. salvage time constraints relating to the period between the granting of a demolition permit and the commencement of new construction and specifications that require virgin material use only.

6.4 Secondary materials markets

As indicated earlier, the success of building deconstruction depends on the supply and demand of salvaged building materials. Not only do we need to make sure that there is a supply of secondary materials, we also need to locate end markets and ensure rapid distribution.

Salvaged material supply

Secondary markets require a constant supply of consistent material. This is possible if deconstruction is taking place in an area where a significant amount of building stock has been identified for demolition. In many cases, building deconstruction encounters problems related to storage space for salvaged materials. Support should thus focus on the provision of storage space in areas where deconstruction is being promoted. In underdeveloped markets deconstruction projects may occur in areas that are far from secondary markets, which has high transport cost implications.

Salvaged material distribution

In order to successfully collect and distribute salvaged materials efforts should be focused on developing sustainable secondary market infrastructure [19]. Investment should be injected into the establishment of secondary material businesses such as used building material stores, recycling companies that convert salvaged waste into secondary materials and product manufacturers that use secondary feedstock.
End markets

Salvage markets so far indicate two types of consumers, high-end buyers who generally want quality-salvaged material e.g. materials with historical or architectural value and low-end buyers who want affordable building materials. Improved material supply and distribution can serve these markets better and possibly even increase the demand.

Other end markets that could potentially increase the demand for secondary materials in future include “green clients” and “green practitioners” who are committed to developing environmentally friendly buildings, and sustainable communities that have set goals for themselves because of various reasons e.g. historical significance, style, socio-economic status, environmental awareness and so on. Government should also lead by example in the use of “green materials”.

Note: A balance should be maintained between efforts dedicated towards secondary market development and those for identifying secondary material resources. For instance, if secondary businesses are developed, will they have enough material supply to keep them in business? If the demand for secondary products increases, will customers get the supplies they need immediately?
7. Benefits of building deconstruction

Deconstruction re-emerged at the end of the twentieth century after approximately fifty years of decline (during which it was substituted by the favoured mechanical demolition process) [10]. The large part of the twentieth century was driven by technology and efficiency, which aimed to advance humankind and create first world economies, but towards the end of the century the world had to finally come to terms with the consequences of over-consumption and environmental abuse. Deconstruction is particularly useful because it presents an opportunity for the construction industry, which is one of the largest industries in the world, to contribute to environmental restoration and preservation. Since C&D waste impacts on more that just the construction industry and the waste sector, (i.e. also the environment, road construction, housing and, trade and industry) improvement in its management will have a huge footprint of positive impacts.

The benefits of building deconstruction can be described according to their historic, social, environmental and economic impacts.

Historical

Older buildings often contain craftsmanship, which has significant value to collectors. Deconstruction can carefully salvage these important historical architectural features because materials are preserved during removal [12]. Deconstruction can also help preserve buildings of historical significance through selective disassembly and renovation or building relocation. Furthermore, old buildings usually contain valuable materials that are no longer available in the market or are very expensive to acquire due to scarcity. Through deconstruction these materials can be made available to the discerning buyer.

Social

Deconstruction can create employment opportunities for unskilled and low-skill labour. Whereas demolition employs a few people to operate mechanical equipment, deconstruction creates more labour hours for building disassembly. Previous studies also show that for every landfill job created, resource recovery creates ten [12]. Deconstruction has two main spin-offs for the construction industry viz. deconstruction trains labour in construction trades thereby creating a bigger labour resource pool. Also, deconstruction can absorb labour from the construction industry during retrenchments.

Deconstruction presents a good opportunity for community regeneration by creating employment opportunities on a local scale and using local resources to dismantle, collect and distribute secondary materials. Salvaged material distribution also presents and opportunity for the development of new businesses e.g. used building material stores. Furthermore, material salvage provides communities with affordable building materials.

Environmental

Possibly the most important benefits of building deconstruction are unfortunately financially un-quantifiable and thus usually go unnoticed when building costs are assessed. Building deconstruction helps divert large volumes of C&D waste away from landfill sites. This helps conserve landfill airspace and extend the life of landfills. The recovered waste material is reused in construction, replacing virgin materials. This reduces the demand for virgin material
extraction, thus preserving our natural resources. Reduced material extraction reduces the pollution associated with extraction and subsequent beneficiation and transportation of virgin materials. Also of major significance is the reduction in energy consumption related to the processes of extraction through to virgin material supply on site.

Building deconstruction allows for a thorough inspection of buildings for hazardous substances, which are otherwise sometimes missed by demolition. This allows for the appropriate and safe disposal of hazardous waste material. Deconstruction also reduces airborne asbestos and lead particles from building explosions as well as dust. The salvage of materials for reuse conserves the embodied energy that is already contained in the materials in buildings. Building deconstruction helps close the loop on material flows thereby contributing to resource recovery in construction.

Economic

Not only does deconstruction have sociological and environmental benefits, but it also makes economic sense. Building disassembly and material salvage for reuse and recycling can save costs and generate extra revenue for business. The economic benefits include:

- Cost saving from avoided transportation and disposal costs of C&D waste.
- Delayed capital expenditure for the development of new landfills due to extended lives of existing landfill sites.
- Delayed closure costs for existing landfills.
- Cost savings from avoided procurement costs of virgin materials.
- The development of a new economic stream i.e. the secondary materials industry of retail businesses for salvaged materials, recycling businesses and recycled content product manufacturers.
- Revenue generation from the resale of salvaged waste materials.
- Improved financial performance of the construction industry due to reduced energy and pollution costs.

It is important to note that current trends in global business practice indicate that opportunities for business are enhanced by the adoption of “green practice”. Compliance with environmental management policies can help boost a company’s image.
8. Deconstruction versus demolition

Definition – Deconstruction means dismantling buildings with the goal of maximising the reuse potential of its components. Demolition, by contrast, means the razing of a building in such a way that the building components are fit for nothing more than recycling and landfill.

Process – Deconstruction uses labour and sometimes mechanical equipment to some extent to disassemble buildings and salvage building components firstly for reuse and secondly for recycling. Demolition on the other hand uses mechanical equipment to tear buildings down converting materials with potential resale value to mixed debris destined for landfill.

Duration – Demolition takes a few days while deconstruction takes a few weeks.

Economics – the economics of demolition and deconstruction (contractor’s perspective) are defined by equations (a) and (b) respectively [22].

(a) \[ \text{Net Income} = (\text{Price paid by owner}) - (\text{Pre-Demolition + Demolition + Transport + Disposal}) \]

(b) \[ \text{Net income} = (\text{Price paid by owner + Salvage Value}) - (\text{Pre-Deconstruction + Deconstruction + Processing + Transport + Disposal}) \]

The cost of deconstruction ranges between slightly higher than demolition to lower than demolition. Deconstruction can cost the same as demolition when all economical factors are considered i.e. including salvaged material resale value, avoided transport and disposal costs and the associated life cycle costing of landfill sites.

According to equation (a), the net income of demolition can be increased by the increase in the diversion of C&D waste from landfill to recycling. However, the mixed nature of demolition C&D waste would increase the pre recycling costs of sorting and screening, possibly removing the advantage of the exercise (unless of course some source control is practiced – essentially a move towards deconstruction).

According to equation (b), the net income of deconstruction can be increased in two ways viz. training and planning labour activities to make deconstruction and processing more efficient, linking salvage material quality to prevailing market resale value to avoid cases where salvage cost > resale value. Increasing landfill tipping fees will favour deconstruction and have a negative impact on demolition.

There are a number of questions that can be raised to argue the case for promoting deconstruction in favour of demolition. These include:

1. Time vs. employment – deconstruction takes longer because it is a labour intensive process, but it creates more employment opportunities than demolition. If a mandatory waiting period between granting demolition permits and commencing new construction were introduced, the current advantage would be removed from demolition.

2. Labour vs. salvage – the main cost of deconstruction is labour. It can be offset by the resale of salvaged materials. This relationship however, depends on issues such as the state of secondary markets and public perceptions of secondary materials.
3. Disposal vs. diversion – the environmental benefits of diverting waste from landfill sites are important and should be included in building assessments (i.e. environmental costs in life cycle costing).

