DECONSTRUCTION AND MATERIALS REUSE: TECHNOLOGY, ECONOMICS AND POLIC

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TG 39

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Preface

In the hierarchy of actions required for closing the materials loop, protecting the environment, and conserving resources, deconstruction and materials reuse ranks above recycling and just below minimizing the mass of materials used in the built environment. Task Group 39 of International Council for Research and Innovation in Building Construction (CIB) was formed on 5 May 1999 in Gainesville, Florida to produce a comprehensive analysis of, and a report on, worldwide building deconstruction and materials reuse programs that address the key technical, economic, and policy issues needed to make deconstruction and reuse of building materials a viable option to demolition and landfilling. The first meeting of TG 39 was on 19 May 2000 in Watford, England and the group's first product is the fully electronic CIB Publication 252, "Overview of Deconstruction in Selected Countries," which addresses the subject of deconstruction in eight countries: Australia, Germany, Israel, Japan, the Netherlands, Norway, the United Kingdom, and the United States.

This electronic Proceedings includes ten fully reviewed papers presented at the second annual meeting of TG 39 that took place in conjunction with the CIB World Building Congress in Wellington, New Zealand on 6 April 2001. The papers address the technical, economic, and policy issues related to deconstruction and materials reuse in eight countries: Australia, Germany, Japan, the Netherlands, South Africa, Sweden, the United Kingdom, and the United States. Both publications can be downloaded at the Center for Construction and Environment website at the University of Florida (www.cce.ufl.edu/affiliations/cib).

Task Group 39 members will meet on 9 April 2002 in Karlsruhe, Germany to discuss Design for Deconstruction to include both building design and building product design. Other collateral issues such as recycling potential and materials reuse will also be included. The final meeting will take place in 2003 in Delft, The Netherlands to work out the details of the final report containing the findings and recommendations of the Task Group.

Thanks to the following TG 39 members for their thorough review of the papers and supply of constructive feedback that improved the overall quality of the papers: Helen Bowes, Bart te Dorsthorst, Emmanuel Garbe, Bryn Golton, Bradley Guy, Gilli Hobbs, James Hurley, Ton Kowalczyk, Charles Kibert, Jennifer Languell, Dennis Macozoma, Lars Myhre, B. Pitzini-Duée, Otto Rentz, Axel Seemann, Frank Schultmann, and Catarina Thormark.

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DEVELOPING AN INCLUSIVE MODEL FOR DESIGN FOR DECONSTRUCTION

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SUMMARY

One of the major hindrances to successful deconstruction, for the reuse of building materials and components, is the difficulty in recovering items in good condition. Modern construction methods are very dependent on permanent fixing methods that allow for little else but destructive demolition. If buildings were initially designed for deconstruction, it would be possible to successfully recover much more material for reuse. This would have significant advantages both economically and environmentally.

In an attempt to establish a knowledge base for understanding design for deconstruction, this paper poses a number of questions. These questions can in part be answered by a number of related theories and research fields. The relationships between these theories and design for deconstruction are investigated and developed. There are four main parts to these investigations:

- an understanding of how design for deconstruction fits into the broader issues of sustainable construction
- the theory of time related building layers
- the theory of a hierarchy of recycling and reuse
- a list of design for deconstruction principles

KEYWORDS: deconstruction, design, model, principles, recycling, reuse.

1 THE QUESTIONS OF DESIGN FOR DISASSEMBLY

As there are no formal rules for design-for-recycling, we resort to heuristics [1].

1.1 The Need for Understanding

Design for deconstruction in architecture is not widely practised and not widely understood. As has been shown in the reports of the preceding Task Group 39 meeting [2] there is little research in this field and only recently have efforts been made to co-ordinate what research there is. As such there are no currently existing rules, guidelines, or principles for design for deconstruction in architecture, nor are there any models for design for deconstruction in architecture.

Tools for assessing the potential for reuse and recycling of building materials have been proposed, though these have been developed for the assessment of existing buildings [3] [4]. A tool for assessing proposed building designs and for guiding the design process to increase rates of future recycling has not been developed.

In brief, ‘buildings are not currently designed to be eventually disassembled’ [5].

1.2 What Knowledge is Needed

There is a basic lack of understanding or knowledge of design for deconstruction in architecture. The types of knowledge that might be needed can be investigated by asking a number of basic questions:

- Why deconstruct
- When to deconstruct
- Where to deconstruct
- What to deconstruct
- How to deconstruct

Why Deconstruct
The general need for an improvement in the current rates of materials and component reuse is well accepted. Any response to this must however fit within the broader understanding of sustainable construction. It is not beneficial to design for deconstruction to increase rates of recycling if the overall life cycle environmental costs of such a strategy are actually greater than the potential benefits.

An understanding of this holistic relationship must form part of any understanding of design for deconstruction in order that the benefits are realised. The issues of design for disassembly need to be located within a general model for sustainable construction so that the external consequences of a design for deconstruction strategy might be highlighted and considered.

When to Deconstruct and Where to Deconstruct
Different parts of buildings have different life expectancies, for economic, service, social, and fashion reasons. An understanding of the life expectancy of parts of a building is an integral part of a strategy of designing for deconstruction. The theory of time related building layers, the idea that a building can be read as a number of distinct layers each with its own different service life, offers some insight into the relationship between life expectancy and deconstruction. Knowing which layer a component is from, and where the layer begins and ends, assists in determining when and where to deconstruct.

What to Deconstruct
There are many possibilities for the recycling of materials and components, from complete relocation and reuse, to material recycling or incineration for energy. The question of what to deconstruct can in part be answered by asking what is the intended form of recycling. What is deconstructed for material recycling may be different to what is deconstructed for component relocation. There is therefore a relation ship between the hierarchy of recycling options and design for deconstruction.

How to Deconstruct
There are several sources of information of how to deconstruct. These include industrial design, architectural technology, buildability, maintenance, and international research into deconstruction. While the question of how to deconstruct buildings has not been well investigated in the past, the above sources of information can be searched for recurring themes. These themes can then be developed as principles for design for deconstruction.

A list of principles for design for deconstruction can act as performance guidelines to assist in the design of a building or to assess a building design for disassembly. Such a list of principles is one of the major components of a knowledge base of deconstruction.

2 A MODEL FOR ENVIRONMENTALLY SUSTAINABLE CONSTRUCTION

2.1 General Model of Life Cycle (Assessment)

Of all the current models for understanding, assessing, and reducing the environmental consequences of our actions, life cycle assessment (LCA) is perhaps the most useful.

> The notion of life cycle assessment has been generally accepted within the environmental research community as the only legitimate basis on which to compare alternative materials, components and services and is, therefore, a logical basis on which to formulate building environmental assessment methods [6].

The idea of the life cycle is that all stages in a system (product or service activity) are recognised, from inception to final disposal. A life cycle assessment is made by investigating all the environmental consequences of each stage in the life cycle of the system. Such an assessment can be represented as a two dimensional matrix. Such a matrix offers a good model for the environmental assessment of a system (product, service, building). In order to do more than simply assess the system, to actually understand how the system might be altered to reduce the environmental burden, it is necessary however to add a third dimension. This will be a dimension of strategic solutions, or of principles for sustainable activity.

2.2 Principles for Sustainable Activity

In order to understand what can be done to reduce the environmental burden of human activity, it has been convenient to consider the range of measures that might be taken within a smaller number of broader principles. There are potentially thousands of strategies that might be implemented in the design of a building in order to reduce the environmental burden of that building. Management of these strategies, and of conflict between them, can be better handled by addressing a few overriding aims.

Numerous authors have proposed such broad principles for sustainable activity, and many of these relate directly to the built environment and to sustainable architecture. The writings, and the built work, of Brenda and Robert Vale illustrate a number of 'green' architecture principles. They suggest six basic principles that could constitute sustainable architectural practice [7];

- *Conserving energy*, a building should be constructed so as to minimise the need for fossil fuels to run it
- *Working with climate*, buildings should be designed to work with climate and natural energy sources
- *Minimise new resources*, a building should be designed so as to minimise the use of new resources and, at the end of its useful life, to form the resources for other architecture
- *Respect for users*, a green architecture recognises the importance of all the people involved with it
- *Respect for site*, a building will 'touch-this-earth-lightly'

- *Holism*, all the green principles need to be embodied in a holistic approach to the built environment

The Royal Australian Institute of Architects' Environmental Design Guide also offers a number of principles for achieving sustainable architecture [8];

- Maintain and restore biodiversity
- Minimise the consumption of resources
- Minimise pollution of air, soil and water
- Maximise health, safety and comfort of building users
- Increase awareness of environmental issues

Another author who offers a list of broad principles is Kibert [9]. His concerns are developed from a number of issues of sustainable construction which include; energy consumption, water use, land use, material selection, indoor environmental quality, exterior environmental quality, building design, community design, construction operations, life cycle operation, and deconstruction. Several principles of how to achieve more environmentally responsible construction are proposed with respect to these issues;

- Minimise resource consumption
- Maximise resource reuse
- Use renewable or recyclable resources
- Protect the natural environment
- Create a healthy, non-toxic environment
- Pursue quality in creating the built environment

These lists of principles are all attempts at grouping the various strategies for achieving sustainable architecture. While these groups vary slightly they all address issues of material use, energy use, health, and a holistic view.

2.3 Adopted Model for Sustainable Construction

Returning to the two-dimensional model of life cycle assessment, it is now possible to add the third dimension of principles of sustainable architecture. Such a combination has already been investigated by Kibert. By combining the two axes of time (Phase) and impact categories (Resources), with the axis of principles, a simple conceptual model is produced. This model then can be graphically represented as three radiating axes (see Figure 1).

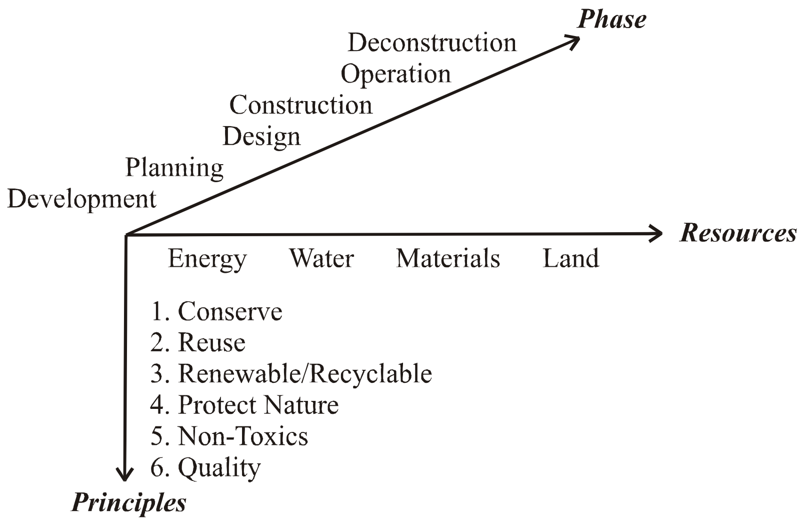

Figure 1 A Conceptual Model for Sustainable Construction [10].

Using this model it is possible to place a particular issue within the broader context of sustainable architecture. In this way it is possible to highlight where the issue of design for deconstruction sits within the broader context of sustainable construction. Design for deconstruction deals with the *design* of a building, for the *reuse* (in preference to recycling or disposal), of *materials*. While it might be considered that design for deconstruction is intended to deal with the *deconstruction* stage of the life cycle, it is a strategy that must be implemented at the design stage, as such it deals with *design* issues that will have later ramification at the deconstruction stage. It might also be considered that design for deconstruction is an issue relating to the *recyclable* nature of a building. However, design for deconstruction is an attempt to raise materials and components up the recycling hierarchy, away from recycling, and up to a more environmentally preferable point of *reuse*. For these reasons design for disassembly is primarily, but not exclusively, an issue of design for the reuse of materials.

2.4 Conclusions to a Model for Environmentally Sustainable Construction

This section has shown how a model for sustainable construction can be built from the principles of sustainable architecture, the categories of resources (or environmental impacts), and the life cycle stages of a building. Such a model has been adopted as a way of locating the issue of design for deconstruction within the broader field of sustainable architecture. Understanding this relationship between design for deconstruction and other sustainability issues is an important part of the knowledge base of design for deconstruction in architecture.

3 THE THEORY OF LAYERS

3.1 A Tradition of Building Layers

The notion of the building as a whole object is still very much the dominant way of thinking about buildings. They are conceived, designed, constructed, and used as complete entities. We speak of ‘a’ building in the singular. This notion of the singular building may however be a misconception, in part, resulting from our reading of the building in a limited time frame. Few, in any, buildings actually remain in their initial state of construction for more than a few years or at most a few decades. Alterations, repairs, additions, and maintenance continually work to alter the building. In the longer time frame, the building is constantly changing in response to changing user demands and changing environmental conditions. There is in fact not ‘a’ building at all but a series of different buildings over time.

Much vernacular building, especially in timber, has made practical use of the notion of time related layers. Traditional Japanese domestic buildings are constructed using a primary frame of major timber members that are placed according to structural requirements of the roof and walls. A secondary frame of timber members is then constructed in accordance with the spatial requirements of the occupants. This secondary frame may be deconstructed and remodelled to suit changes in the occupants’ requirements without affecting the primary structure and without the wastage of building materials that other techniques produce [11].

> Japanese wooden architecture . . . is a complete architectural system in which the expansion, remodelling, removal and reconstruction of buildings is possible according to life styles [12].

Similar technologies in Europe and other parts of the world were also utilised to produce buildings that consisted of a primary frame and a series of secondary enclosing, and space defining, elements [13].

3.2 The Beginnings of a Theory of Building Layers

While there are vernacular traditions of designing and constructing buildings so that they can respond more readily to changes over time in a layered way, an expressed theoretical stance on this issue as a way of *modern* building did not first appear untill the writings of the Japanese Metabolism architects and of John Habraken in the 1960’s. Habraken [14], in later writings, discusses the *traditions of two stage building* as he calls it, in which vernacular buildings are constructed first as a primary structural frame which typically supports the roof, then a secondary system of construction which defines the internal spaces. Habraken claims that virtually all timber framed structures can be analysed in terms of the two-level theory.

Before this however, Habraken had already used this theory of *two stage building* to address his concerns with social mass housing and the design of housing with more input from the users. Habraken writes at length on the social problems of current (1950’s) mass housing models and the lack of user satisfaction. His main technical solution to these problems is in the proposal for *Support Structures*.

> A support structure is a construction which allows the provision of dwellings which can be built, altered and taken down, independently of the others [15].

In building terms the proposal is for a large multi-storey concrete frame with floors, ‘one above the other, stretching out through the town’ [16]. Between the floors, dwellings are built, side by side, similar to units in a high-rise housing block, but with each dwelling being independently designed and built. The main structure contains all the relevant services and circulation spaces.