4. Avoided costs vs. incurred costs – deconstruction presents an opportunity to avoid C&D waste transport and disposal costs as well as virgin material procurement costs, not to mention the delayed capital costs of landfill closure and new landfill development.
9. Conclusions

- Building deconstruction is concerned with the dismantling of buildings to maximise material salvage for reuse. This technique can be easily located in the model for sustainable construction, which presents sustainability principles that need to be applied to the resources used in a building at the various stages of a building’s life.

- Building deconstruction is not only a technique for building removal that can be used to improve the performance of demolition contractors, but it can also be used as a waste minimisation strategy to reduce the waste generated by the construction industry, it can be used as an urban renewal tool to help dismantle, renew and reuse old and abandoned buildings and it can also be used as a community economic regeneration strategy to help create employment, local businesses and use local resources.

- Salvaged building materials can serve the low-end markets of low-income communities that are looking for affordable building materials as well as the high-end markets of discerning buyers that are looking for quality in salvaged materials. In addition, a new breed of markets are developing which consists of “green” clients and practitioners that want to develop “green” buildings out of commitment to environmental responsibility in construction.

- The process of deconstruction is basically ‘construction in reverse’ and predominantly uses labour intensive methods. This makes it a good tool for training workers in construction trades. This has two main spin offs for the construction industry, i.e. it creates a large resource pool for labour and can absorb excess labour from the construction industry.

- Because deconstruction is a labour intensive activity, labour issues, environmental issues and occupational health and safety issues require special attention.

- If feasible, building deconstruction can support a secondary construction materials market and guarantee the supply of secondary materials to meet the demand.

- Designers need to increasingly consider design for deconstruction during the design stage of a building because the decisions made during design affect the deconstructability of a building at its end-of-life. (Incorporating design for deconstruction will ensure that the subsequent building stages of remodelling, repair and removal are conducted more efficiently.)

- A feasibility study needs to be conducted before a decision to implement deconstruction can be made. The feasibility depends on physical conditions e.g. available building stock and the building condition and economic conditions e.g. local economic and construction activity and secondary markets.

- Deconstruction has economic and social benefits that can contribute to the economy and help improve people’s lives, but perhaps the most important are the often-unnoticed environmental benefits.

The feasibility of building deconstruction will vary with region, country and continent, mainly because different areas use different building methods and materials. If applicable, deconstruction can become a giant step in the construction industry’s quest to achieve sustainability in construction (in all three pillars i.e. economic, social and environmental).
10. Case Studies

10.1 USA - Fort Ord Pilot Deconstruction Project, Reference [10]

Background

The Fort Ord US Army Military Reservation was on the first list of US military bases that were earmarked for closure or realignment and conversion to civilian use. The base had a total area of 28 000 acres with 7000 buildings, approximately 1200 of which did not meet civilian building code requirements and had to be removed. Initial work was done to identify suitable reuse of the base and to determine a more environmentally effective approach to remove the substandard buildings and abate hazardous substances. Some of the issues related to base reuse that were considered include land use, economic development, education, housing, utilities, infrastructure, pollution cleanup, health, community and public services.

The Fort Ord Reuse Authority (FORA) was formed to prepare, adopt financing and implement a plan for the development of the former base. The FORA development plan covered commercial, leisure, residential and recreational development. The plan’s underlying principles were to ensure that economic development would not take place at the expense of the environment and to identify environmentally appropriate and economically sound methods to address this. FORA adopted a combination of deconstruction, structure relocation and aggressive recycling for building removal, however demolition was left as an option in case funding, markets or other feasibility factors indicated that it would be a cost effective option. FORA received a grant of $200 000 from the David Lucille Packard Foundation to explore deconstruction methods that could result in reduced cost to the reuse of Fort Ord.

Institutional

The Fort Ord project represents one of the good examples of partnerships in building deconstruction. FORA executed the project in conjunction with the University of California at Santa Cruz (UCSC). The project was directed and guided by a technical support group that comprised representatives from academia, business, communities, labour, government and the construction industry.

Objectives

The purpose of the FORA Pilot Deconstruction Project was to explore and examine deconstruction methods that could result in reduced cost to the reuse of the former Fort Ord Military Base. The project focus was on identifying and developing processes to handle materials, determining the best ways to isolate and dispose of hazardous waste and serving as a model for reuse. Part of the outputs of the project were training course material that was developed to train labour in the Fort Ord project and also to be incorporated into the curriculum of USCS as well as video footage of deconstruction activities to supplement the project report and training material.

Building disassembly

The deconstruction project was implemented in April 1998. Four representative buildings (timber structures) were deconstructed, an additional three were relocated and one concrete building was disassembled. The buildings were deconstructed in the following sequence:
i. Removal of fixtures and appliances
ii. The roof
iii. The walls and
iv. The floor

The buildings were deconstructed predominantly using labour intensive methods. All workers were given basic training in construction trades and lead awareness prior to the commencement of the project. All reusable materials were removed, processed and stored inside a storage warehouse. Recyclable waste was stored in recycling containers and all remaining unwanted waste was disposed in waste container for landfill. All asbestos containing materials were removed and abated by a licensed asbestos abatement professional, while lead based paint containing materials were removed by trained workers.

Salvaged materials management

The Fort Ord deconstruction project provided diversion rates in the range of 60-90% for the four deconstructed houses. The materials that were predominantly offered for sale were pre-sorted stacks of structural lumber. Other materials that were for sale include fluorescent lights, ceiling tiles, wood flooring, and furnaces. There was a demand for salvaged windows, but these were not sold because they contained lead based paint. In summary, the analysis of the secondary material sales and markets is as follows:

- A total revenue of $3000 was made from the sale of a portion of the materials salvaged from one of the buildings.
- Over 1000 pieces of deconstructed structural lumber were re-graded and shipped to the US Department of Agriculture (USDA) Forest Products Laboratory for strength testing.
- The bulk of the consumers showed satisfaction with a price value equivalent to 50% of the retail price of virgin materials.
- Salvaged materials were sold locally to determine the local secondary materials market, which was found to be in a radius of 75 miles (120km) around Fort Ord.
- The contractors bids were typically low. They said that larger volumes of materials and more emphasis on material trimming to standard sizes would increase the interest and willingness to pay higher prices. Also cited was the need for lumber grading to increase consumer confidence.
- The secondary materials that were sold found use predominantly in agricultural and storage applications.
- Consumers in the area were found to be educated professionals.
- The reasons for buying salvaged materials included superior quality, perceived value of material compared to its cost, environmental sympathy to reuse concepts and past success with secondary materials.
- Material storage in a central storage warehouse resulted in double handling and material damage.
- Salvaged fixtures and appliances did not appeal to this buying group.

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8 Initial estimates – final estimates were not available yet due to some complicating factors such as the storage of hazardous materials for research, which would possibly be disposed eventually and recyclable materials that were uneconomical to recycle.
Summary

The Fort Ord pilot deconstruction project was successful in demonstrating deconstruction to be an environmentally appropriate alternative for building removal. Large quantities of waste were diverted from landfill sites and some were sold for reuse elsewhere. The project was also successful in serving as a model for reuse. It produced training material and video footage of the deconstruction process for future use at Fort Ord and in other similar projects elsewhere. FORA also developed a website for networking and communication with relevant stakeholders involved in deconstruction. Finally, the project identified possible areas for future research in order to advance knowledge in building deconstruction.

10.2 USA – Riverdale Deconstruction Project, Reference [7]

Background

The Riverdale Village housing development is located in Baltimore, Maryland. The village has a total of 1100 housing units, approximately 600 of which are owned by the Maryland State Office of Housing and Urban Development (MSOHUD) with the remainder privately owned. The building units consist of 25 two-storey brick veneer buildings, most of which contain 20 to 24, four-plex units. All 600 of the MSOHUD owned building units were slated for demolition to allow for the future development of the area into a public park.

The MSOHUD was interested in the potential for using a new approach to building removal at Riverdale. It offered to allow access to any building that would be needed for this purpose. This resulted in the decision to manually deconstruct and salvage a 2000 square foot (~186m²) four unit building in the Riverdale site. This project was particularly important because it would serve as a demonstration project for the feasibility of deconstructing public housing. The information gathered in this project would be useful in the decision making for the removal of about 200 000 public housing units across the US that have been slated for demolition by the HUD.