Habraken’s proposal provides medium to high-density housing but avoids the problems of the anonymous unit in the giant housing block. The support structure and the dwelling unit are treated as separate individual layers where the dwellings can be changed with no effect on the support. Similarly the dwellings can be designed independently of the support structure or the adjoining dwellings. Habraken [17] makes the distinction that while the support structure may look like the unfinished frame of any large building, it is in fact ‘not an uncompleted building, but in itself a wholly completed one’.

Habraken has made the first conceptual step in dissecting the building into layers. He recognises that there can exist, within the one building, two buildings with two different service lives, as in vernacular timber building; the *permanent* support, and the *temporary* dwelling.

3.3 Developing the Theory of Building Layers

Another innovative thinker who was also concerned with the life expectancy of buildings and in particular the way that different parts of a building might have different life expectancies was Cedric Price. His design scheme of 1961 for the *Fun Palace* was an inspirational work in the realm of adaptable buildings. It was influential, a decade later, on the design for the Pompidou Centre by Rogers and Piano. Price’s design consisted of a steel framed structure that contained hanging auditoria with movable floors, walls, ceilings and walkways. The whole building had been designed with obsolescence in mind and was serviced by cranes on the top of the structure which allowed the component parts of the building to be manipulated, relocated, removed or replaced to suit various proposed activities [18].

Although the Fun Palace was not realised, the Inter-action community centre in Kentish Town was built in the 1970’s following many of the same principles. This multi purpose community centre, of approximately 2000 square metres floor area, was designed with unlimited permutations of flexible space to house continually changing uses. It consisted of a major steel structure set out on a regular grid with a series of secondary flexible enclosed spaces that were independent of the main structure and could be disassembled and reassembled independently of it. Separate self contained modules, that housed service zones such as toilets, could be plugged into the frame where ever they were required.

A strong hierarchy of structure allowed the building to expand or contract in the future without interrupting the existing building. The Inter-action centre was actually classified by the council as a *temporary* structure and the architect prepared complete instructions for the buildings eventual disassembly [19].

Many architects were influenced by the work of Price. One such group of British architects, calling themselves Archigram, produced an almost endless stream of designs for portable, adaptable and temporary buildings during the late 1960’s and early 1970’s.

One of their schemes, the Plug-in City, was directly concerned with separating the time related layers of the building. The Plug-in City, in which ‘the whole urban environment can be programmed and structured for change’ [20], was based on a steel mega-structure that contained the major transport corridors and services. This structure supported a series of detachable living and working units that could be manoeuvred by cranes fixed to the main structure. The units responded to a hierarchy of obsolescence where those parts of the building that would need to be serviced or replaced most frequently were most accessible. For example the living modules and shopping areas, that had a three year to eight year rating, were nearer the top of the structure, and the heavy elements such as railways and roads, with a twenty year life expectancy, were nearer the bottom. Other service life expectancies were:

• Bathroom and kitchen	3 years
• Living rooms and bedroom	5-8 years
• Location of house module	15 years
• Tenancy in a shop	6 months
• Shopping location	3-6 years
• Workplaces and offices	4 years
• Roads and civil works	20 years

At the same time as Archigram were investigating high tech architecture in Britain, the Metabolism Group in Japan were pursuing similar idealised environments. They took the two-stage building principles of time traditional timber dwellings and applied it to modern high tech architecture. The key to the work of the Metabolists was a philosophy of allowing for replaceability and changeability of components in such a way as to not disturb the remainder of the building. This designing for disassembly was evident in early works such as the Mova-house system, which, in a similar design to the Plug-in City, used housing modules, with a life expectancy of twenty five years, that were attached to a mega-structure support system [21].

In writing about the philosophies of the Metabolist group, Kurokawa [22] offers the following hierarchy of service life expectancies for various elements of the built environment:

• Services	5 years
• Space for consumer goods	5 years
• Shops, businesses, education facilities	10 years
• Dwellings	25 years
• Public spaces between buildings	125 years
• Cultural facilities and monuments	625 years
• Natural areas	15 000 years

Although much of the Metabolist Group's work was unrealised, the 1970 World Exposition in Japan did allow for some of the disassembly technology to be tested in full scale. The Capsule House in the Theme Pavilion of Expo '70 and the Takara Pavilion both allowed the building to be altered over time by designing a building that consisted of a primary structural frame and a secondary collection of space making elements.

These visionary projects, many of them unrealised, all exhibit a common practice of separating the building into a number of time related layers. While these projects might be called experimental in their way of dealing with technology, other architects and researchers, who were dealing with more traditional building technology, were also investigating the notion of time related layers.

3.4 Expanding the Theory of Building Layers

In investigating the office accommodation needs of London banks, accountant, and financiers, Duffy and Henney [23] independently established a theory of building layers. Duffy [24] writes that, 'our basic argument is that there isn't such a thing as a building . . . a building properly conceived is several layers of longevity of built components'. Duffy introduces here his own theory of layers of building, time related layers that can change independently of each other.

Unlike Habraken who establishes two layers within the building, or the Metabolists and Archigram who define no fixed number of layers, Duffy and Henney [25] identify four layers of building in descending order of longevity; the *Shell*, the *Services*, the *Scenery*, and the *Set*.

Importantly, Duffy and Henney also assign a service life to each of these layers. This service life is based on the expected life span of the layer based on experience of changes resulting from the users changing demands and the need to upgrade or expand plant and equipment. The rate of change for each layer is different as technological and social changes impact differently on different parts of the built environment.

- The *Shell,* Duffy describes as the foundations, the structure of the building, with a life span of fifty years. The shell is a framework onto which services and space making components can be attached in an adaptable way. He also makes suggestions on the spans of floor plates, the location of service cores and the grid of the floor and ceiling.

- The *Services* include electrical, hydraulic, HVAC, lifts, and data, which have a life span of ten to fifteen years.

- The *Scenery* is the internal partitioning system, the finishes and the furniture, which have a life span of five to seven years.

- The *Sets* are the arrangements of movable items that the users move freely about the building to suit their daily or weekly needs.

Duffy's development of this theory of layers is derived from an analysis of office buildings, particularly in London, but the theory is just as appropriate to other building types though the life spans may be slightly different.

The relevance of the theory of layers is in that the parts of the building with a short service life can be separated from the parts of the building with a long service life. This means that when for example the services of a building are no longer providing a service that meets with contemporary requirements, the whole building does not have to be upgraded or replaced, just the services.

It is interesting to note that Duffy limits his analysis of the buildings to what might be interpreted as the internal parts of the building; the furniture, internal partitions, services (that serve the internal spaces), and the shell of the building (a term which implies enclosure). This is not surprising since his concern is primarily with the provision of accommodation, in the form of office buildings, for financial and business corporations. Duffy's concern is with providing internally adaptable buildings so that the building itself does not need to be replaced when the internal spaces no longer satisfy the users needs.

For a similar but expanded analysis of the layers of buildings that also includes the fabric of the building itself in more detail, the work of Stewart Brand is noteworthy. Brand [26] builds directly on Duffy's theory of layers but expands it, by dissecting the *Shell* into *Structure* and Skin, and adding the layer of the *Site* on which the building stands. Brand also assigns each layer an expected service life.

- The *Site* is defined as geographical setting, the ground on which the building sits. 'Site is eternal'.

- The *Structure* is the foundations and load bearing components of the building, those parts that make the building stand up. Structure is expected to last from 30 to 300 years.

- The *Skin* of the building is the cladding and roofing system that excludes (or controls) the natural elements from the interior. This will last an expected twenty years due to wholesale maintenance, changing technology and fashion.

- The *Services,* which are defined the same as Duffy, have an expected life of from seven to fifteen years.

- The *Space Plan,* which corresponds to Duffy's *Scenery*, will change every three years in a commercial building and up to every thirty years in a domestic building.

- The *Stuff*, which corresponds to Duffy's *Sets*, will change daily to monthly. Brand points out that furniture is called *mobilia* in Italian, for good reason.

Brand goes to great lengths to explain the technical and social benefits of designing and constructing buildings in a layered manner. Like Habraken he recognises the lessons already learned by vernacular builders. He further suggests specific lessons for designers based on historic study of layered buildings and their adaptation, addition, and relocation over time.

Duffy and Brand both suggest typical service life expectancies for their layers. Duffy establishes his times from the point of view of designing adaptable office accommodation. Brand's times are derived from a general understanding of how buildings change over time. Cook et al [27] also suggest appropriate life expectancies, though theirs are for a particular building design (the Plug-in City). Other writers have also suggested times for the service life expectancies of different layers of buildings, based on different concerns (see Table 1).

Table 1 Life spans of building layers in years (and their sources)

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

Curwell [28] and Storey [29] write with regard for issues of sustainability and 'green' building. Their concerns are for designing more environmentally sustainable buildings that will have a reduced environmental burden by accounting for the different life spans of certain elements or layers.

Howard and Sutcliffe [30], Adalberth [31], McCoubrie and Treloar [32], and Suzuki and Oka [33], write with regard for issues of embodied energy. Their concern is also for environmental sustainability, primarily through reduced energy consumption and reduced embodied energy, which is achieved through reduced material use or greater material recycling.

Tucker and Rahilly [34] are concerned with the life cycle cost (in monetary terms) of the building, in this case housing. Their research attempts to establish maintenance programmes for government housing assets through an understanding of the separate life expectancies of different parts of the building.

While the times that are established by each of these writers are different, there is still a common acceptance that different parts of buildings have different service lives and that these parts might be considered in layers. While Duffy and Brand discuss these layers explicitly, the other writers do not, but the layers none the less exist within the times proposed for various elements.

The number of layers proposed by Brand should not be seen as an upper limit. The six layers he proposes are convenient for illustrating his argument of buildings changing over time, but when the consideration is of building deconstruction, it may be appropriate to divide the building into more or less layers depending on the building typology and the specific design. The lesson is simply that items or components of substantially different service life expectancies should be treated as separable in the building design. In general though, a study of architectural technology suggests that Brand's six layers are appropriate for most building designs.

3.5 Building Layers and Deconstruction

These theories of building layers can have a major impact on the design of, or analysis of, buildings for deconstruction. The interfaces between the layers can obviously become primary points of deconstruction for the building. The argument is not just however that they *can* become points of deconstruction, but that they *should* become points of deconstruction. As Habraken, Duffy and Brand point out, separation of the building layers along the lines of layer longevity is of paramount importance in making a more technically and socially adaptable and responsible building.

This importance of longevity layers has already been recognised in the field of design for deconstruction of buildings. Fletcher, Popovic and Plank [35] write that the theory of 'time dependant layers . . . will be fundamental in thinking about buildings in the future', specifically with regard to disassembly for materials and component recovery. They do not however indicate how this theory can be implemented within a strategy of design for deconstruction, nor how it actually interacts with other ideas of material recovery or sustainable architecture.

Other researchers have also recognised the importance of the theory of layers regarding building deconstruction for material recovery. Craven, Okraglik and Eilenberg [36] place the model of time related layers within a system of life cycle assessment. In a life cycle assessment the cumulative effects of a building over time are made evident, and within this model the importance of material and component recovery are highlighted.

The concept of buildings as a collection of time related layers is fully consistent with the approaches of life cycle assessment in which the life span of the building becomes an important multiplying factor for all other environmental considerations. Failure to separate the layers will result in total building failure at that point in time when the first layer fails. The resulting need for total building replacement defies all environmentally sustainable principles.

Although Craven highlights the importance of the theory of layers using a life cycle assessment model, he also stops short of suggesting how this theory might be used. While he recognises the strategy of design for deconstruction, no attempt is made to link it with the theory of time related layers to design buildings in a way that will improve the current rates of material and component recovery.

3.6 Conclusions to the Theory of Layers

The theory of time related building layers is then an important consideration in determining at what points in a building deconstruction might occur. Ideally to achieve full deconstruction for recovery of materials and components, all parts of the building should be totally separable. This would however be prohibitively complex and expensive. The theory of layers allows the components of the building to be broken down into packages of same or similar life expectance so that a whole package might be conveniently deconstructed from the building for replacement, recycling and/or reuse elsewhere.

This section shows how buildings can be considered not as a single entity but as a collection of layers, each with a different service life. A model with six layers is adopted; site, structure, skin, services, space plan, and stuff. These layers are useful in physically determining the places within a building that deconstruction might most usefully occur, and at what time deconstruction might occur.

4 RECYCLING HIERARCHY

4.1 The Flow of Materials

The use of resources in our industrialised 20th century society is very much a matter of use it once and throw it away, and the built environment is no exception. The commonly used model for this consumption of materials and energy is based on a linear system of the building over time. This linear model of the building's life treats the project as a once through system in which the building progresses through a number of stages from inception, through design, construction, operation and maintenance, refurbishment, and finally to demolition. Similarly the model for how raw materials pass through the built environment uses a number of life cycle stages from extraction, through processing, manufacture, assembly, use, demolition, and disposal (see Figure 2). This life cycle model is commonly used in discussing the life cycle impacts of a building or product (as in a life cycle assessment) and is often referred to as a 'cradle to grave' model.

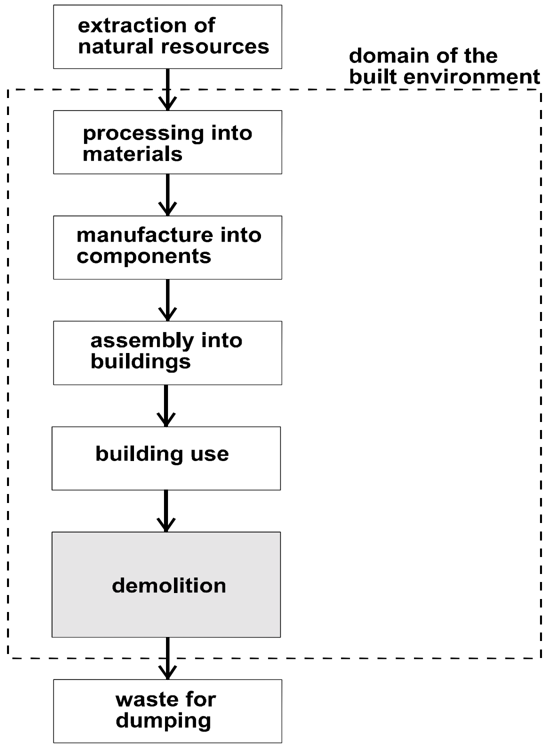

Figure 2 Dominant Life Cycle of the Built Environment (cradle to grave)

Such a once-through life cycle is not the only option. The building industry does not have a good understanding or practical record in this matter, but the disciplines of industrial design and product manufacture have addressed many of these issues and developed strategies within the field of industrial ecology.

4.2 Recycling Hierarchy in Industrial Ecology

Industrial ecology identifies many ways to reduce the environmental impact of a product or service, and one of the major strategies proposed is to alter the once-through cycle to increase the rates of recycling. The scenario of recycling, as it is commonly referred to, can however be better understood if it is replaced with the notion of *end-of-life scenarios*. There are in fact many possible end-of-life scenarios for any given product or building but they can be loosely classified into a few basic scenarios. Several writers have suggested appropriate options for end-of-life scenarios for industrial products.

Young [37], in writing on industrial design and product manufacture for reduced life cycle energy consumption, discusses the '3Rs' model. The three Rs are *re-use*, *remanufacturing* and *recycling*. Young expands on this to also include *maintenance* as an end-of-life scenario.

- *Re-using* involves a product being simply re-used more than once for its intended purpose. For example, a milk bottle being returned to the dairy to be refilled with milk.

- *Remanufacturing* involves the product being returned to the place of manufacture to be disassembled into its base components which, if still serviceable, are then re-used in the manufacture of new products.

- *Recycling* involves the collection of products for separation into their base materials, which can then be re-used as a resource to replace raw materials in the production process.

- *Maintenance* involves the repair and servicing of a product to extend its initial service life.

Importantly Young notes that some of these scenarios are more environmentally favourable than other scenarios. From the point of view of conserving energy during manufacturing, Young notes that re-use is preferable to remanufacturing, which is in turn preferable to recycling. This hierarchy is established based on the energy costs of collecting, transporting and processing products through the various scenarios. In general the least processing, the least energy and the least environmental burden.

The dissection of recycling into separate distinguishable scenarios has also been addressed by Ayres and Ayres [38] within a general discussion of industrial ecology strategies. They identify the scenarios of *re-use*, *repair*, and *remanufacture* as well as *recycling*. Ayres and Ayers' use of the terms re-use, remanufacture and recycling are the same as Young's, but repair is somewhat different to the scenario of maintenance. Ayres uses the term in a way that describes the mending of a product for re-use elsewhere rather than mending a product for continued use in its original application.

Like Young, Ayres and Ayres note that the scenarios of 're-use, repair and remanufacture avoid many of the problems of recycling'. The problems identified are waste production and pollution directly resulting from the act of recycling, and the fact that recycling may not always reduce waste and pollution creation but may potentially increase them.

Also writing on the topic of Industrial Ecology, Graedel and Allenby [39] propose the end-of-life scenarios of *maintenance*, *recycle subassemblies*, *recycle components*, and *recycle materials*. Within the context of Young's or Ayres and Ayers' scenarios, the recycling of components and subassemblies might alternatively be called remanufacturing since it involves the same process of disassembling components for use in new products. Graedel and Allenby also recognise the environmental hierarchy of the scenarios, in which maintenance is preferable to remanufacturing, which is in turn preferable to recycling.

Yet another group of end-of-life scenarios is proposed by Magrab [40] who explicitly refers to the scenarios as a hierarchy. He uses the terms reuse, re-manufacture, recycle to high-grade materials, recycle to low-grade materials, incineration for energy content, and dump in landfill site. Here the scenario of maintenance is lost, but the scenario of recycle has been further broken down to high-grade and low-grade materials. A new scenario of incineration for energy content has also been added. Magrab notes that 'the higher one is in the . . . hierarchy the more the investment of raw materials, labor and energy is conserved'.

4.3 Recycling Hierarchy in the Built Environment

While the field of industrial design has addressed some of the issues of reuse and recycling through the theories of industrial ecology, the field of architecture and building design has not. Most writers in the field of environmentally sustainable architecture have noted the environmental advantages of reuse and recycling, and there are many excellent examples of built work where materials and components have been reused. Despite this there has been until recently a lack of critical analysis of the possible effects that reuse and recycling might have on the built environment, and in particular a lack of debate on the implications of a hierarchy of end-of-life scenarios.

Three groups of writers who have noted the relevance to the built environment of a hierarchy of end-of-life scenarios are Fletcher, Popovic and Plank, Guequierre and Kristinsson , and Kibert and Chini.

Fletcher, Popovic and Plank [41], build directly on the lessons of industrial ecology and start their analysis of the problem with the four end-of-life scenarios identified by industrial ecologists; *reuse*, *repair*, *reconditioning*, and *recycling of materials*. The model is then simplified by grouping the scenarios into two levels; the product level, and the material level. The scenarios of reuse, repair, and reconditioning are placed in the product level since they are concerned with product components or subassemblies. The scenario of recycling is placed in the material level since it is concerned with base materials.

In adapting this model to the built environment, and in an attempt to accommodate the theory of time related building layers, this two level approach is then prefaced by a third level, the systems level.

- *Systems level: Adaptable building which can change to suit changing requirement*

- *Product level: The products (or layers) of the building are designed to allow upgrading, repair and replacement. The replaced products can then enter the replenishing loop.*

- *Material level: When a product has been stripped back its constituent materials these can undergo recycling.*

Exactly how the theory of time related building layers relates to the hierarchy of end-of-life scenarios in this model is not explained. The model does however recognise a hierarchy in which some options are environmentally preferable to others, such as product level reuse being a more ‘efficient use of resources’ than material level recycling.

Guequierre and Kristinsson [42] have also identified a number of end-of-life scenarios for materials in the built environment. Unlike Fletcher, Popovic and Plank, and the industrial ecology researchers, Guequierre and Kristinsson are not as concerned with the design of new buildings or products, but with the analysis of existing buildings to determine the most appropriate end-of-life scenario. Their concerns are not with how to achieve a higher end-of-life scenario through design, but with what can be done with existing building materials and components. For this reason their model includes the non-reuse scenarios of *landfill*, and *incineration*.

Guequierre and Krstinsson’s model is also simplified by grouping the product scaled scenarios together. This results in a model with the four scenarios of; *repair of products*, *recycling of materials*, *incineration*, and *landfill*. Since the model has been devised as an assessment tool for existing buildings, there is no consideration of a scenario for whole building reuse as a system.

Kibert and Chini [43] write on the topic of deconstruction as a means to reducing the environmental burden of the built environment. They propose an explicit waste management hierarchy that includes the levels of landfill, burning, composting, recycling, reuse, and reduction. In this hierarchy the level of recycling is further broken down in to downcycling, recycling and upcycling, in which each is slightly more environmentally advantageous than the previous. The level of reuse is similarly broken into the reuse of materials and the more advantageous reuse of components or products.

The previously unmentioned level of reduction is an important waste management strategy with profound environmental benefits, but in the context of this study it has little bearing on recycling of building materials and components, other than to suggest a general reduction in material usage.

On the separate topic of buildability, not related to recycling, there is one interesting piece of research that identifies a hierarch in building assembly. Moore [44] builds an assembly process hierarchy based on Furguson’s buildability hierarch. This hierarchy consists of materials, components, subassemblies and final assemblies (buildings). Though this hierarchy is concerned with levels of assembly and production in an effort to determine better buildability, it is still relevant to deconstruction and recycling.

4.4 A Proposal of Levels

In comparing the proposed end-of-life scenarios of the industrial designers with the architects, it can be seen that the subtle differences between product reuse, remanufacture, and repair may not be as relevant to the construction of the built environment as to product manufacturing (see Table 2). If the building is considered as a product, then the vagaries of the sub-assemblies may be beyond the direct control and concern of the product (building) designer. It is appropriate then to combine product remanufacture and product repair, since both are concerned with the production of ‘new’ products. In this way it is possible to consider the technical results of the scenarios as a way of defining them.

Table 2 Levels of Hierarchy of End-of-life Scenarios (Recycling).

Reference	**Young (1995)**	**Ayres (1996)**	**Graedel (1995)**	**Magrab (1997)**	**Fletcher (2000)**	**Guequierre (1999)**	**Kibert & Chini (2000)**	**Crowther (2000)**
Most desirable					System level			Reuse building
	Reuse	Reuse		Reuse	Product level	Repair product	Reuse of product	Reuse product
↑	Maintain	Repair	Maintain		Product level	Repair product	Reuse of material	Reprocess material
End-of-life scenarios	Reman-ufacture	Reman-ufacture	Recycle component	Reman-ufacture	Product level	Repair product		Reprocess material
	Recycle	Recycle	Recycle material	Recycle	Material level	Recycle material	Recycle	Recycle material
↓							Compost	
Least desirable				Burning		Burning	Burning	
				Landfill		Landfill	Landfill	

There are four (differently scaled) possible technical results, which have been previously proposed by the author [45];

- the reuse of a whole building
- the production of a 'new' building
- the production of 'new' components
- the production of 'new' materials

These would relate to the four end-of-life scenarios of;

- **building reuse** or relocation
- **component reuse** or relocation in a new building
- **material reuse** in the manufacture of new component
- **material recycling** into new materials.

If the strategies of *recycling* as used in industrial ecology were applied to the built environment, the life cycle stage of demolition could be replaced with a stage of deconstruction. The typical once-through life cycle of materials in the built environment could then be altered to accommodate the possible end-of-life scenarios and produce a range of alternative life cycles (see Figure 3).

We can now look briefly at some examples of these scenarios.

Building Reuse
The first scenario is that of relocation or reuse of an entire building. This may occur where a building is needed for a limited time period but can later be reused elsewhere for the same or similar purpose. A good example of this is the Crystal Palace of 1851. This modular exhibition building designed by Joseph Paxton was based on a simple system of prefabricated structural and cladding units that could be easily joined together. These factory produced

elements allowed for the quick assembly and disassembly of the building, and its eventual relocation and reuse after the exhibition [46].

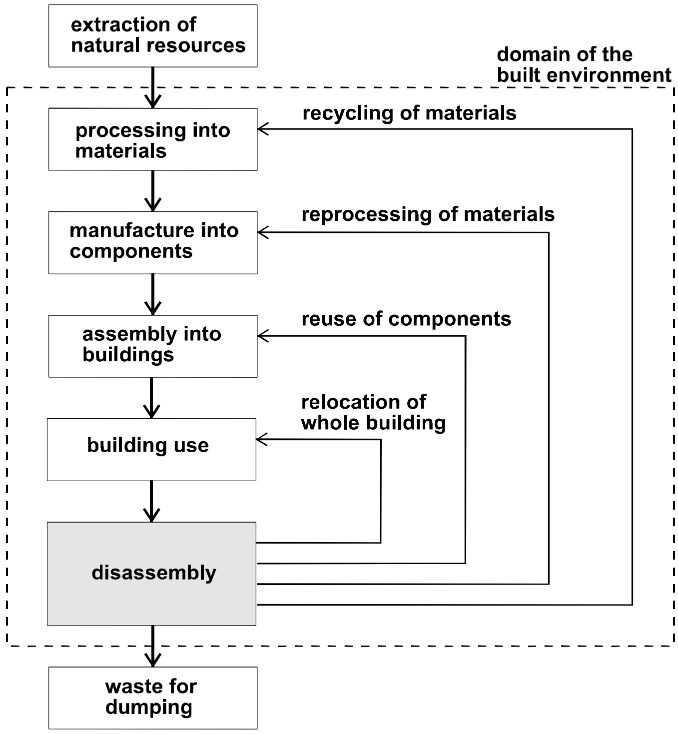

Figure 3 Possible End-of-life Scenarios for the Built Environment

Component Reuse

The second scenario is the reuse of components in a new building or elsewhere on the same building. This may include components such as cladding element or internal fitout elements that are of a *standard* design. A recent example of this is the IGUS factory by Nicholas Grimshaw. The cladding of this building consists of panels that are interchangeable and can be easily moved by just two people. This allows the buildings cladding to be altered to suit changes in the internal use of the building. It is also possible for these components to be used on other buildings of the same design [47]. This scenario of reuse saves on resources, waste disposal, and energy use during material processing as well as energy use during component manufacture and transport.

Material Reuse

The third scenario, that of reprocessing of materials into new components, will involve materials or products still in good condition being used in the manufacture of new building components. A good example of this is the re-milling of timber. In most parts of the world that use timber as a building materials there is a strong vernacular tradition of constructing buildings so that members may be removed and reused or re-processed into smaller members. Even today we still see the reuse of old timber in this way. As well as the waste disposal advantages of the recycling scenario, this reprocessing also reduces the energy required for material processing.

Material Recycling

The final scenario, recycling of resources to make new materials, will involve used materials being used as a substitute for natural resources in the production of manufactured materials. One of the most common current examples of this is the crushing of reinforced concrete to make aggregate that is used for road base. While this scenario does reduce the solid waste stream, other environmental issues may actually not be so positive. While the natural resource use and waste disposal problems are alleviated, the total energy use, and the resultant pollution, may actually be greater than if new resources were used.

4.5 Recycling Hierarchy and Design for Deconstruction

The relevance of the hierarchy of end-of-life scenarios to the design process is that it is possible to design a product or building to facilitate the more environmentally advantageous scenarios.

Graedel and Allenby [48] make an important contribution to the debate by noting that the end-of-life scenarios that are possible for a product will be determined by the physical characteristics of that product. That is to say that the actual design of the product will determine whether it is possible to achieve the environmentally preferable scenarios of maintenance and reuse, rather than just recycling or disposal. Attempts to address this issue have been through promoting the notion of design for disassembly and in the development of guidelines for design for disassembly in the field of industrial design.

In building design, Guequierre and Kristinsson [49], like Graedel and Allenby, make the point that there are physical features of the product (building) that will determine which end-of-life scenarios are possible or probable. This notion suggests that it will be possible to design a product (building) in a way that will facilitate or encourage the implementation of the higher (more environmentally preferable) end-of-life options.

4.6 Conclusions to Recycling Hierarchy

This section has shown how the concept of *recycling* can be more appropriately represented by a group of end-of-life scenarios;

- building reuse or relocation
- component reuse or relocation in a new building
- material reuse in the manufacture of new component
- material recycling into new materials.

These scenarios can be arranged in a hierarchy, in which reuse is (generally) more environmentally beneficial than recycling or disposal. Environmentally responsible building design should attempt to facilitate the higher level scenarios.

There is a direct relationship between the physical design features of a building and what can be done with the building, or its components, when the end of its service life has been reached. It will therefore be possible, through design for deconstruction, to produce new buildings that can achieve more environmentally beneficial end-of-life scenarios.

5 PRINCIPLES OF DESIGN FOR DECONSTRUCTION

5.1 Sources of Information

The strategy of design for deconstruction, has not yet become a major issue in the construction industry. There are however various sources of information on design for deconstruction that can be assessed for recurring themes [50]. These themes have been developed into principles to be used by building designers to either develop building designs, or to assess existing designs or buildings, for future disassembly. The sources of information used in this research include:

- Industrial design
- Architectural technology
- Buildability
- Building maintenance
- Research into deconstruction

Industrial Design
In the fields of industrial and product design, there is already a good understanding of the environmental benefits of recycling and reuse. The concept of Industrial Ecology has to some extent addressed the notion of reduced environmental impact through improved rates of material and component reuse to minimise waste. There are in fact many researchers who have already identified explicit guidelines for design for deconstruction, or design for disassembly, of industrial or manufactured products. Similarly numerous car, computer and household product manufacturers have already implemented the actual practice of design for disassembly.