Institutional

The Riverdale deconstruction project was sponsored by the US Environmental Protection Agency’s (EPA) Urban and Economic Development Division. The property owner, as indicated earlier, was the MSOHUD. The National Association of Home Builders (NAHB) Research Center was appointed project manager to handle aspects such as site identification, the appointment of a prime contractor and, site monitoring and management. In addition, a deconstruction specialist was appointed to provide expert advise on deconstruction techniques on site.

Objectives

Many questions have been asked about how and under what conditions building disassembly and material salvage can be cost-competitive with standard demolition. Previous studies have investigated answers to some of these questions particularly for heavy timber framed structures. This project intended to investigate some of these issues for light frame brick buildings.

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9 “Light frame” usually refers to structures of three storeys or less, usually stick framed in wood.
The objectives of the Riverdale case study were:

- To identify major issues hindering deconstruction as an alternative to conventional demolition
- To determine unit labour requirements (hours per square foot or linear foot of material) for specific deconstruction activities
- To evaluate jobsite practices such as sequencing, layout of operations, tools and workers required and the flow of materials
- To determine market opportunities and values of salvaged building materials
- To disseminate information on building disassembly and salvage

The project focused on hazardous materials since deconstruction is predominantly labour intensive. In addition, the project tried to ascertain the impact and application of environmental, health and safety legislation to deconstruction.

**Building disassembly**

The building was essentially deconstructed in the reverse order of construction with the components that were installed last going first and so on. The general sequence of deconstruction was:

- Removal of fixtures and appliances
- The floor finish
- Chimney top
- Interior walls
- The roof
- 2nd storey walls
- 2nd storey floor
- Stairs
- Lower storey walls
- Floor

The building was deconstructed predominantly using labour intensive methods. Mechanical equipment (truck) was used to collapse brick walls. All workers were given basic training in construction trades and lead awareness prior to the commencement of the project. Salvaged materials were processed (i.e. de-nailed, cleaned, sorted, bundled and stacked) and stored either indoors or outdoors depending on sensitivity. Recyclable waste was stored in recycling containers and all remaining unwanted waste was disposed in waste container for landfill. All asbestos containing materials were removed and abated by a licensed asbestos abatement professional, while lead based paint containing materials were removed by trained workers.

**Project results**

The labour requirement study produced some interesting results that were presented in various forms including:

- Labour time requirements per task performed
- Labour time requirements per building component (see Table10)
- Brick recovery rate by floor of building
- Labour time requirement per task category (see Table 11)
Table 10: Time required per building component (as percentage of total), source [7]

<table>
<thead>
<tr>
<th>Item</th>
<th>Building Component</th>
<th>% of Total Labour Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>Structural</td>
<td>Masonry (incl. chimney)</td>
<td>41</td>
</tr>
<tr>
<td></td>
<td>Wood framing, sheathing</td>
<td>28</td>
</tr>
<tr>
<td>Weather - proofing</td>
<td>Asphalt shingles</td>
<td>4.8</td>
</tr>
<tr>
<td></td>
<td>Windows</td>
<td>1.6</td>
</tr>
<tr>
<td>Finish</td>
<td>Plaster</td>
<td>10.9</td>
</tr>
<tr>
<td></td>
<td>Oak strip flooring</td>
<td>5.9</td>
</tr>
<tr>
<td></td>
<td>Doors, door frames, baseboards, trim</td>
<td>2.6</td>
</tr>
<tr>
<td></td>
<td>Plumbing fixtures, appliances, cabinets</td>
<td>2.3</td>
</tr>
<tr>
<td></td>
<td>Bathroom tiles</td>
<td>0.4</td>
</tr>
<tr>
<td>Other</td>
<td>Piping, wiring</td>
<td>1.3</td>
</tr>
<tr>
<td></td>
<td>Gutters, fascias, rakes</td>
<td>0.4</td>
</tr>
</tbody>
</table>

Table 11: Time required per task category, source [7]

<table>
<thead>
<tr>
<th>Task Category</th>
<th>% of Total Labour Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>Disassembly</td>
<td>37</td>
</tr>
<tr>
<td>Processing</td>
<td>55</td>
</tr>
<tr>
<td>Production Support</td>
<td>8</td>
</tr>
</tbody>
</table>

Deconstruction and material salvage at Riverdale managed to divert 70% of C&D waste by volume and 76% by mass. Table 12 gives a summarised breakdown of the diverted C&D waste material.

Table 12: Management of materials, source [15]

<table>
<thead>
<tr>
<th>Salvaged Materials Management</th>
<th>Description</th>
<th>Volume</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cubic Yards</td>
<td>%</td>
<td>Tons</td>
</tr>
<tr>
<td>Diverted</td>
<td>192.5</td>
<td>70</td>
<td>96.5</td>
</tr>
<tr>
<td>Reused</td>
<td>81.5</td>
<td>30</td>
<td>29.1</td>
</tr>
<tr>
<td>Recycled</td>
<td>111.0</td>
<td>40</td>
<td>67.4</td>
</tr>
<tr>
<td>Landfilled</td>
<td>81.0</td>
<td>30</td>
<td>30.7</td>
</tr>
<tr>
<td>Total</td>
<td>273.5</td>
<td>100</td>
<td>127.2</td>
</tr>
</tbody>
</table>

The Riverdale project evaluated four methods of marketing salvaged materials viz. direct marketing, using a broker, regional/periodic auctions and a site sale. A decision was made to use a site sale and not pursue the other options\(^{10} \). The site sale generated total revenues amounting to $2440. Total costs for building deconstruction with the sale revenue and recycling included amounted to an estimated range of $9021-$10 802. In comparison, demolition cost estimates were in the range of $7000 - $10 000.

\(^{10}\) The reasons for this decision were:
Direct marketing – limited interest from potential buyers
Broker – difference in price between broker and project team
Auction – concerns with cost effectiveness
Note: Final deconstruction figures could not be calculated because some of the salvaged material had not yet been sold.

Summary

The Riverdale project was able to demonstrate that brick low-rise buildings can be deconstructed, however an assessment of the relative cost of salvage and the market value of salvaged materials should be made. The project produced important information that relates to labour requirements for a deconstruction project, detailing time requirements per task, building component and deconstruction category. This information will be useful in future planning for the use of deconstruction in building removal projects. The project was able to disseminate the findings in order to encourage networking and communication for the advancement of the technique of building deconstruction. The project also identified areas that needed further research.

10.3 Netherlands – Reuse of apartment buildings in Maassluis, Reference [18]

Background

The apartment buildings in Maassluis, a community located not far from Rotterdam, were constructed in the sixties and seventies. Most of these apartments were built with what is known as the Elementum System\(^{11}\) (i.e. a prefabricated concrete building system). The five storey buildings were designed to have a life of 70-80 years however, they became obsolete in just 30 years (due to reasons other than structural integrity) and were slated for demolition. In 1997 the Netherlands passed legislation that prohibits the disposal of reusable C&D waste in landfill sites. The norm has thus recently been to demolish buildings and recover waste materials for recycling purposes, for instance concrete waste is crushed and used almost exclusively for road construction.

The project team was concerned with the potential loss of useful building elements that could be reused for long periods still. It was decided that other possible options should be explored instead of demolition and recycling. For this purpose, the project team used what is known as the Delft Ladder (see Figure 2), which is a hierarchy of end-of-life scenarios for buildings that are slated for removal.

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**Delft Ladder**

1. Prevention  
2. Object renovation  
3. Element reuse  
4. Material reuse  
5. Useful application  
6. Immobilisation with useful application  
7. Immobilisation  
8. Incineration with energy recovery  
9. Incineration  
10. Landfill

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\(^{11}\) The Elementum system assembled factory made prefabricated walls and floors on site during construction. The Elementum factory was located in Maassluis so this system was used extensively in the area.
After a detailed analysis of all available options it was decided that the following options applied:

- Object renovation – reuse of concrete skeleton
- Element reuse – reuse of elements (at another site)
- Element reuse – reuse of foundation
- Material reuse – reuse of concrete, roof gravel
- Incineration – wood and insulation for energy recovery
- Landfill – asbestos containing materials

A decision was made to reuse the apartment buildings. The existing buildings would be selectively deconstructed to recover useful elements for reuse during remodelling. One complicating factor to the reuse option was the change of regulations since the buildings were first constructed e.g. the wall elements of the old buildings did not meet the current sound insulation requirements and structural sections needed to be tested before reuse.

**Institutional**

The project team consisted of the housing association that owned the buildings, a demolition contractor and a building contractor. The project did not receive government funding.