A study of industrial design practice and research reveals a number of these design for disassembly or deconstruction guidelines that may have application in the construction industry. These guidelines typically cover issues such as material compatibility, connection type, number of connections, handling facilitation, and information management.

Architectural Technology
While design for disassembly or deconstruction has not become a major part of mainstream construction practice, there have been a considerable number of unique architectural efforts that have used such a technique. Throughout history there have been many cases of buildings designed for deconstruction, either to allow for material reuse or for whole building relocation. From primitive huts to the Crystal Palace, and from traditional Japanese timber building to the schemes of Archigram and the Metabolists, there are valuable lessons in design for deconstruction.

A survey of these historic examples reveals a number of common technological trends that suggest the possibility of developing guidelines for designing for deconstruction in buildings. These trends can be roughly grouped into ideas about materials, structural systems, access, connection type, number of components, and appropriate technology.

Buildability
If the process of deconstruction is considered as the opposite of the process of construction, there may be some value in the study of making construction easier. If a building is easier to put together, it should be easier to take apart. The notion of buildability, making buildings

easier to construct, has received some research attention. This research has resulted in some explicit guidelines for buildability that should also assist in design for deconstruction. These guidelines are primarily concerned with issues of handling, access, and prefabrication.

Building Maintenance
The maintenance of buildings often requires the replacement of components or materials. To achieve such replacement it is necessary to deconstruct parts of the building. Research into this facet of building maintenance may therefor offer guidance on how to make such disassembly easier. Investigation of research into replacement maintenance has resulted in some principles of design that make such replacement easier. These principles can be adapted to inform the field of design for deconstruction for reasons other than maintenance.

Research into Deconstruction
The International Council for Research and Innovation in Building and Construction (CIB) Task Group 39 on *Deconstruction* is concerned with research into the disassembly and deconstruction of buildings to achieve higher rates of material and component reuse and recycling. This group has identified a number of research projects dealing primarily with the deconstruction of existing building [51]. From this research, and other related projects, a number of desirable attributes of buildings can be deduced if buildings are to be designed to be easily deconstructed in the future.

5.2 List of Principles

A total of twenty-seven principles can be derived from all information sources [52]. The basis for inclusion of a principle is in how explicitly it is presented as a principle, and in how broadly it is mentioned. Most principles are informed by several of the fields studied.

These principles have been previously presented in a relationship with the hierarchy of recycling. This has taken the form of categorising the principles into four exclusive groups relating to the four end-of-life scenarios. While this categorisation replicated research in industrial design that attempted to link principles and the recycling hierarchy, it was eventually considered to be undesirable due to the exclusivity of the categorisation method.

A more appropriate way to represent the relationship between principles and the recycling hierarchy, one which allows for principles to be relevant to all end-of-life scenarios, is in a tabulated matrix (see Table 3). In this way the relevance of each principle to each level of recycling can be noted.

6 CONCLUSIONS

This paper concludes that a thorough understanding of design for deconstruction in architecture must concern itself with four major issues:

- an overriding *model of sustainable construction*
- the theory *of time related building layers*
- a *hierarchy of recycling*
- the *principles* of design for deconstruction

Knowledge of these issues will help to answer basic questions of why, when, where, what and how to design for deconstruction.

Design for deconstruction is one of many useful strategies to assist in reducing the environmental burden of our built environment. It has not however been well investigated, or well implemented on a broad scale. With a greater understanding of the issues and their interrelationships it is hoped that design for deconstruction might become an important consideration in any construction project.

Table 3 Principles of Design for Deconstruction and the Hierarchy of Recycling

Legend – level of relevance: ● highly relevant • relevant . not normally relevant

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

22	Use a standard structural grid for set outs	.	.	.	●
23	Use prefabrication and mass production	.	.	●	●
24	Use lightweight materials and components	●	●	●	●
25	Identify points of disassembly	.	•	●	●
26	Provide spare parts and on site storage for during disassembly	.	.	.	●
27	Sustain all information of components and materials	.	.	•	●

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METHODOLOGIES AND GUIDELINES FOR DECONSTRUCTION IN GERMANY AND FRANCE

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SUMMARY

The deconstruction of buildings has gained more and more attraction in recent years. The deconstruction and dismantling of buildings instead of their demolition helps to increase the amount of components to be reused or materials to be recycled. Thus, the share of demolition waste deposited in landfills can be reduced. In Germany and France several research projects have proven that dismantling of buildings also helps to reduce the environmental burden of recycled construction materials by encouraging the production of recycling materials containing less harmful substances. Furthermore, it can be shown, that environment-friendly dismantling and recycling strategies can even be advantageous from an economic point of view.

This paper presents sophisticated methodologies as well as the current guidelines for the deconstruction and recycling of buildings. Based on a review and a comparison of different research projects carried out in Germany and France by the French-German Institute for Environmental Research, the relevant problems and solutions concerning the planning of deconstruction work are addressed. Guidelines established recently in Germany and France in order to encourage economically viable and environment-friendly deconstruction strategies will be presented. These guidelines may also serve as a basis for forthcoming standards for the deconstruction and recycling of buildings and for the reuse of components.

KEYWORDS: Guidelines; Methodologies for Deconstruction; Case Studies

1 INTRODUCTION

Maintenance, renovation and removal of the building stock has gained more and more attraction in Europe in recent years. While cost efficiency used to be the major goal when buildings had to be removed, nowadays environmental compliance has also to be respected. In Germany as well as in France legislation encourages the prevention of adverse effects such as emissions and waste. Concerning waste management in the construction sector, both Germany and France have issued several legislative instruments with the aim of prevention and recovery of waste. Accordingly, waste arising due to the deconstruction of buildings should be recycled as much as possible. Nevertheless, a large proportion of construction and demolition waste is still sent to landfill and recycled materials are still used in minor utilisation options. One of the main obstacles for the use of recycled construction materials in high grade applications is the heterogeneity of the composition and the contamination of construction and demolition waste (C&D waste) resulting from the demolition of buildings. Since improvements in the quality of recycled materials in processing are technically limited, efforts have been made to improve the quality of the waste arising on demolition sites. While demolition often leads to the mixing of various materials and contamination of non hazardous components, deconstruction or selective dismantling of buildings instead of demolition help to preserve and reuse material [1].

In Germany and France several research projects have proven that the dismantling of buildings also helps to reduce the environmental burden of recycled construction materials by encouraging the production of recycling materials containing less harmful substances. Furthermore, projects have shown, that environment-friendly dismantling and recycling strategies can sometimes be even advantageous from an economic point of view. In order to encourage cost efficiency as well as the fulfilment of environmental requirements such as high grade recycling, sophisticated planning approaches have to be applied [2]. Adequate planning models and software tools make it possible to evaluate strategies for optimised construction site management even when technical or economic circumstances are adverse [3]. Model-based optimisation shows that the economics of deconstruction can be considerably improved while strict quality standards for the construction site as well as for the materials are met.

In the following, the current guidelines as well as approaches for deconstruction planning and reuse or recycling of buildings in Germany and France are presented.

2 METHODOLOGIES AND GUIDELINES IN GERMANY

2.1 Market situation

In the field of renovation and demolition of buildings, significant improvements in the quality of waste arising can be achieved by the application of selective dismantling techniques. As the dismantling of buildings generally requires more manpower and technical equipment than traditional demolition, the costs also tend to be higher but might be compensated by lower costs for the recycling or disposal of the materials, if dismantling and recycling are planned well. In Germany the costs for recycling and disposal of demolition waste range in the same category as the costs for demolition. So it can be advantageous to dismantle as many building elements as possible if this leads to a decreasing of the recycling and disposal costs. The following table 1 shows the average costs for the recycling and disposal of various kinds of demolition waste.

Table 1 Average deposit fees and recycling costs for various types of materials in Germany.

Category of Materials	Deposit Fees [EUR]	Recycling Costs [EUR]
Mineral materials		
Concrete Scrap	-	7 to 10 EUR/t
Bricks	-	7 to 10 EUR/t
Mixed mineral Materials	80 to 200 EUR/t	9 to 13 EUR/t
Metals		
Iron	-	-40 to 0 EUR/t
Aluminium	-	-250 to -100 EUR/t
Copper	-	-1000 to -250 EUR/t
Wood		
Untreated Wood	-	35 to 65 EUR/t
Lightly treated Wood	-	50 to 100 EUR/t
Treated Wood (pressure impregnation)		50 to 250 EUR/t
Other Building Materials		
Glass	-	30 to 65 EUR/t
Plastics	-	50 to 200 EUR/t
Mixed Building Materials *		

Mixed Materials (only recycling)		125 to 200 EUR/t
Mixed Materials (recycling and disposal)	125 to 300 EUR/t	
Mixed Materials (only disposal)	125 to 300 EUR/t	

* Mixed Material have to be sorted according to their material composition

2.2 Legislative Background

In Germany the first federal law dealing with waste was enacted in 1972, it was the law for the prevention and disposal of waste of 27th August 1986, which outlined for the first time the principles for the transition from disposal to waste management. Accordingly, the first goal must be the prevention of waste and if prevention is not possible, the composition of waste must be improved in order to permit reuse or recycling.

In July 1994, the Recycling and Waste Management Act "Kreislaufwirtschafts- und Abfallgesetz (KrW-/AbfG)" [4] was passed by parliament. This law, which was enacted in October 1996, set new principles for the development of waste management towards a closed loop economy. It introduced several principles for waste management. For instance a new hierarchy for waste treatment where the avoidance of waste is better than the recycling of waste, but recycling is more preferable to the disposal of waste. The disposal of waste is only allowed when recycling is much more expensive or impossible and the waste is unavoidable. Another important innovation of the new Recycling and Waste Management Act is the responsibility of the producers for the waste arising from their products.

The German waste legislation is supported by subordinate regulations and Technical Instructions. The German Technical Instruction for Municipal Waste ("TA Siedlungsabfall") [5] specifies the treatment and disposal of waste and deals with waste streams of great importance such as domestic waste and building and demolition waste. The goals of this administrative order are to recycle unavoidable waste, to reduce the toxicity of waste and to ensure that an environment friendly treatment or disposal of waste is maintained.

2.3 Guidelines and regulations for deconstruction in Germany

In the field of demolition and deconstruction of buildings several guidelines were published during recent years by public authorities. The aim of these guidelines is to inform how demolition and deconstruction work can be performed in an economical way without neglecting ecological issues. This was necessary because on the one hand significant improvements in the quality of waste arising can be achieved by the application of selective dismantling techniques. On the other hand the dismantling of buildings requires more manpower and technical equipment than traditional demolition which leads to increasing costs. These higher costs can be compensated in some cases by lower costs for the reuse, recycling or disposal of the materials, if dismantling and recycling are planned well. These guidelines were published in order to facilitate the planning of the renovation or dismantling of a building.

In the following a table with a short summary of some of the existing guidelines for the deconstruction of buildings in Germany are presented. In the example of one guideline published in Baden-Württemberg [6] the basic issues are explained.

Table 2: Guidelines for the deconstruction of buildings in Germany.

Title	Content	Date
Demolition of residential and administrative buildings -guideline **(Abbruch von Wohn- und Verwaltungsgebäuden-Handlungsanleitung)** Landesanstalt für Umweltschutz Baden-Württemberg (LfU) [6]	• See text below	2001
Guideline for sustainable construction of public buildings **(Leitfaden nachhaltiges Bauen bei Bundesbauten)** Bundesministerium für Raumordnung und Städtebau [7]	• Guideline only for public buildings • Ecological assessment of construction, use and deconstruction of a building • Basic demands on planning of sustainable construction • Proposal for a building certificate	2000
Development of methodologies for the assessment of contamination of building materials before deconstruction **(Entwicklung von Verfahren zur Beurteilung der Kontaminierung der Baustoffe vor dem Abbruch)** Deutscher Ausschuss für Stahlbeton [8]	• General view of analysis methodologies for building materials • Instructions for testing	2000
Guideline for the determination of masses and recycling planning of buildings to be demolished **(Leitfaden für die Erfassung und Verwertung der Materialien eines Abbruchobjektes)** Deutscher Ausschuss für Stahlbeton [9]	• Check list for: - Inspection of the building - investigation of building elements - investigation of the foundation of the building - analysis of harmful substances - information about buildings in the neighbourhood • detailed example	1999
Deconstruction and demolition of buildings **(Rückbau und Abbruch baulicher Anlagen)** Umweltamt Düsseldorf [10]	• Basic facts of laws in the field of waste • Procedure of deconstruction planning (inspection, bill of quantities, recycling planning) • Flowchart of deconstruction • Demands on recycling concepts	1997
Recycling guideline **(Arbeitshilfen Recycling)** Bundesministerium für Raumordnung und Städtebau [11]	• Guideline only for public buildings • Basic facts of laws in the field of waste • Waste management for the construction of public buildings • Deconstruction of public buildings - instructions for inspection of the building in tecninal and historical respect - investigation of harmful substances • - Instructions about deconstruction planning, calling for tenders and contract letting-	1997
Environmentally advantageous and low cost treatment of demolition waste **(Umweltgerechter und kostensparender Umgang mit Bauabfällen)** Zentralverband des Deutschen Baugewerbes [12]	• Basic facts of laws in the field of waste • Explanation of recycling options • Instructions for a recycling strategy (deals also with construction)	1997

The guideline "Demolition of residential and administrative buildings" [6] gives a short general view of current terms in the field of deconstruction of buildings as well as a summary of laws concerning demolition. The guideline explains the three principal procedures for the demolition of buildings: conventional demolition, partly selective dismantling and selective dismantling. In the chapter on legislation in the field of waste, the most important laws and administrative orders are summarised. To permit a quick understanding of the legislative situation, the guideline has a table containing the main laws and administrative orders arranged under "Demolition", "Recycling" and "Harmful Materials".

Due to the fact, that buildings and building elements can contain many different harmful substances, the guideline informs about building elements which could contain such substances. Furthermore advice is given on which procedure has to be carried out before the demolition of buildings containing the mentioned building elements.

The guideline aims mainly to provide a decision support for the choice of the adequate demolition techniques. Therefore advantages and disadvantages of the different demolition techniques will be analysed according to economic, environmental and other aspects. The guideline lists different tools for disposal to support this decision: a flowchart showing the procedure of planning, permission and contract letting of the deconstruction of a building (compare Figure 1), a calculation sheet for the determination of costs for demolition and recycling/disposal and a computer tool.

The computer tool permits a quick survey of the material composition of the building as well as the costs for demolition and recycling/disposal of the demolition waste arising. The program contains a data base which supports the data input supplying information concerning the costs of dismantling and recycling. The calculation can be performed using two different calculation methods.

1. A rough estimation of costs and material composition of the building on the basis of the type and the volume of the building.
2. A detailed determination of the building masses including mineral building structure as well as the internal finish. For each building element, data concerning dismantling and recycling can be determined by the user or can be found in the data base.

Both calculation methods permit the calculation of three deconstruction scenarios: conventional demolition, partly selective dismantling and selective dismantling.

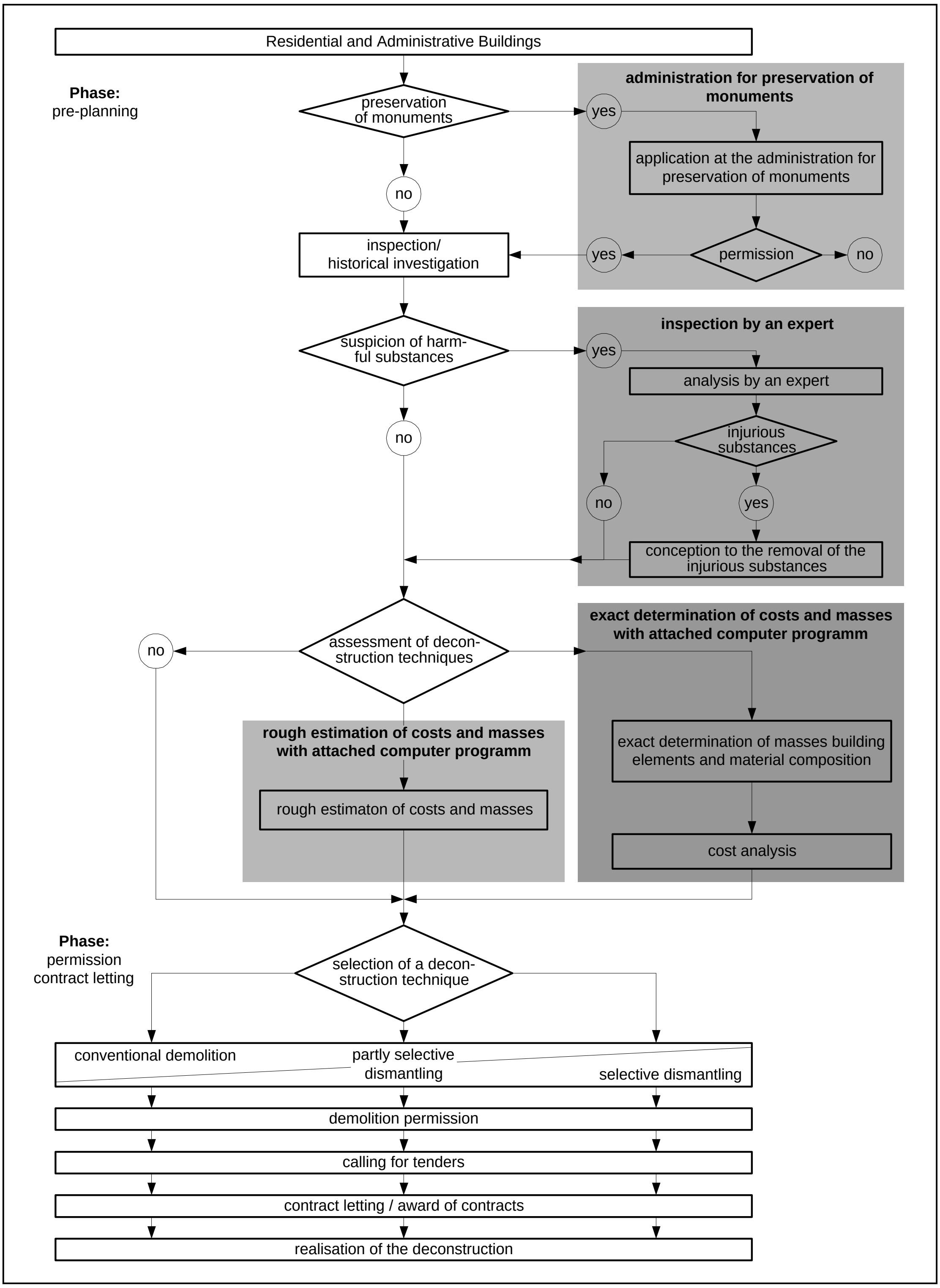

Figure 1 Flowchart of planning, permission and contract letting of the deconstruction of a building [6].

3 METHODOLOGIES AND GUIDELINES IN FRANCE

3.1 Legislative Background

In France, the Ministry of Territorial Planning and the Environment has stipulated that the elimination of demolition waste must be achieved in a very strict regulation context. The law of 15 July 1975 on the waste elimination and the recovery of materials imposed first great legislative principles, especially on the "polluter-pays" principle: the waste producer has the responsibility of their elimination [13]. The circular of 15 February 2000 imposes at departmental level the planning of the public buildings and works sector waste management in order to respect the requirements set out in the law of 13 July 1992 on waste elimination (altering the law of 15 July 1975); starting in 2002, disposal will be limited to non recyclable and toxic wastes [14] [15] [16]. This planning must take into account the existing planning of household and industrial waste management requested by the Ministry in the law of 28 April 1998 [17]. Such planning complies with the European commitments of France.

As for the other types of waste, the principles of reducing quantities (for example reuse of construction elements), sorting and recycling of materials are put forward. The objective of the main regulations is to reduce the quantities of demolition waste to be landfilled and to protect non renewable natural resources. The Ministry of the Environment promotes the elaboration of a demolition waste treatment network according to waste streams, on the basis of a clever geographic distribution of recycling installations (in order to limit waste transport) and of sorting plate-forms for recyclable materials [15]. Furthermore, the Ministry of the Environment points out that reducing quantities of deconstruction waste to be landfilled is possible only thanks to the committed behaviour of all participants of the construction field: construction professionals, elected officials, public and private building owners, managers and contractors [14]. Building owners have to be more involved in waste management; from now on they are invited to take into account systematically the costs for waste treatment in their public invitations to tender [14]. Another strategy in accordance with the development of deconstruction of buildings, is to promote the reuse of construction elements and secondary raw materials in new buildings [14].

3.2 Guidelines and regulations for deconstruction in France

High Environmental Quality concept

After Germany, the Netherlands and England, for a few years now in France, High Environmental Quality in the construction field has been extensively growing. This concept has been defined by its creators, investigators (Ministry of Equipment, Transport and Housing, Office of Urban Housing and Construction, Ministry of Territorial Planning and the Environment, ADEME…) and representatives from the public and private sectors as a set of social, ecological and economic requirements that allow buildings to ensure the comfort (acoustic, thermal, visual comfort…) of the residents and a good quality of life, to reduce health risks, to minimise negative impacts on the environment and to preserve natural resources. In concrete terms, it utilises a set of techniques and methods designed to favour the implementation of sustainable development principles [18]. It encompasses the entire life cycle of a building, from conception, construction to maintenance, renovation and demolition or deconstruction; that is why this approach will from now on be part of many invitations to tender, called High Environmental Quality invitations to tender, of public building owners concerned with their image and environmentally friendly innovations. From an economic point of view, High Environmental Quality urges building owners to view at a new work site not only capital costs, but future costs too: maintenance and running costs for a construction work site, costs for waste management in the case of deconstruction. In France, many High Environmental Quality buildings, such as schools, cultural centres, multi-purpose halls, hospitals and residential buildings in the framework of experimental High Environmental Quality constructions of residential buildings launched by urban construction and architecture (PUCA) between 1994 and 1999 have been built in recent years [19]. Other projects on the level of neighbourhood, housing estates are currently in the experimental phase and programmes of High Environmental Quality town planning are being discussed [20].

Among all its principles, called targets (targets for the managing of the impact of the building and its effect on the environment, targets for residents´ comfort and health), this modern High Environmental Quality concept includes two interesting targets for deconstruction: first the integrated choice of construction techniques and products in order to facilitate the future deconstruction of buildings, and then construction or deconstruction with low impact, waste sorting and the reduction of noise and pollution [21]. In the framework of a High Environmental Quality project for a building deconstruction, work is divided into a few essential characteristic stages:

- Building audit in order to evaluate qualitatively and quantitatively constituent construction materials.
- After invitation to tender, choice of enterprises for deconstruction work. The commitment to carry out such an environmental project is an important criterion: observance of specifications, ability to adopt new work methods and implementation of new equipment.
- Deconstruction work causing little negative impact on the environment.
- Storage of construction elements for reuse, on-site sorting of materials and recycling.
- Study of the environmental impact of the utilisation of reused elements in new buildings.
- Inventory of construction materials and elements used in the new construction in order to facilitate the future deconstruction of the building.

The High Environmental Quality process is a recently established guideline, or more exactly a set of guidelines, allowing the development of the deconstruction of buildings and facilitating the achievement of its different stages (works planning, waste management…).

In the framework of a High Environmental Quality project, the deconstruction of a high school (Galilée in Genevilliers) in the vicinity of Paris is in progress. The building owner, the Ile-de-France Regional Council, has entrusted the French-German Institute for Environmental Research to plan the different tasks (see section 3.3.)

Methodological approaches for deconstruction and applications
Since 1995, the French Office of Housing and Construction (Ministry of Equipment, Transport and Housing) has planned several studies making it possible to formalise methods for demolition waste management, and has launched pilot projects for deconstruction in order to test these methods. The analysis of the results has permitted the issue of two documents published in 1997 by the Office of Housing and Construction: Methodology of specifications and of choice of offers for the demolition, and buildings audit before demolition [22] [23]. These documents are tools at the disposal of building owners, who wish to optimise the

environmental management of their demolition projects. In the document entitled “buildings audit before demolition”, a methodology for an audit is presented. The aim of this building audit is to provide building owners, before the stage of invitations to tender, with a qualitative and quantitative valuation of the constituent materials of the building to be demolished and to inform them of the deconstruction possibilities according to the building characteristics, existing techniques and local options for waste recycling.

Persons in charge of the audit, selected by the building owner, must:

- look for general information and data about the building (historical, technical or environmental data).
- inspect the building in order to estimate the constituent materials and especially materials harmful to health and the environment.
- look for local options of waste elimination.
  The following flowchart (figure 2) shows the different options of demolition waste elimination and the corresponding costs.
- evaluate specific operations of demolition for the extraction of dangerous materials (Asbestos…).

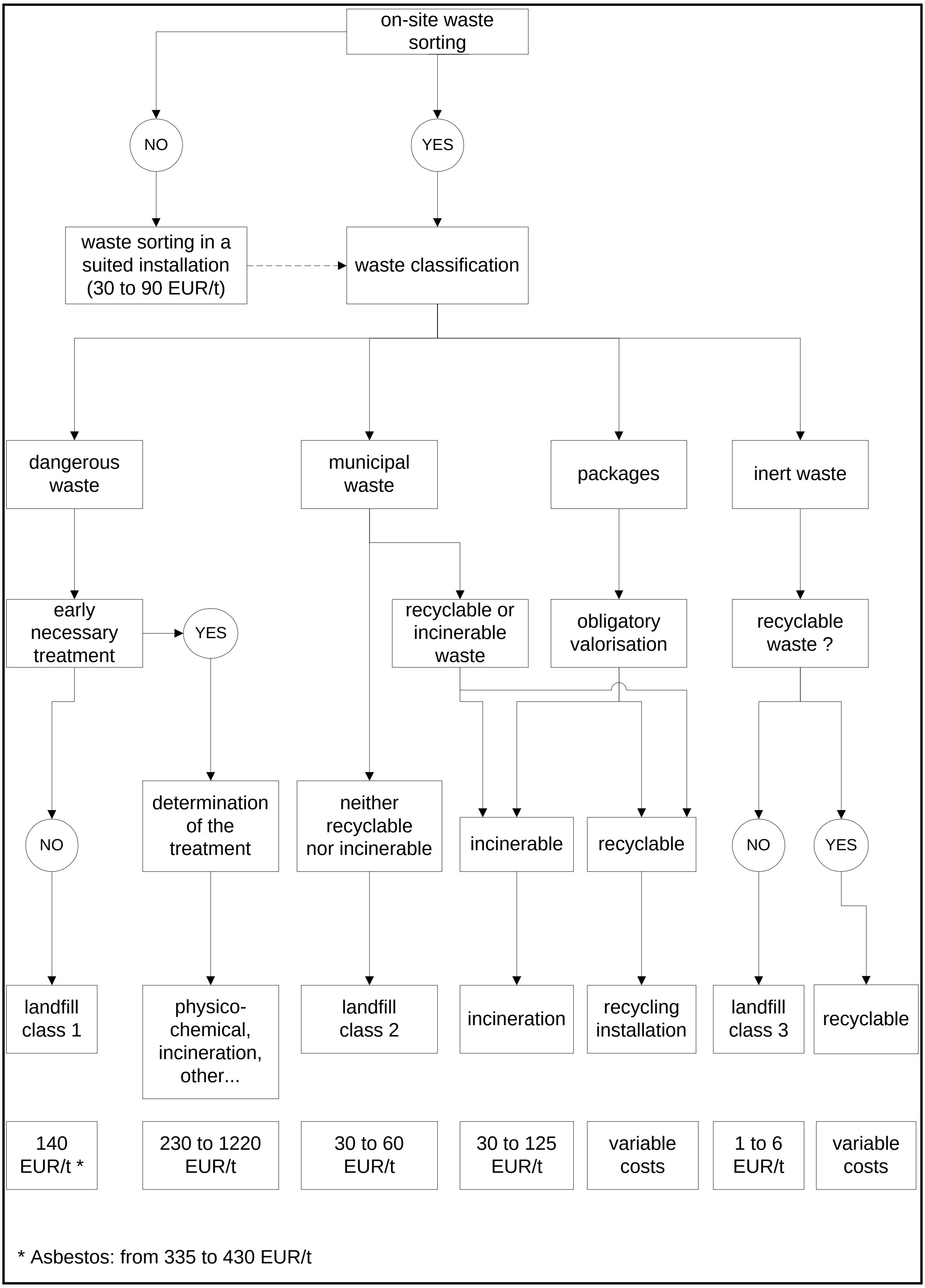

Figure 2 Flowchart of demolition waste elimination and corresponding costs [24].

The audit report must comprise:

- a chapter on the general data of the building to be demolished.

- a specific part dealing with the presence of dangerous or toxic materials.
- tables that list the different types of materials in the building and the estimated quantities of each material. The total quantity of waste generated by the demolition can be calculated easily.
- evaluation of the demolition work in terms of costs and turnaround time. This provides very helpful data for the building owner for the analysis of offers from enterprises after the invitation to tender.

The audit report is integrated by the building owner into the documents of the invitation to tender. Therefore, demolition enterprises will answer the invitation to tender only from an outline of the building to be demolished.