**Objectives**

The main aim of the project was to explore the potential for a higher-level use of potential building waste that would otherwise be reduced to materials suitable only for recycling. This had to be done with due consideration for the technical, environmental, economic and regulatory aspects as they relate to building remodelling and removal.

**Building disassembly**

A total of six buildings were dismantled either partly or completely. Two of the buildings were stripped and joined horizontally to improve the floor area. An extra floor was subsequently added to these buildings. The top three floors of the other three buildings were deconstructed. The remaining floors were remodelled as single-family dwellings. The sixth building was completely demolished except for the foundation, which was used for new dwellings. The general sequence of deconstruction that was adopted was:

1. Removal of fixtures
2. The roof
3. The walls
4. The floor
5. The foundation

The buildings were deconstructed using mechanical equipment. The project team discovered discrepancies between the building designs and the as built structure e.g. the designs specified a sand-cement grout to fill the connections between the walls and the floor, but the contractor used a stronger mix. This made the disassembly process very difficult and resulted in many damaged elements that were not suitable for reuse. Recovered elements were stored on site and all recyclable materials were sent to recycling companies for reprocessing. All asbestos

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12 The buildings were high-rise concrete structures that were not suitable for labour methods.
containing materials were removed before the commencement of the project and disposed accordingly.

**Materials management**

Good quality salvaged building elements were reused in the remodelling of the apartments. The recovered walls could only be used as interior walls because they did not meet the sound requirements.

A large proportion of the salvaged elements could not be reused because they were damaged during disassembly. The problems related to discrepancies in connections and the techniques used for dismantling led to the concrete elements being crushed to secondary materials and used for road construction on site.

Wood recovered from the building façade and the insulation material were incinerated for energy recovery.

**Summary**

This project was a first in the Netherlands and presented a learning opportunity for similar projects in future. The Netherlands has about 2 million apartments of this kind that were built between 1940 and 1980, many of them do not meet today’s requirements and will most likely follow the same route. The project team was innovative in evaluating available options using the Delft ladder of end-of-life scenarios, instead of settling for the conventional demolition for recycling option. The Maassluis project was a learning opportunity and as a result incurred huge costs related to dismantling techniques, building design, reusability of disassembled concrete elements, time constraints, lack of government funding and changing regulations. The project however, demonstrated the feasibility of deconstructing and reusing apartment buildings instead of demolishing them. The project also helped identify areas for future research to advance the field of building deconstruction.
11. References


13. Bowes Helen and Golton Byron, *Obsolescence and Demolition of Local Authority Dwellings in the UK – A Case Study*, University of Salford, UK and University of Vasco de Gama, Portugal, prepared for the CIB World Congress meeting of CIB Task Group 39 on Deconstruction, New Zealand, April 2001.


APPENDIX A
Appendix A: Principles and a model for sustainable construction

Adopted directly from: Proceedings of the Conference on Sustainable Construction

Principles for Sustainable Construction

Technical criteria for materials selection viz. embodied energy, greenhouse warming gases and toxics generated/content are too difficult to apply in the real world of construction. In the past the criteria for energy and water resources were not connected to one another, to materials selection, or to the other issues of sustainable construction.

In this light a major challenge is establishing the principles of sustainable construction and creating a common vocabulary that can be used to exchange information, define methods, create appropriate materials, transition technology, and accomplish other related activities. The principles must be sufficiently broad to cover the issues of sustainable construction and flexible enough to adapt to evolving technologies. They must also be easy to utilize to evaluate alternatives. Creating the built environment with environmental awareness and sensitivity would be the outcome of using the principles.

For the purposes of this discussion, we must first define what is meant by “construction industry.” We will use the broad definition: all parties that design, build, alter, or maintain the built environment over its life cycle: developers, planners, architects, engineers, builders, and operators. We can further separate the industry into two layers. Layer 1 are those agencies who most influence the physical content and creation of the built environment because they have design and execution roles: architects, engineers, and builders. This triumvirate uses the sustainability principles to specify and lay out the structures and infrastructure of the built environment and then bring the resources to the site to construct the structures. Layer 2 are those units who influence the built environment on either end of the construction process: developers, planners, and operators. Developers have powerful influence over the location of elements of the built environment and the fate of the land that will be utilized. Planners spell out the details of the interaction of the individual components or units of the built environment. Operators or facility managers begin a huge investment of energy and other resources over the life cycle of the building and need to be integrated into the process so that they will insure the principles of sustainable construction are kept in mind.

To begin the development of these principles we must first understand that sustainable construction is just one component of creating an overall sustainable environment. This latter overarching goal has the direction of insuring that we leave the world in a condition that will allow future inhabitants to enjoy at least the quality of life we have experienced. Simply put this can be accomplished by eliminating (1) resource depletion, and (2) environmental degradation. As noted earlier we can add (3) create a healthy environment, accounting for the need to have good interior and exterior environments. Sustainable construction principles must also focus on these three goals in order to make sense and have merit.

We will define the resources to create the built environment as: energy, water, materials, and land. There are arguably other resources such as human energy and creativity, waste materials, and information. Water may also be considered to be a material. However for our
purposes the division of resources into these four categories is logical and useful. We can then propose Six Principles of Sustainable Construction (Figure A1).

![Figure A1: The principles of sustainable construction](image)

Each of the Six Principles has huge ramifications that need exploration. The Sixth Principle is a repeat of one of the traditional criteria, but is included because of a new sense and importance attached to it. The following sections cover the principles in sufficient detail to underscore their importance and the range of their application.

**Principle 1: Conserve**

Another label for the First Principle might be the Conservation Principle because this is its essence. It is the starting Principle because it contrasts the major problem that forces us to address sustainability in the first place: over-consumption. It leads us to the use of passive measures to provide heating, cooling, ventilation, and lighting for our structures because the minimization of energy consumption is an absolutely essential. It forces us to consider high efficiency systems, high levels of insulation, low flow fixtures, and high performance windows. It also leads us to the use of durable materials that have long lifetimes and require low maintenance.

**Principle 2: Reuse**

In addition to reducing resource consumption to the minimum we need to consider that it is highly desirable to reuse resources we have already extracted. Reuse contrasts to recycling in that reused items are simply used intact with minimal reprocessing while recycled items are in essence reduced to raw materials and used in new products. A significant business in architectural items such as windows, doors, and bricks that can be reused in new construction and renovation has proven to be profitable as owners and architects strive to recapture a sense of the past in new spaces. Other resources such as water can be reused via use of greywater systems and use of third main systems. Land can be used by creating new spaces in “grey zones,” areas formerly used for buildings.

**Principle 3: Recycle/Renewable**

If resources must be used then it resources that are recyclable, have recycled content, or that are from renewable resources must have priority over others. This Principle applies to energy where renewable sources such as solar and wind power are available for use. It applies to
materials such as wood. This common construction material can be supplied from certified sustainable forests that provide the buyer with a reasonable level of assurance that the suppliers are managing their resources in a manner that protects the environment. A wide range of materials have recycled or waste content from engineered wood systems, agriboard panels, tiles with recycled tire or glass content, roofing shingles made of recycled plastics, and many others. One of the problems that must be sorted out with respect to recycled materials is to determine if their content is simply convenient waste from other industries or bona fide recycled content. Products that consist of the former may be said to be downcycled or cascaded uses with the built environment serving as a convenient dumping ground for otherwise difficult to dispose of materials. Some schools of thought would place the onus on each industry to solve its own “end of pipeline waste” problems and not simply seek out convenient large dumping grounds such as construction materials as a repository for their industrial residue. This is not a simple problem, however, nor should it be treated tritely. Fly ash, a post-industrial waste, is successfully utilized to displace cement in concrete, a high-energy content material and one of the largest generators of carbon dioxide. An inevitable by-product of steel production and power generation, it is a major disposal headache for these industries, and a waste that will be produced for many decades as a consequence of dependence on fossil fuels as an energy source. One could cite several other examples that make sense at the present time but that as technical evolution and innovation occur, may be relegated to their proper place.

**Principle 4: Protect Nature**

Inevitably our actions in creating the built environment will impact the natural environment and its ecological systems. Considering the past negative effects on the natural environment, perhaps it is time to do better than just “sustain,” but to “restore” where possible. Grey zones can be remediated, detoxified and returned nearly to their original state. The abuses of river straightening, marsh draining, and deforestation can be remedied by intelligent intervention in creating the future built environment. In our quest for materials we can scrutinize the impacts of materials acquisition practices, whether logging, mining, or consuming energy, to minimize environmental effects. Some of the choices are not easy but will inevitably be forced on us by global environmental effects, scarcity, or other reasons.