The French Office of Housing and Construction gives a clear methodology for performing the audit but it does not resolve the problems of it practical application. The High Environmental Quality approach advocates at the stage of the audit only the qualitative and quantitative evaluation of the constituent materials of the building. Thanks to several studies of deconstruction projects in Germany and in France, the French-German Institute for Environmental Research has gained experience with the audit of buildings as a method of global evaluation of buildings [1]. The development of a software tool for the audit of buildings and many data base (data on dismantling techniques, costs and duration, on the existing options for waste management, on materials…) makes it possible to accomplish the different stages of the methodology of the audit on site[25].

3.3 Recent case studies in France

In the following, two recently accomplished case studies in France are presented. The background of these works was the need not only for a building audit , but also the analysis and the choice of local waste recycling options. In order to guarantee a high quality recycling, several criteria have to be considered: the distance between the work site and the recycling installation in order to limit costs for transport, technical characteristics of the installation to obtain very high quality recycled materials allowing the substitution of natural materials in new constructions, and the reception capacity of the installation that have to fit the estimated quantity of waste in the audit report. From an economic point of view, landfilling must be the ultimate resort for the deconstruction waste elimination. The French landfill fees are increasing and, according to an estimation, in 2002 demolition waste elimination will be twice as expensive as today, if waste management does not change or improve.

Case study in Gennevilliers

In the framework of a High Environmental Quality project of deconstruction, launched by the building owner, the Ile-de-France Regional council, the French-German Institute for Environmental Research has audited the 29 buildings of the high school Galilée in Gennevilliers in the vicinity of Paris [26]. This school complex is made up mainly of educational and residential buildings, workshops. The audit permitted a study three different construction systems: a reinforced concrete structure with prefabricated asbestos panels for frontages in the educational and residential buildings, metallic structures in workshops and prefabricated buildings with composite materials. The inventory of construction elements for each building was drawn up for planning their reuse or sale (from the economic point of view, it is important to evaluate the profit between costs for dismantling, so costs for manpower and technical equipment and gains after the resale of construction elements); 150 types of construction elements have been identified. A classification of constituent materials of buildings was made according to their options of valorisation or elimination. The mass repartition of materials of the 29 buildings is shown in Figure 3.

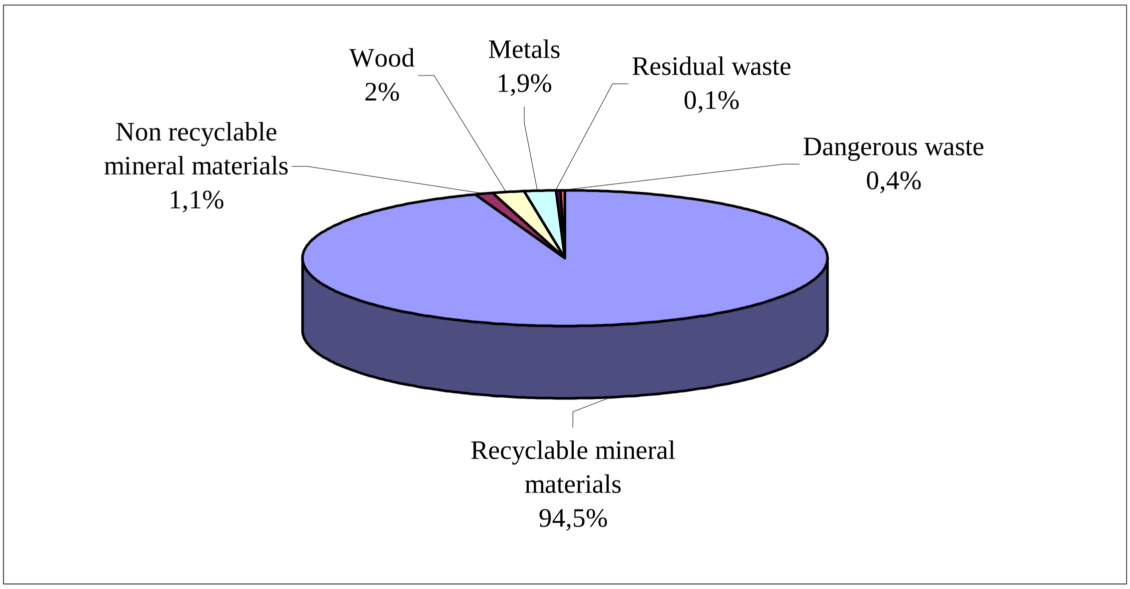

Figure 3 Mass repartition of materials generated by the deconstruction of the 29 buildings.

Six construction materials groups have been determined. Mineral materials which can be recycled are concrete and glass. Non recyclable mineral materials are mainly reinforced glass, plaster and glass wool. Residual waste consists essentially plastics and carpets, and dangerous waste is asbestos used in the sandwich panels, for roofing, etc. An asbestos cartography, integrated in the report of the audit, was carried out thanks to CAD-System. The audit report itself formed part of the documents for the invitation to tender.

Case study in Nantua

In 1998, the Region Rhônes-Alpes answered to a call to building owner launched by ADEME and the French Ministry of Equipment, Transport and Housing for the accomplishment of deconstruction projects, in this case the high school in Nantua [27]. The French-German Institute for Environmental Research, performed the audit of the building, identified the local options for waste management, determined the dismantling modes and planned the deconstruction. Three scenarios for dismantling the building were studied:

- scenario S1: to preserve characteristics of the mineral materials; sorting and separately concrete recycling.
- scenario S2: recycling of inert mineral materials (no sorting according to material characteristics).
- scenario S3: sorting to preserve the inert character of waste to be disposed in lanfill class III.

For each scenario, the duration and costs of the work were evaluated. The total costs of scenario S2 are slightly higher (+7%) than the costs of scenario S3. This additional cost is explained by the difference between recycling costs and storage costs of mineral materials. The additional cost of scenario S1 (+13% in comparison with S2) is caused by the concrete sorting. It is scenario S2 (recycling of mineral materials) that was conserved and included in documents for the invitation to tender: it presented the best link costs/profits.

The French-German Institute for Environmental Research followed the deconstruction. The total costs of the deconstruction are as follows: 32% for asbestos evacuation, 31% for dismantling, 16% for waste management, 11% for security and protection, 5% for on-site sorting and 5% for structure demolition. The deconstruction has allowed the recycling of mineral materials (88% of the mass of the building).Some building elements were sold (roof, heaters…). The intervention of specialised enterprises in order to dismantle building elements was especially efficient. They had very good knowledge of construction systems, security measures to implement on-site and could reuse a few building elements in work on another construction site.

Acknowledgement
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NATIONAL R&D PROJECT TO PROMOTE RECYCLE AND REUSE OF TIMBER CONSTRUCTIONS IN JAPAN

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SUMMARY

The volume of waste generated in the process of dismantling wooden buildings is increasing year by year in Japan and the resulting wood waste is having serious local environmental impacts. To improve this situation it is necessary to promote the recycling and reuse of the resources used in the process of building wooden structures. It is also necessary to develop new systems and technologies that enable the reduction of the volume of the waste generated in construction activities.

A new national research project was started in 2000 to reduce waste generated in the process of dismantling wooden buildings. In this research project, new technologies and new social systems will be developed to reduce the waste products over the life cycle of wooden construction. The project deals with three main research subjects. The research subjects are as follows:

(1) Development of design and construction methods to reduce waste in the construction of wooden buildings.
(2) Development of the recycling and reuse technologies for building materials and components.
(3) Development of social systems to disseminate the developed technologies.

The final objective of the first research subject is to propose technical guidelines for choosing low environmental impact building materials and components and to develop design and construction manuals for recyclable, sustainable wooden buildings. The final objective of the second research subject is to develop recycling technologies and to propose reuse and recycle systems for building materials and components. The final objective of the third research subject is to develop a system dynamic model to simulate the effects of technologies and policies on materials flows in the construction of wood buildings.

KEYWORDS: Waste products, Wooden Buildings, Dismantling, Recycle, Reuse, Construction Methods

1. INTRODUCTION

Each year, there is an increasing amount of wooden materials left behind from the renovation or dismantling of timber structures. A large portion of these wood materials become waste rather than being recycled, thereby damaging the local and global environment and creating serious community issues. In order to sustain the timber construction business into the 21st century, including the construction of wooden houses, broad-ranging recycling technologies that reuse materials removed throughout the life cycle of buildings should be developed.

Large quantities of resources are consumed in the process of building wooden houses and, as the life spans of these wooden houses are very short in Japan, these resources are disposed of over a short period of time. There is a pressing need for the development of technologies to increase the life span of wooden houses and to create a large stock of wooden houses.

Because the waste generated by the construction industry is becoming a serious social problem in Japan, several organizations and groups have started new projects to reduce the production of waste and to promote the reuse and recycling of construction and demolition waste. In May 2000 the Ministry of Construction officially announced a new law that stipulates the deconstruction process and promotes the recycling of construction and demolition waste.

In the Building Research Institute three R&D projects that concern reducing, reusing and recycling of the timber buildings are now ongoing. The titles and the research periods of the three R&D projects are as follows:

(1) Development of technologies for increasing the life span and the stock of wooden houses. (From year 1998 to 2001)
(2) Research and technological development for the prevention of dioxin contamination and waste reduction in the construction industry. (From year 2000 to 2003)
(3) Development of advanced technologies for recycling building materials and components. (From year 2000 to 2002)

The final target of these R&D projects is to reduce the amount of waste and also to promote the recycling and reuse of construction and demolition waste during the life-cycle of timber buildings.

2. CURRENT SITUATION OF C&D WASTE IN JAPAN

There are several recent reports on the current situation of C&D waste in Japan [1][2]. The summaries of these reports are introduced in this section.

Almost 45 percents of the natural resources extracted in Japan are consumed by the construction industry and almost 20 percent of Japan’s waste is produced by construction activities. Almost 45 percents of the waste that goes to the landfill site is produced in the process of construction and demolition of buildings and civil structures. And the construction industry is responsible for almost all of the illegally disposed waste. (See Table.1)

Table 1 Resource consumption and waste discharge.

		All Industry (billion tons)	Construction Industry (billion tons)	Ratio (%)
Natural Resource	Consumed	2.40	1.10	46
Waste	Discharged	0.40	0.08	21
	Recycled	0.31	0.05	15
	Legally disposed	0.08	0.04	44
	Illegally disposed	3.90	3.40	87

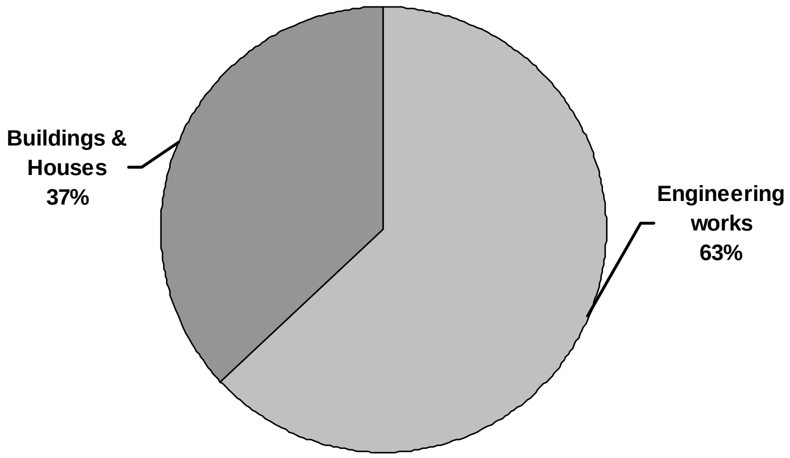

Figure 1 Waste discharged from the construction industry.

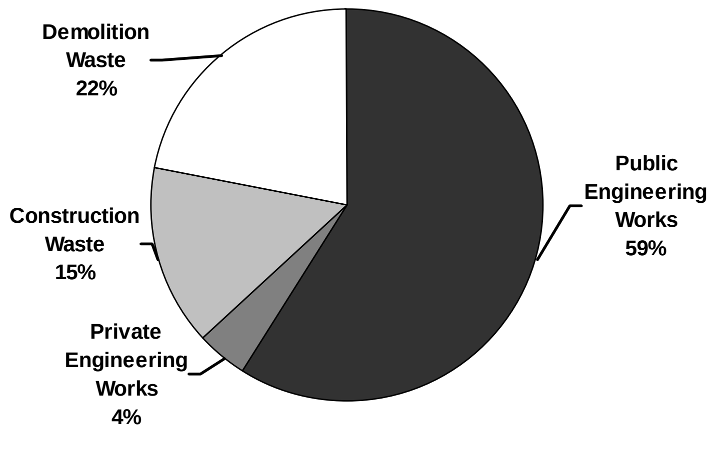

Figure 2 Details of the waste discharged from the construction industry.

The total weight of the waste discharged by the construction industries in 1995 was approximately 100 million tons and three fifths of the waste was from the civil engineering activities and two fifths of the waste was from the building activities. And as to the waste from the building activities two fifths of the waste was construction waste and three fifth of the waste was demolition waste. (See Figure 1 and Figure 2)

Table 2 shows the type, amount and recycle ratio of the waste discharged by the construction industry in 1995. The waste from the building activities is mainly composed of concrete aggregate, mixed waste and wooden waste. And the mixed waste and the wooden waste show the lower recycle ratio than concrete aggregates. The waste from the building activities is not so much recycled as the waste from the civil engineering activities.

Table 2 Type, amount and recycle ratio of the waste

Type of waste	Civil engineering		Building	
	Weight (million tons)	Recycle ratio (%)	Weight (million tons)	Recycle ratio (%)
Construction waste	61.6	68	37.6	42
Asphalt and Concrete	34.5	80	1.2	62
Concrete	17.8	69	18.6	60
Mixed	1.6	8	7.9	11
Wood	0.6	69	5.7	37
Soil and rock	7.0	14	2.7	14

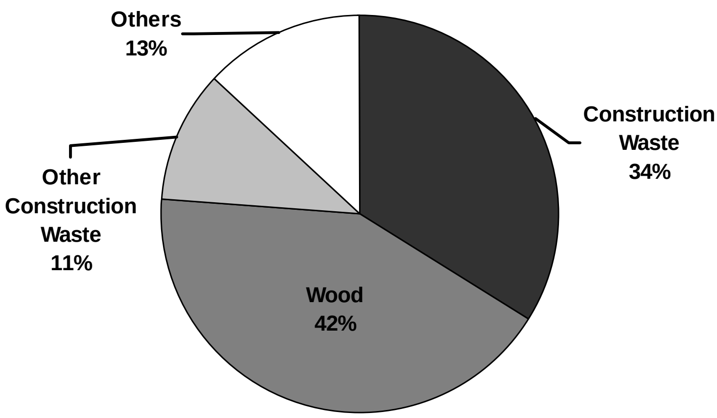

Figure 3 Types and amount of the improperly disposed waste.

Figure 3 shows the types and amount of the improperly disposed waste. In 1995, studies showed that 389,507 tons of wastes were improperly disposed in 1995 and more than 40 percent of this improperly disposed of waste was wood. It is thought that this improperly disposed of waste was generated in the process of constructing and dismantling wooden houses.