Another expression of Principle 4 is to exercise environmental stewardship. This acknowledges the human power to destroy the world’s complex ecological systems and reminds us that we must tread carefully less we destroy ourselves in the process. The complex tapestry of earth’s many natural resources evolved over many thousands of centuries and the interdependence of life forms on one another and on other resources is barely understood. Clearly we have no notion of what extinction of one life form may do to others nor do we have the smallest grasp of what the results of man’s genetic engineering experimentation may be. Our recent experience with both pesticides and antibiotics are merely preliminary warnings to what disasters may lay ahead. Creating the built environment, while perhaps not having these same complex impacts, can lead to resource depletion, destruction of plants and wildlife, water and air pollution.

**Principle 5: Non-Toxics**

Modern industry has created a wealth of miracle products, drugs, chemicals, and machines that have had many positive contributions to the quality of life of man. One of has been the proliferation of toxic substances produced by these industries that have invaded the environment and had inevitable negative effects on humans. Lead, mercury, asbestos, and dioxins come quickly to mind. The products constituting the built environment and the actual
construction of the built environment are accompanied by a wide variety of hazardous and toxic substances that ultimately threaten human health and well-being. This is another area, similar to the appropriateness of downcycling, that is not easily defined. Clearly toxic materials must be handled with care and eliminated to the greatest extent possible. One approach is to consider the ultimate elimination of these materials except in cases where the manufacturers can keep them in a closed system. An example of this is mercury, used in thermostats, fluorescent light bulbs, and television sets. Reverse Distribution, a procedure in which products are returned to the manufacturer for extraction of toxic materials for recycling into other products, is a new idea that the US EPA and others are beginning to consider for implementation.

The outcome of this Principle in a practical sense is the elimination of toxics in the indoor and exterior built environment. One of the major objectives is to achieve good indoor air quality by selecting materials that will not off-gas or contribute particulate loading to the environment. Relative to the exterior environment, landscape design should provide for the use of plants and vegetation that are hardy, drought tolerant, and insect resistant. These qualities are usually provided by vegetation native to the region. Using this so-called “xeriscaping” strategy will minimize and perhaps eliminate the application of pesticides, herbicides, fungicides, and fertilizers that ultimately end up polluting groundwater.

**Principle 6: Quality**

Although often cited and equally often abused, the notion of quality as a component of sustainable construction is vital. It includes planning of communities to reduce automobile trips, increase interpersonal activity, and provide a good quality of life. It includes excellence in design of buildings as an absolutely essential component of sustainable construction because spaces that are not valued by their occupants will, by their very nature, fall into disuse, disrepair, and disorder, contributing to the exact antithesis of what sustainability strives to achieve. Selection of materials, energy systems, design of passive energy and lighting systems, and a host of other decisions rest on the idea that significant analysis and design are required to lay out spaces, build the spaces, and occupy them.

The outcome of stating and exploring these principles is to acknowledge just how interconnected all these matters are and how badly integration of this knowledge is needed. Issues of energy crises, water shortages, air pollution, sick building syndrome, crumbling neighborhoods and infrastructure, and many others are all tightly coupled, not independent events as usually portrayed. Perhaps it may be said that one of the problems of recognizing how tightly interwoven these matters are is that the specialists in these issues have treated each of them in isolation. To solve the problems of the built environment we must discover how to integrate these isolated and compartmentalized areas of interest. Only then will we be well on our way to creating sustainable construction as an important component of a sustainable environment.

**A Conceptual Model for Sustainable Construction**

We can combine the Principles with the resources and the time dimension to create an easily understood model of sustainable construction. The simple version would have the three axes shown below in Figure A2. In each case the intersection Principle, Resource, and Time is a decision point for determining what should be accomplished with regard to minimizing resource consumption and preventing environmental damage. For example, during Design, when examining potential materials resources to be used, the Six Principles should be
followed to minimize the materials required, reuse materials if at all feasible, use recycled or renewable materials, insure the materials used did not harm the environment in their extraction, that toxics were not generated in the materials creation nor are they potential contributors to indoor environmental problems, and that the design of the materials layout and details is of high quality, with attention paid to all these issues. The design stage should also lay the foundation for future stages so that during construction and operation the excellent environmental intent of the space is able to be maintained.

Figure A2: A simple conceptual model for sustainable construction

Figure A3 is a more detailed version of the conceptual model and shows the principles, the resources to which the principles must be applied, and the stages of the built environment during which this must occur. For the sake of simplicity, the stage entitled operation also includes activities such as renovation and refurbishment.

Figure A3: A conceptual model for sustainable construction
The model can serve many functions, the first of which is the articulation of the many issues of sustainable construction. It distills a wide range of complex issues into a simple graphic that allow us to grasp, at least in a reasonable fashion, the overall idea of sustainable construction. It allows the debate to be engaged over the appropriateness of activities meant to build or maintain the built environment. A second application is a decision making tool for use in examining the options that may occur during the creation, operation, or deconstruction of buildings. In this regard it can also serve as a checklist for the sustainability issues that should be considered by the construction professions in their activities.

Principles of Sustainable Development

Adopted directly from: A Masters Thesis submission

Table A1: Principles of sustainable development

<table>
<thead>
<tr>
<th>Principles of Sustainable Development</th>
<th>Environmental</th>
<th>Economical</th>
<th>Social</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>• Conserve the earth’s vitality and diversity</td>
<td>• Promote equity between nations and generations</td>
<td>• Allow improvement in the quality of human life</td>
</tr>
<tr>
<td></td>
<td>• Conserve life support systems</td>
<td>• Avoid unequal exchange</td>
<td>• Promote social equity amongst all peoples</td>
</tr>
<tr>
<td></td>
<td>• Use renewable resources sustainably</td>
<td>• Do not impoverish one group to enrich another</td>
<td>• Allow for cultural and social integrity</td>
</tr>
<tr>
<td></td>
<td>• Minimise use of non-renewable resources</td>
<td>• Ensure real-cost pricing</td>
<td>• Foster self-reliance and self-determination</td>
</tr>
<tr>
<td></td>
<td>• Minimise pollution and damage to the environment and health of all living</td>
<td>• Encourage ethical procurement and investment policies</td>
<td>• Encourage participation and co-operation in decision making on all</td>
</tr>
<tr>
<td></td>
<td>creatures</td>
<td>• Promote equitable distribution of costs and benefits</td>
<td>levels from the individual to the international</td>
</tr>
<tr>
<td></td>
<td>• Conserve the cultural and historical environment</td>
<td>• Support local economies</td>
<td>• Empower people and provide opportunity for capacity enhancement</td>
</tr>
</tbody>
</table>
APPENDIX B
Appendix B: Waste Management and End-of-life Scenario Hierarchies

University of Florida Waste Hierarchy

Adopted directly from: TG39 CIB\textsuperscript{13} Publication 252 – Overview of Deconstruction in Selected Countries


![Waste Management Hierarchy Diagram](attachment:image.png)

Figure B1  Waste Management Hierarchy

According to the University of Florida waste management hierarchy, the priority order of dealing with C&D waste in particular begins with reduction because this produces the most beneficial effect for natural systems. This includes resource optimization during design, waste reduction through accurate material estimation and ordering, reduced packaging waste and waste prevention though innovative methods. Reuse is just below reduction and is considered to be a higher-level option compared to recycling. This is because reuse presents an opportunity to place recovered building components into direct use without processing. Reuse includes deconstruction and component/materials reuse. Third on the hierarchy is recycling, which takes three forms viz. upcycling (the creation of value added products), recycling (conventional recycling of materials into products) and downcycling (the creation of lower grade products). Composting and incineration are lower in the hierarchy with landfill being the last option.