Figure 4 shows the projected amount of the building waste in the next 25 years. The amount of the waste will increase year by year and in the year 2025 the total amount of building waste is forecast to be approximately 50 million tons. Though the amount of the building waste generated in the process of constructing or dismantling wooden buildings will not increase, as constant volume of waste will still be generated during the process of constructing, renovating and demolishing wooden houses. And it is estimated that the landfills have their capacities to accept waste no longer than 0.9 years in the Tokyo area and 2.6 years in the whole country.

Figure 4 Estimated amount of the building waste in the next 25 years.

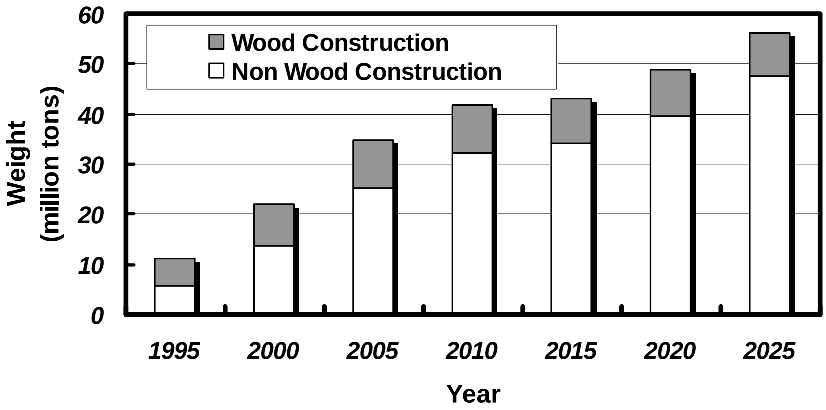

Photo 1 shows the deconstruction site of the post and beam wooden house in Japan. There are three methods for dismantling wooden houses in Japan: by hand, by machine and by machine and hand. The ratio of the wooden waste that is discharged in the process of dismantling post and beam houses is approximately 20% in weight and 45% in volume. And the ratio of the mixed waste is approximately 20% in weight and 10% in volume.

Photo 1 Deconstruction site of the post and beam wooden house.

To improve the current situation and to give a hopeful light to the next generation the government worked on a new law that stipulates the deconstruction process and promotes the recycling of construction and demolition waste. The details of the law were officially announced in May 2000. The law is roughly composed of five items as follows:

(1) Requirement for selective dismantling and recycling.
(2) Action to promote recycling and demolition.
(3) Adjust the contract between the owner and the dealer.
(4) The establishment of registration system to demolition dealer.
(5) The setting of objective concerning recycles.

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(10) The setting of objective concerning recycles.

Requirement for selective dismantling and recycling
For buildings beyond a certain minimum size, selective dismantling to recover specific materials such as concrete, asphalt and wood is required. It is expected that these requirements will be expanded and increased in the future.

Action to promote recycling and demolition
The owner of the building scheduled for removal is required to report the removal prior to demolition and the results of dismantling and recycling of materials at the end of the process.

Adjust the contract between the owner and the dealer
The subcontractor undertaking deconstruction must provide a plan for selective dismantling to the owner. The method of selective dismantling and the expense must be specified for the demolition work.

The establishment of registration system to demolition dealer
The subcontractor undertaking demolition needs to register with the municipality and local district. The demolition subcontractor must engage an engineer who manages the various technologies for demolition. Because the budget for demolition is typically small, it is not necessary to get the permission of local government. Thus it is easy for an unqualified and unlicensed contractor to provide demolition services. This is one of the reasons why illegal dumping of waste occurs as well as indiscriminate dismantling of structures.

The setting of objective concerning recycles
As the basic policy, the recycling and the reuse of construction materials are promoted by creating an action plan. Getting the cooperation of the owner is very helpful in recycling and reuse.

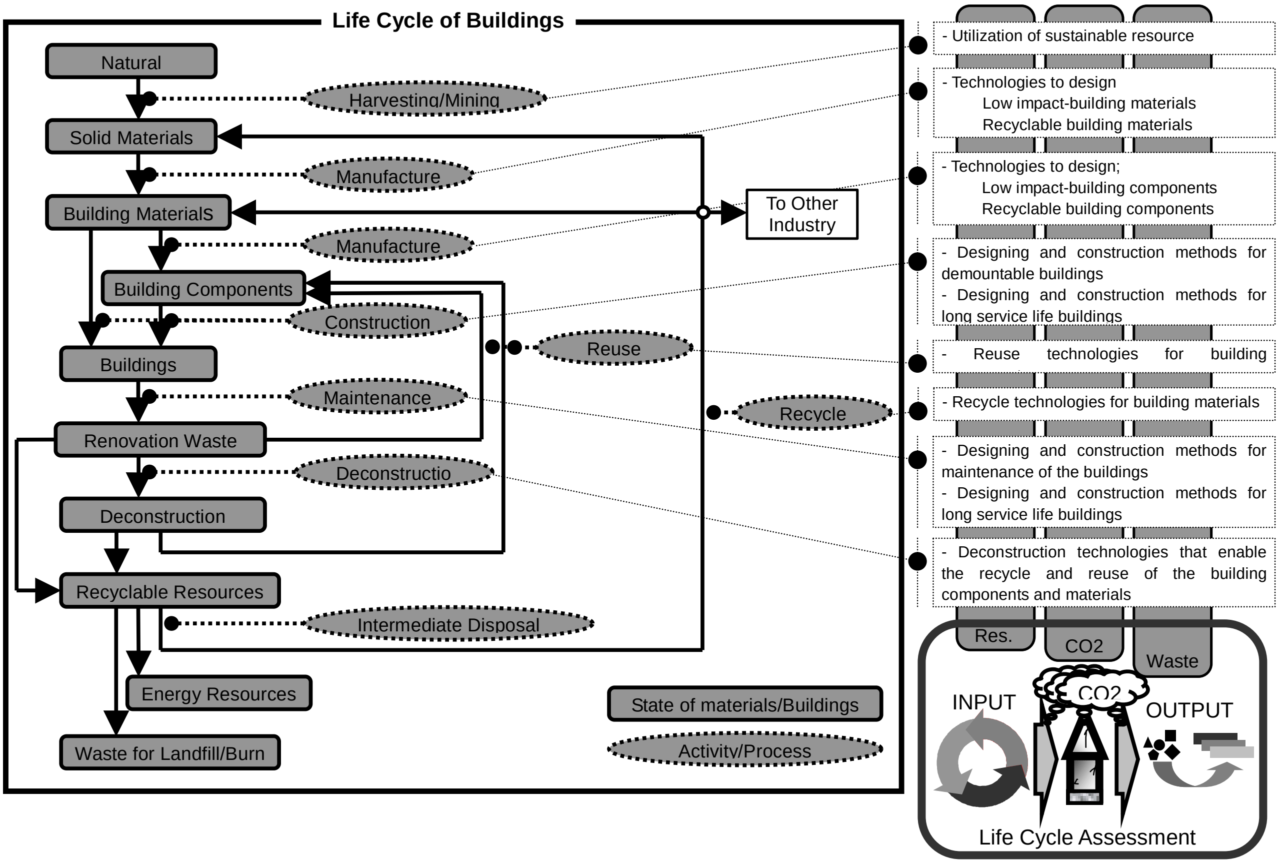

Figure 5　Life cycle of buildings

3. R&D PROJECTS

In the Building Research Institute we are working on three R&D projects to develop technologies to reduce the waste from the wooden houses and to promote the reuse and recycle of C&D waste.　Figure 5 shows the life cycle of buildings and the technologies needed to reduce the environmental impacts.　In these R&D projects we are planing to develop almost all of the necessary technologies to reduce environmental impact of the wooden buildings listed in the left part of the figure.　The outline of each project is introduced in the following paragraphs.

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3.1 Development of technologies for increasing the life span and the stock of wooden houses

Backgrounds

The service life of the wooden residential houses in Japan is about twenty-five to thirty five years and in most cases wooden residential houses are in use for only fourteen to seventeen years.　Wooden houses are easily constructed and easily demolished in a short period and a huge amount of resources is consumed and a huge amount of waste is generated.　These activities disrupt the global and local environment.　In other cases we are forced to reduce the scale and the quality of the houses for social reasons and according to the reduction of the scale and the quality of the residential houses the residential environments can be poor.

On the other hand, in advanced countries, for example in North America and in Europe, the service life of the wooden residential houses is far longer in comparison with that of the wooden residential houses in Japan. In the North American countries wooden residential houses are in use almost forty five to sixty years and this use period is almost three times longer than that of the wooden residential houses in Japan. As the improvement of the quality of the residences is appropriately evaluated in the North American countries it is quite easy in these countries to use the wooden residential houses continuously for a long period. For example, upgrade in the quality of a residence is appropriately evaluated according to the quality of the maintenance and remodeling. And the quality of the residence is reasonably reflected to the price of the residence. The prices of the residence and attention to the quality of the residence and the lifestyles in the North American countries also have something to do with the long service life of the wooden residential houses. The situation with wooden houses in Japan is quite different from that in the North American countries and in most cases houses are rebuilt within a short period in Japan.

Although there is little economic difference between Japan and North America, the service life of wooden residential houses is quite different between Japan and the other developed countries. It is becoming a very important task for us to propose technology systems that will prolong the service life of wooden residential houses in Japan. And we have to develop a new technology that will improve the quality of the residential houses drastically.

Summary of the Research Project

The project is a three years project and it started in 1998 and the annual research budget is approximately 15,000,000JPY. The outline of the research project is shown in Figure 6. The aim of this project is to promote the effective use of resources and enhance the residential environment. The research project is a joint project with private companies and associations and organized by the Ministry of Construction and the Building Research Institute. The main items of this research project are as follows:

(1) Development of technology for reusing the wooden residential houses and upgrading the quality of the stock of the existing houses.
(2) Development of design and construction technology to produce long lasting wooden residential houses.
(3) Development of a system to disseminate the developed technologies.

In the first research subject we developed the technologies that will promote the reuse of the exiting wooden residential houses. These technologies are quite necessary to increase the quantity of high quality wooden residential houses. In detail we developed the following two new technologies:

- Practical building diagnosis technologies that enable the evaluation of the quality of the existing wooden residential houses.
- Maintenance and repair technologies for the existing wooden residential houses.

In the second research subject we proposed new designing methods for newly constructed, long lasting houses. We discussed the necessary performance of the materials and components and decided the designing methods and also developed the maintenance and repair technologies. In detail we developed the following four new technologies:

- Wooden materials and components adequate for the long lasting wooden residential houses.
- Design methods.
- Technology for evaluating the durability of long lasting wooden houses.
- Maintenance and repairing technologies.

In the third research subject we proposed a system for disseminating the newly developed technologies. To do this we prepared the following documents and software:

- Software to use when inspecting the quality of existing wooden residential houses.
- Manual to use when maintaining and repairing existing wooden residential houses.
- Technical manual book for use when constructing a long lasting wooden residential houses.

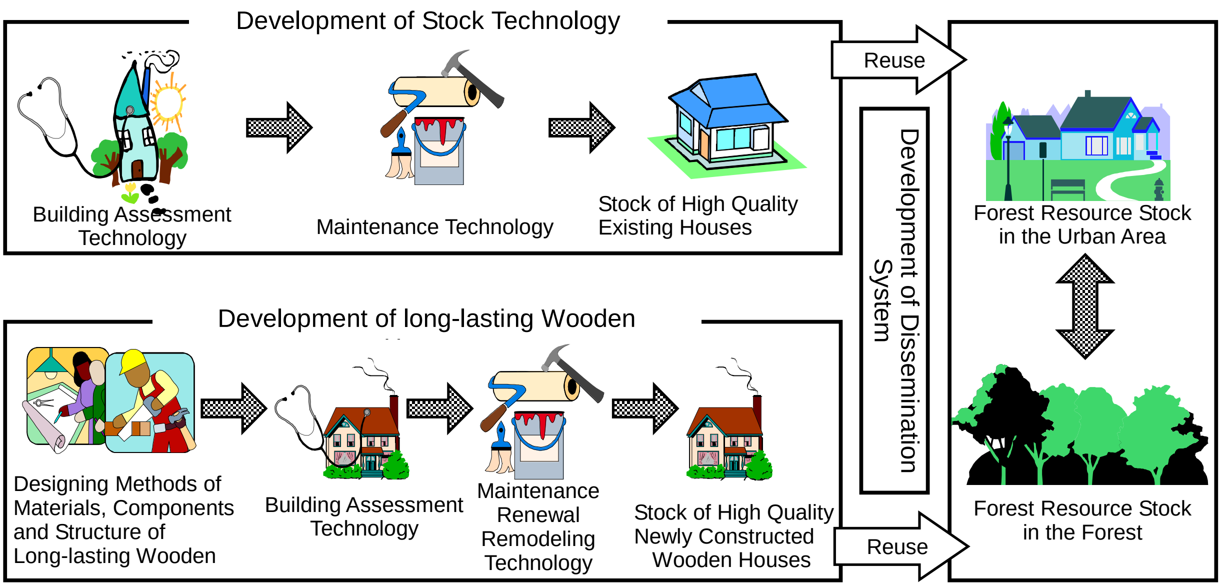


Figure 6 Summary of the research project. (Development of technologies for increasing the life span and the stock of wooden houses)

3.2 Research and technological development for the prevention of dioxin contamination and the waste reduction in the construction industry

Background

The volume of waste generated in the process of dismantling wooden buildings is increasing yearly. It is necessary to promote the recycling and reuse of the resources consumed in the process of building wooden structures. And new systems and technologies that enable the reduction of the volume of the waste generated in the building activities are also strongly required.

Summary of the Research Project

The project is a three years project and it started in the year 2000. And the annual research budget is approximately 50,000,000JPY. In the project we will develop new construction methods, formulate technical guidelines and compile design and building manual for remountable wooden constructions and we will also develop recycle and reuse technologies to reduce the waste products in the process of dismantling wooden buildings.

The project is composed of three research subjects. The research subjects are as follows:

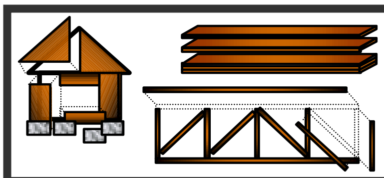
(1) Development of design and construction methods to reduce the waste products in the wooden building activities.
(2) Development of recycling technologies for building materials and components.
(3) Development of dissemination system to disseminate the developed technologies.

Figure 7 shows the outline of the research program of the first research subject. In the first research subject we will develop the designing and construction technologies for recyclable and remountable wooden constructions. The current designing and construction methods for the 2 by 4 construction and the post and beam construction will be modified and new design and construction technologies will be proposed. In detail we will develop the following three new technologies.