\textsuperscript{13} Task Group 39 of the International Council for Research and Innovation in Building and Construction (CIB)
The Delft Ladder

Adopted directly from: TG39 CIB Publication 252 – Overview of Deconstruction in Selected Countries

![Delft Ladder Diagram](image)

Figure B2: The Delft ladder, a hierarchy of end-of-life scenarios

This hierarchy was adopted in the Netherlands to replace a previous ladder of waste options that was perceived to be rigid in nature. The Delft ladder is intended to be flexible, not top down and all options should be evaluated for a specific project. High on the hierarchy is prevention, which tries to prevent the production of construction and demolition waste in the first place. This can be achieved through proper design in the early stages of the building project. Second on the ladder is object renovation. This means re-use of a great part of the building on site (i.e. renovation). The third option of element reuse is possible if the old elements of a building can be dismantled without too much damage. The fourth and fifth options refer to the recovery of materials for reuse and recycling applications. Options six and seven, refer to the recovery, neutralization and reuse (if applicable) of hazardous wastes. Incineration for energy recovery and volume reduction is much lower in the ladder. The last option of landfill is prohibited in the Netherlands and thus will usually not be an option for consideration.
End-of-life Scenario Hierarchies

Adopted directly from: TG39 CIB Publication 266 – Deconstruction and Material Salvage: Technology, Economic and Policy
Title: Developing an Inclusive Model for Design for Deconstruction, by Crowther Philip, Queensland University of Technology, Australia, in proceedings of the CIB Task Group 39 Meeting, Wellington, New Zealand, April 2001.

Table B1: Levels of Hierarchy of End-of-life Scenarios

<table>
<thead>
<tr>
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<tbody>
<tr>
<td>Most Desirable</td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Reuse</td>
<td>Reuse</td>
<td>Reuse</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maintain</td>
<td>Repair</td>
<td>Maintain</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Remanufacture</td>
<td>Remanufacture</td>
<td>Recycle component</td>
<td>Remanufacture</td>
<td>Product level</td>
<td>Repair product</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Least Desirable</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Recycle</td>
<td>Recycle</td>
<td>Recycle</td>
<td>Recycle</td>
<td>Recycle</td>
<td>Material level</td>
<td>Recycle material</td>
<td>Recycle</td>
</tr>
<tr>
<td></td>
<td></td>
<td>material</td>
<td></td>
<td>material</td>
<td>level</td>
<td></td>
<td>material</td>
</tr>
<tr>
<td></td>
<td></td>
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<td>Com</td>
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<td></td>
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<td></td>
<td></td>
<td>Landfill</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Landfill</td>
</tr>
</tbody>
</table>

Table B1 has a common thread through the various options proposed by the different authors. It indicates a consideration to a possible use of a building “as is” before demolition i.e. building reuse, the recovery of building elements for immediate reuse elsewhere i.e. component reuse, the reuse of materials on site or in the manufacture of other components i.e. material reuse and the input of materials into processed to manufacture new materials and products i.e. material recycling. Composting, incineration and landfill are again shown as the least desirable options for C&D waste management.

14 Fletcher uses three main levels of a building:
Systems level: An adaptable building, which can change to suit a changing requirement
Product level: The products (or layers) of the building that are designed to allow upgrading, repair and replacement.
Material level: The constituent elements of a product that can be recycled.
References in Table B1

Young JM *Life Cycle Energy Modeling of a Telephone*,


Fletcher SL, Popovic O and Plank R, *Designing for Future Reuse and Recycling*,
Proceedings of the "Deconstruction - Closing the Loop" conference, BRE, Watford, UK, 18 May 2000


Kibert C J and Chini AR *Overview of Deconstruction in Selected Countries*, CIB

Crowther P, *Developing Guidelines for Design for Deconstruction*, Proceedings of the
APPENDIX C
Appendix C: Building Site Assessment

Adopted directly from: NAHB Research Center Report

Building (Material) Inventory

The most important part of assessing the feasibility of deconstruction for a particular structure is a detailed inventory of how and what the building is made. Every component, its condition, and the manner in which it is secured to the structure can have an impact on the cost-effective salvage of the material.

A detailed building material inventory requires invasive inspection of the structure. This will identify hazardous materials that may have been omitted during the environmental surveys described in Appendix D, as well as identify construction methods and fasteners, which may impact the feasibility of deconstruction.

The Building Material Inventory Form (Table C1) lists the information necessary for a baseline evaluation. In addition to the form, sketching a floor plan may be helpful during follow-up calculations. Depending on the size of the building a thorough building inventory can be conducted in approximately four to 8 hours. Compiling the field notes into a written report, and preparing a final analysis of the feasibility of deconstructing the building will require additional time. With the inventory form completed the quantity of material in the building can be calculated (by square foot, linear foot, board foot, weight or volume), which will help determine the salvage value of recoverable material. (See material estimating tools)
## Building Material Assessment Form

### Building Identification:

<table>
<thead>
<tr>
<th><strong>Roof System</strong></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Wood Framing</td>
<td></td>
</tr>
<tr>
<td>Roof type (gable, hip, mansard, etc.):</td>
<td>Pitch:</td>
</tr>
<tr>
<td>Roofing material:</td>
<td># of layers:</td>
</tr>
<tr>
<td>Rafter:</td>
<td>Size: Length:</td>
</tr>
<tr>
<td>Ridge beam:</td>
<td>Size: Length:</td>
</tr>
<tr>
<td>Spacing of framing members:</td>
<td></td>
</tr>
<tr>
<td>Sheathing type (T&amp;G, butt joint):</td>
<td>Size:</td>
</tr>
<tr>
<td>Ceiling joists:</td>
<td>Size: Length:</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Exterior Wall System</strong></th>
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</tr>
</thead>
<tbody>
<tr>
<td>Masonry</td>
<td></td>
</tr>
<tr>
<td>Wythe (single or double wythe, cavity etc.):</td>
<td></td>
</tr>
<tr>
<td>Location of rebar:</td>
<td></td>
</tr>
<tr>
<td>Steel lintels:</td>
<td></td>
</tr>
<tr>
<td>Wood Framing</td>
<td></td>
</tr>
<tr>
<td>Stud:</td>
<td>Size: Height:</td>
</tr>
<tr>
<td>Plate – Top</td>
<td></td>
</tr>
<tr>
<td>Bottom:</td>
<td></td>
</tr>
<tr>
<td>Spacing of framing members:</td>
<td></td>
</tr>
<tr>
<td>Sheathing type:</td>
<td>Size: Length:</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Floor System</strong></th>
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</thead>
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<td>Wood Framing</td>
<td></td>
</tr>
<tr>
<td>Joist:</td>
<td>Size: Length:</td>
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<tr>
<td>Spacing of framing members:</td>
<td></td>
</tr>
<tr>
<td>Center carrying beam for joists:</td>
<td>Size Length:</td>
</tr>
<tr>
<td>Sheathing/Subfloor type</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Interior Walls - Wood Framing</strong></th>
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</tr>
</thead>
<tbody>
<tr>
<td>Load Bearing</td>
<td></td>
</tr>
<tr>
<td>Stud:</td>
<td>Size: Height:</td>
</tr>
<tr>
<td>Plate – Top:</td>
<td></td>
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<tr>
<td>Bottom:</td>
<td></td>
</tr>
<tr>
<td>Spacing of framing members:</td>
<td></td>
</tr>
<tr>
<td>Total linear feet of wall:</td>
<td></td>
</tr>
<tr>
<td>Partition Walls</td>
<td></td>
</tr>
<tr>
<td>Stud:</td>
<td>Size: Height:</td>
</tr>
<tr>
<td>Plate – Top:</td>
<td></td>
</tr>
<tr>
<td>Bottom:</td>
<td></td>
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<tr>
<td>Spacing of framing members:</td>
<td></td>
</tr>
<tr>
<td>Total linear feet of wall:</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Foundation – Masonry</strong></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Type (block, poured):</td>
<td>Width: Height:</td>
</tr>
<tr>
<td>Location of rebar:</td>
<td></td>
</tr>
<tr>
<td>Slab:</td>
<td>Thickness: Rebar:</td>
</tr>
<tr>
<td>Chimney type (solid, lined):</td>
<td>Size:</td>
</tr>
<tr>
<td>Sump pump:</td>
<td></td>
</tr>
<tr>
<td>Fascia/Eave</td>
<td></td>
</tr>
<tr>
<td>---------------------</td>
<td></td>
</tr>
<tr>
<td>Fascia:</td>
<td></td>
</tr>
<tr>
<td>Rake:</td>
<td></td>
</tr>
<tr>
<td>Gutters:</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Connections Between Building Elements (anchors, bolts, strapping, holdowns, etc)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Floor/Wall:</td>
</tr>
<tr>
<td>Wall/Roof:</td>
</tr>
<tr>
<td>Window/Wall:</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Finish Materials</th>
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</thead>
<tbody>
<tr>
<td>Plaster/lath</td>
</tr>
<tr>
<td>Ceiling height</td>
</tr>
<tr>
<td>Finish flooring (type):</td>
</tr>
<tr>
<td>Fastening:</td>
</tr>
<tr>
<td>Unpainted wood (type):</td>
</tr>
<tr>
<td>Linear feet:</td>
</tr>
<tr>
<td>Cabinets (type):</td>
</tr>
<tr>
<td>Stair treads (type):</td>
</tr>
<tr>
<td>Number:</td>
</tr>
<tr>
<td>Width:</td>
</tr>
<tr>
<td>Shelving (type):</td>
</tr>
<tr>
<td>Plumbing fixtures (type):</td>
</tr>
<tr>
<td>Appliances (type):</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Heating System</th>
</tr>
</thead>
<tbody>
<tr>
<td>System (type):</td>
</tr>
<tr>
<td>Boiler/furnace:</td>
</tr>
<tr>
<td>Hot water heater:</td>
</tr>
<tr>
<td>Radiators:</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>Doors (type):</td>
</tr>
<tr>
<td>Size:</td>
</tr>
<tr>
<td>Windows (type):</td>
</tr>
<tr>
<td>Size:</td>
</tr>
<tr>
<td>Metals – plumbing etc.:</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Miscellaneous</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extent of rot:</td>
</tr>
<tr>
<td>Lumber grading stamp:</td>
</tr>
<tr>
<td>Overall building dimensions:</td>
</tr>
<tr>
<td>Date of construction (approx.):</td>
</tr>
<tr>
<td>Complicating site conditions – steep grade, trees near building etc.:</td>
</tr>
</tbody>
</table>

**Note:** This table is for illustration only. It was designed by the NAHB Research Centre for use in the US construction industry where there is, for instance, extensive use of timber in construction. It can be used as a guide for specific building assessments in other countries.
Material Estimation Tools

Adopted directly from: NAHB Research Center Report

One Component of the deconstruction process is the ability to properly inventory and estimate material values. This can easily be accomplished through the use of a computer spreadsheet program. Materials can be entered line-item along with a brief description, quantity and unit value. Units can be entered numerically or in specific weights and measures. The corresponding retail unit value can then be used to calculate total estimated material values for all items. The sum of all estimated material values is the total estimated material value for the whole building.

Individual building materials listed on a field survey form are transcribed to the “Deconstruction Inventory” spreadsheet. The description and quantity of the material is noted, and an estimated range of each material’s value is assigned based on information received from several building material salvage firms and actual values of materials sold in previous case studies.

Factors affecting salvage value:

- Types of materials – framing lumber has wide applications, is used in large quantities, and is relatively easy to sell. Finish materials such as windows and doors have specific dimensions, specific uses, and require more targeted marketing.
- Retail building material prices – the value of used building materials can be considered a function of new building material prices. When lumber prices go up, any alternative to conventional retail becomes more attractive.
- Condition of local economy – demand for all building materials can be expected to be stronger when construction and remodelling activity is strong.
- Time of year – depending on geographic location, construction firms and do-it-yourselfers may be more interested in building materials in the spring or summer than in winter.

Other off-the-shelf software programs are available that can be utilized to model building structures, such as Broderbund’s 3D Home Design Suite®. This program allows you to model a structure based on field measurements, and gives a 2D or 3D illustration of the building including a material list. As an example, measurements, dimensions and material types can be plugged into the computer program. The program will display either a 2D or 3D picture of the building, allow you to do a virtual walk through and also print out a materials list including quantities and values.

Estimating material value provides the property owner with a general idea of what the material might be worth should a deconstruction project occur.
APPENDIX D
Appendix D: Environmental Site Assessments – Hazardous Substances

Adopted directly from: NAHB Research Center Report

Asbestos Containing Materials

Identification

There is no definitive way to determine the presence or absence of asbestos in the field. While experienced abatement contractors often have a good sense of which building components are suspect, identification and asbestos content can only be accomplished using polarized light microscopy and quantification of asbestos content must be done by certified laboratories following exacting standard procedures.

US Environmental Protection Agency (EPA) Regulations

According to EPA rules, the removal and disposal of all friable ACM must be accomplished prior to any building removal work. The techniques and equipment required for abating friable asbestos (full-mask respirators, negative air pressure systems) mean that only licensed, professional abatement firms handle these materials. EPA rules identify two other types of ACM: category I non-friable (materials such as asphalt roofing shingles and floor tiles) and category II non-friable (materials such as asbestos siding shingles and transite board). Category I ACM need only be removed prior to building removal if the material's condition is such that the material has become friable. Category II ACM need only be removed if the material is likely to become friable during the building removal process.

US Occupational Safety and Health Administration (OSHA) Regulations

According to OSHA rules, handling any ACM without asbestos abatement techniques and equipment is based on a permissible exposure limit (PEL) of no more than a 8-hour, time-weighted average (TWA) of 0.1 fiber per cubic centimeter or an excursion limit of 1.0 fiber per cubic centimeter in a sampling period of thirty minutes. Exposure to workers above this limit requires asbestos abatement measures (including full respirators, negative pressure systems, etc.). Typically the measurement of these exposures is handled by an industrial hygienist obtaining filter samples from workers wearing powered air supplies and respirators.

Disposal of friable asbestos is the responsibility of the licensed abatement contractor. The disposal of non-friable ACMs such as roofing shingles and resilient floor coverings is not regulated at the federal level. In most cases, these materials can be disposed of in a construction and demolition (C&D) or municipal solid waste (MSW) landfill, but check local landfill policies beforehand.

15 Friable is defined in the regulations as the capability, when dry, to be crumbled, pulverized, or reduced to a powder by hand pressure.
Lead Based Paint

Identification

There are several different tests for lead-based paint—understanding the nature and reason for each test is important in understanding how to handle LBP.

1. **LBP Test Sticks** - The general presence or absence of lead can easily be determined in the field using paint sticks (the stick or "crayon" or swab is part of a rhodizonate spot test kit). The stick must come in direct contact with each layer of paint being tested. These test kits are relatively inexpensive (less than $20), are readily available, and can be used by anyone. This test should only be used as an initial determination of the magnitude of the LBP problem on a project—positive results suggest more detailed analysis and negative results from test sticks are not accepted by regulatory agencies as conclusive evidence of the absence of lead.

2. **X-ray Fluorescence (XRF) and Atomic Absorption Spectroscopy (AAS)** - Determination of the concentration of lead in paint or coatings can be accomplished in the field by XRF equipment—milligrams per square centimeter—or in a laboratory by AAS—% by weight. These tests must be performed with highly trained technicians with equipment ranging in cost from $4,000 to $40,000. These tests have limited utility for the building removal industry (see discussion following number 4) and are most useful for large HUD or other rehabilitation projects.

3. **Toxicity Characteristic Leaching Procedure (TCLP)** - Determination of the lead leaching potential in mixed debris is accomplished by a TCLP. A TCLP must be conducted according to standard procedures with the sample sent to a certified laboratory for analysis. TCLP tests cost approximately $50 or less. A TCLP test determines whether or not a load of demolition debris must be handled as hazardous waste (5 parts per million or greater).

4. **Air Monitoring of Workers** - The determination of lead concentration in the air is done by collecting respiratory filter samples over a specific time period that are subsequently analyzed by a lab—micrograms per cubic meter. Usually, an industrial hygienist collects the samples and sends the samples out for laboratory analysis. Air sampling and testing can cost several hundred dollars. This test is required by OSHA to forego extensive worker protection practices for specific demolition activities such as plaster removal.

There is considerable discussion regarding the relationships between XRF (field test) and AAS (lab test) determinations of lead concentration, between XRF/AAS (concentrations of lead on surfaces) and TCLP determinations (concentrations of lead in mixed debris), and between XRF/AAS (surface concentration tests) and air sampling determinations (concentration of lead in air in work settings).

1. Uncertainties in XRF field determinations can require verification by AAS analysis.
2. No study has ever established a statistically satisfactory relationship between XRF/AAS and TCLP results.
3. The number of variables affecting the relationship between XRF/AAS and air sampling results lead to little if any relationship between concentrations of lead in materials and lead in the air during demolition or deconstruction activities.
The final result of all these uncertainties is that the best information most likely to be available on lead-based paint in a building--XRF or AAS test results--will provide little help and certainly no conclusive evidence that can be used in complying with EPA disposal regulations and OSHA worker protection requirements.

**US EPA Regulations**

EPA rules on the disposal of LBP building materials require that the material be handled as hazardous if a Toxicity Characteristic Leaching Procedure (TCLP) reads more than 5 parts per million in lead. The TCLP is a test performed by certified laboratories. Building demolition debris--mixed plaster, masonry, roofing shingles, and LBP wood--generally passes the TCLP and so little demolition debris is, from a disposal perspective, handled as hazardous. Any time building components with significant lead levels (1.0 mg/cm² or greater) are segregated for disposal, a TCLP test should be considered.

Although unlikely to result in a failed TCLP, it is possible that salvage of building materials could change the overall concentration of lead in the fraction of the building destined for the landfill. The important points here are that you may not intentionally dilute your disposal mix to pass a TCLP but you are also not required to intentionally segregate LBP building materials. Recent research suggests that the long term leaching characteristics of LBP materials are such that disposal of these materials in either a C&D or a MSW landfill is appropriate.

**US OSHA Regulations**

All of OSHA rules pertaining to LBP materials are based on exposure levels--the concentration of lead in the air. There is an action level (AL)--30 g/m³ for an 8-hour time-weighted average--and a permissible exposure limit (PEL)--50 g/m³. The action level triggers compliance measures--respirators, protective work clothing, change areas, hand washing facilities, biological monitoring (blood level checks), and training. The PEL sets an absolute level of exposure for an 8-hour workday. It is the responsibility of the employer to observe the compliance measures if workers are conducting activities at or beyond the AL. Research data or data from other work projects can be used to demonstrate that specific activities and or materials do not lead to conditions at or beyond the action level--EXCEPT for specific activities identified by OSHA as an activity that is assumed to involve exposure levels at or above the AL. One of the activities so cited is manual demolition.

**Other Information**

If LBP building materials are to be reused, steps must be taken to minimize lead hazards. The painted surface may be stripped using stripping solutions, recoated with non-LBP, or coated with some other protective coating. It the LBP building material is to be used for energy recovery, it may only be burned in combustors operated in compliance with air pollution prevention requirements. The use of LBP building material as mulch or ground cover is not appropriate since it may result in exposure to lead through inhalation or ingestion.

Lead abatement should always be cleared with authorities at a local level to ensure compliance with all applicable regulations.
APPENDIX E
Appendix E: Useful Tools for Deconstruction

Adopted directly from: Fort Ord Reuse Authority (FORA) Report
Title: Fort Ord Pilot Deconstruction Project, Final Report, Monterey Peninsula, California, USA, December 1997.

And from: NAHB Research Center Report

Deconstruction tools are generally simple construction tools that are intended to provide easy, low-level skill building material disassembly and produce minimal damage to salvaged materials. The tools should represent the simplest form of deconstruction and should enable deconstruction to be easily reproducible at low-cost in other projects.

Typical deconstruction tools include, but are not limited to:

**Individual worker tools**

- Tool belt
- “Bear Claw” style nail puller
- Hammers (claw and masonry)
- Screw drivers
- Wire-cutting pliers
- Utility knives
- Air purifying, half face respirator
- Safety boots
- Long pants
- Hard hat

**Shared tools and equipment**

- Generator
- Hepa-vac
- Extension cords
- Saws (reciprocating saw and circular saw)
- Saw horses
- Reversible drill, drill bits and extension cords
- Sledge hammer
- Axe
- Wrecking bar
- Ropes and chains
- Crowbars (various lengths)
- Mechanical nail puller
- Hydraulic pallet jack
- Wheel barrows
- Shovels (various types), forks and rakes
- Brooms (various types)
• Scrapers
• Wrenches
• Ladders (various lengths)
• Truck (light loads)
• Tape measures
• Fire extinguisher
• First aid kit
• Masonry chisels

Supporting Equipment

• Dumpsters
• Chutes
• Fork lift
• Pallets
• Recycling containers

Heavy-duty equipment such as cranes, waste disposal trucks, heavy-duty trucks etc. may sometimes be required depending on project specific conditions.
APPENDIX F

Appendix F: Building Layers
Table F1: Life spans of building layers (and their sources)

<table>
<thead>
<tr>
<th>Building layers and Lifespan (years)</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Structure</td>
<td>Skin</td>
</tr>
<tr>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>30-300 (typically 60)</td>
<td>20</td>
</tr>
<tr>
<td>40</td>
<td>15</td>
</tr>
<tr>
<td>25-125</td>
<td>25</td>
</tr>
<tr>
<td>60-100</td>
<td>15-40</td>
</tr>
<tr>
<td>60*</td>
<td>20</td>
</tr>
<tr>
<td>65</td>
<td>65</td>
</tr>
<tr>
<td>50*</td>
<td>30-50</td>
</tr>
<tr>
<td>40*</td>
<td>36</td>
</tr>
<tr>
<td>-</td>
<td>15-30</td>
</tr>
<tr>
<td>40 (for brick veneer house)</td>
<td>12-30</td>
</tr>
</tbody>
</table>

* Assumed maximum life of building

Where:

- The **Structure** is the foundation and load bearing components of the building, those parts that make the building stand up.
- The **Skin** of the building is the cladding and roofing system that excludes (or controls) the natural elements from the interior.
- The **Services** include electrical, hydraulic, HVAC, lifts etc.
- The **Space plan** is the internal partitioning system, the finishes and the furniture.

References in Table F1


APPENDIX G

Appendix G: Principles of design for deconstruction
Table G1 is arranged in a matrix format to show the relevance of each of the principles to the available options in the hierarchy of end-of-life scenarios for building removal.

Table G1: Principles of design for deconstruction and the Hierarchy of Recycling

<table>
<thead>
<tr>
<th>No.</th>
<th>Principle</th>
<th>Material recycling</th>
<th>Component remanufacture</th>
<th>Component reuse</th>
<th>Building relocation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Use recycled and recyclable materials</td>
<td>_</td>
<td>_</td>
<td>_</td>
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<tr>
<td>2</td>
<td>Minimise the different types of materials</td>
<td>_</td>
<td>_</td>
<td>_</td>
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<tr>
<td>3</td>
<td>Avoid toxic and hazardous materials</td>
<td>_</td>
<td>_</td>
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<tr>
<td>4</td>
<td>Make inseparable assemblies from the same materials</td>
<td>_</td>
<td>_</td>
<td>_</td>
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<tr>
<td>5</td>
<td>Avoid secondary finishes to materials</td>
<td>_</td>
<td>_</td>
<td>_</td>
<td>_</td>
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<tr>
<td>6</td>
<td>Provide identification of material types</td>
<td>_</td>
<td>_</td>
<td>_</td>
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<tr>
<td>7</td>
<td>Minimise the number of different types of materials</td>
<td>_</td>
<td>_</td>
<td>_</td>
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<tr>
<td>8</td>
<td>Use mechanical not chemical connections</td>
<td>_</td>
<td>_</td>
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<tr>
<td>9</td>
<td>Use an open building system not a closed one</td>
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<td>_</td>
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<tr>
<td>10</td>
<td>Use modular design</td>
<td>_</td>
<td>_</td>
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<tr>
<td>11</td>
<td>Design to use common tools and equipment, avoid specialist plant</td>
<td>_</td>
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<tr>
<td>12</td>
<td>Separate the structure from the cladding for parallel disassembly</td>
<td>_</td>
<td>_</td>
<td>_</td>
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<tr>
<td>13</td>
<td>Provide access to all parts and connection points</td>
<td>_</td>
<td>_</td>
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<tr>
<td>14</td>
<td>Make components sized to suit the means of handling</td>
<td>_</td>
<td>_</td>
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<tr>
<td>15</td>
<td>Provide a means of handling and locating</td>
<td>_</td>
<td>_</td>
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<tr>
<td>16</td>
<td>Provide realistic tolerances for assembly</td>
<td>_</td>
<td>_</td>
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<tr>
<td></td>
<td>and disassembly</td>
<td>17</td>
<td>Use a minimum number of connectors</td>
<td>18</td>
<td>Use a minimum number of different types of connectors</td>
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