- Technologies to design and evaluate low environmental impact building materials.
- Technologies to design and construct recyclable and remountable wooden buildings.
- Technologies to design and construct sustainable wooden buildings.

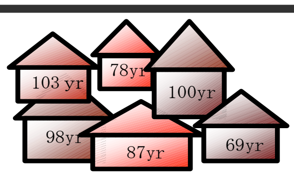
Development of low environmental impact building materials

- Environmental impact evaluation of the preserved wood.
- Environmental impact evaluation of wooden composite materials.



Development of design and construction methods for recyclable wooden buildings

- Structural design of the joints and the structure.
- Design and evaluation of the structural members.
- Design and evaluation of the wooden materials and



Development of design and construction methods for sustainable wooden buildings

- Designing and construction methods to construct long service life wooden buildings.

Figure 7 Outline of the research program of the first research subject.

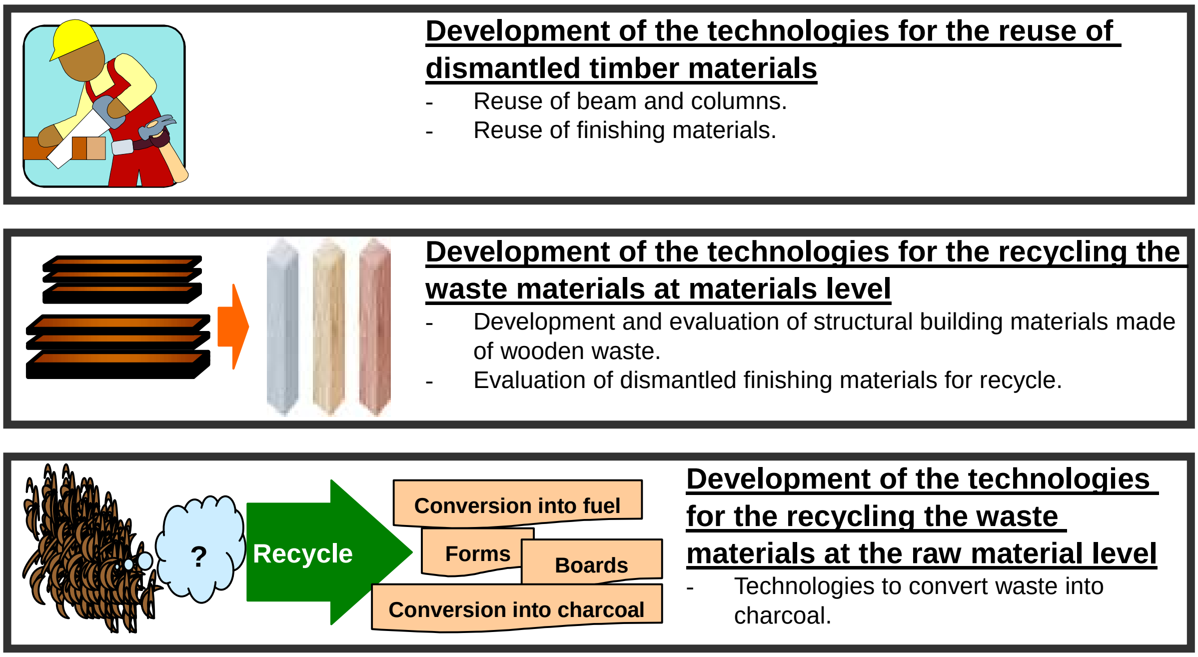


Figure 8 Outline of the research program of the second research area.

Figure 8 shows the outline of the research program of the second research area. In this research area, we will develop new technologies for reusing and recycling wood waste materials and other waste materials. In detail we developed the following three new technologies:

- Technologies to reuse the dismantled timber materials.
- Technologies to recycle the waste at the materials level.
- Technologies to recycle the waste at the raw materials level.

We will also propose a reuse and recycle system that will work well to reduce the landfill waste.

In the third research area we will discuss the factors inhibiting waste reduction and recycling of waste and also propose a simulation model to estimate the waste produced in the future. And we will do some case study to make clear the possibility of the newly developed technologies and social systems to reduce the waste coming out from whole life cycle of the wooden buildings.

3.3 Development of advanced technologies for recycling building materials and components

Backgrounds

This research project was proposed to develop broad-range recycling technologies to reuse and recycle the dismantled materials that appear throughout the lifecycle of wooden buildings. In this research project, technologies for reusing wood construction waste and technologies for recycling waste materials at the materials and raw materials level were collected publicly from the whole country. Two proposals were selected from among 10 proposals. The target of this research project is to radically reduce waste materials by establishing broad-ranging and advanced recycling technologies for timber structures.

Summary of the Research Project

The project is a two years project and it started in the year 2000 and the annual research budget is approximately 15,000,000JPY. Figure 9 shows the outline of the research project. The technologies that will be developed in this project are as follows:

- Technologies to produce charcoals from wood and ceramic mixed waste.
- Technologies to produce wood fiber insulation materials from waste wood by the dry manufacturing process.

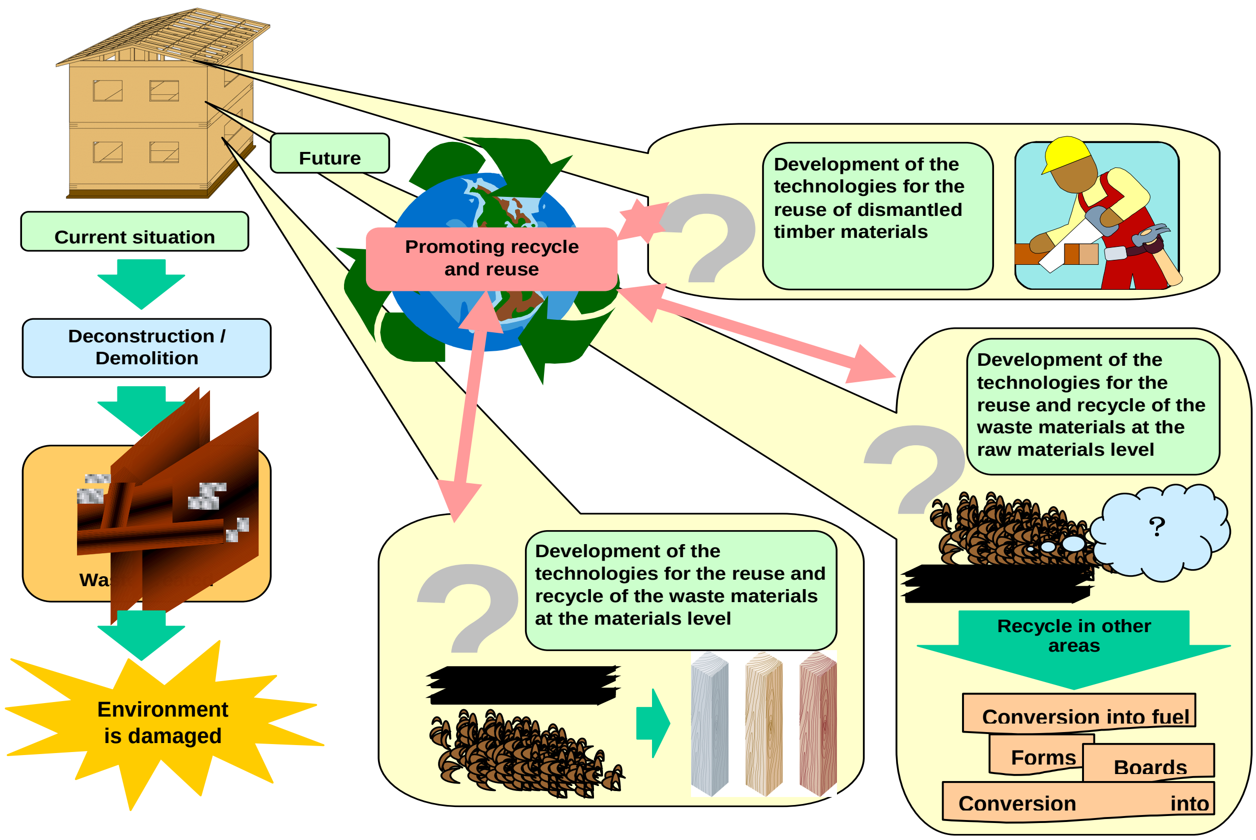


Figure 9 Outline of the research program of the third research subject.

4. CONCLUSION

Our country is now experiencing a very serious waste problem that is caused by the huge volume of construction waste produced day by day. The results of the three research projects described in this paper may provide some good solutions for improving this situation. We have just reached the starting point and we have to make every effort to make the situation better.

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RE-USE OF APARTMENT BUILDINGS: A CASE STUDY

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SUMMARY

Re-use of construction and demolition waste is common practice in the Netherlands. But almost all of this material is used as a road base material. The Dutch Government passed a law on the first of April 1997, which states: "Dumping reusable building waste is prohibited" (short version). The question that arises is, have these material more re-use potential?

This paper describes a study about the re-use of six apartment buildings in The Netherlands. These buildings are located in an area in Maassluis, which was redesigned. The re-use options are discussed both on technical and financial aspects. For the technical aspects the Delft Ladder, a flexible waste treatment order, was used.

Finally a first intention of a model is presented which can calculate the environmental and financial aspects of different end of life scenarios.

KEYWORDS: Construction and demolition waste, Deconstruction, Dismantling, Environmental impact and Integral chain management

1. INTRODUCTION

The Netherlands produces 16 million tonnes of construction and demolition waste per year, for example: this quantity can be used for a road basement of a 250 km, six lane highway, 20 meters wide and 2 meters thick (fig. 1). This is an enormous amount for a small country like The Netherlands. The Dutch Government passed a law on the first of April 1997, which states: "Dumping reusable building waste is prohibited" (short version).

Figure 1: Highway on re-used materials in The Netherlands (Noord et al, 1998)

To make a choice between different materials, which can be used for the manufacturing of products or constructions, the main issue is how they can perform the requirements like: strength, corrosion, durability, etc. The level of the performance will then be compared with the price paid for it. In time the choosing became more complex, more requirements were added: safety, utility, fire resistance and low energy use. There were more and more discussions about environmental and health aspects. To solve this complicated matter there was an attempt made to express the total (environmental) performance in one grade and with these grades for all the different materials to divide them in different categories. This is for two reasons a worrying approach:

- The total view of the environment is a collection of several (ca. 14) aspects which have less or no mutual connections and it is difficult to express them in the same dimension;
- The effect on the environment will not only determined by the material used but also by the way of application.

Therefore a different approach is needed. This approach has three elements:
- ‘life cycle thinking’;
- ‘design for recycling’;
- ‘ecocost-value ratio’.

One of the possible contributions to sustainable building is to keep the building materials in their own cycle as long as possible, ’life cycle thinking’ (fig. 2). This can be done on two occasions: during the stage of design or during the demolition stage. In the stage of design a suitable dismantable building system can be chosen, enabling all the elements and components to be re-used easily and

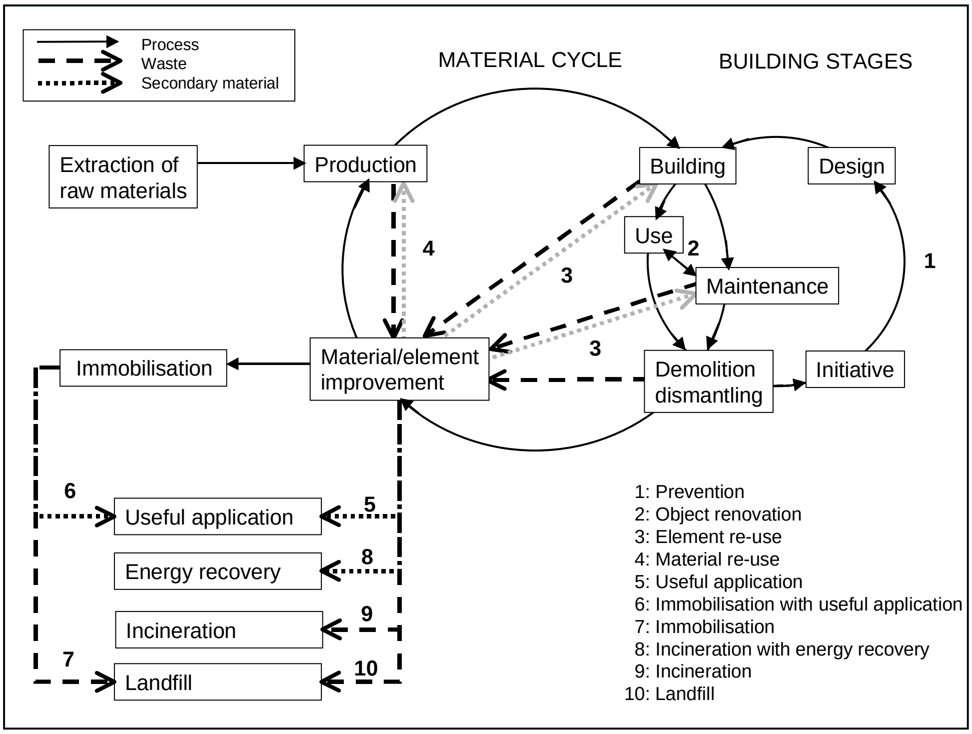

Figure 2: Integral Chain Management (Dorsthorst, 2000)

directly after dismantling. This stage of design is called Design For Dismantling (DFD). Design For Recycling (DFR) is another building system where, during the stage of design, consideration is given to what to do with the building materials after demolition. Separation of building materials is rather simple during the demolition process and after further processing (e.g. crushing), the separated materials can be used as a raw material for the production of new building materials.

The second alternative is to do everything that is possible at the demolition site in order to improve the recycling of materials and elements. This is the most common solution nowadays, because the greater part of the buildings ever built, were not built for dismantling. So the present emphasis lies on the demolition process.

2 CASE-STUDY MAASSLUIS

Maassluis is a community of about 35000 inhabitants, not far from Rotterdam. A lot of apartment buildings were built in this city in the sixties and seventies. Most of them were built with the Elementum system (prefabricated concrete) because the Elementum factory was in this city.
Prefab concrete elements were made in the factory and the building is assembled at the construction site. Most of the connections between the elements were filled up with cement, in order to get a monolithic construction.

Normally these constructions have a lifetime of about 70 to 80 years, but due to other reasons (not the technical state of the construction) these apartment buildings must be removed. In this case a part of the neighbourhood, six existing apartment buildings has to be redesigned. Normally these apartment buildings would be demolished and the concrete and masonry rubble would be crushed and used as a road base material. The question arises what more can be done with these constructions.

2.1 Materials

The skeleton of these old apartments are built with prefabricated concrete walls and prefabricated concrete floors. These elements, now 30 years old, have a lifetime of about 70 to 80 years, so they can serve a second lifetime. Thanks to new regulations in the field of noise reduction between dwellings these elements cannot be used as a dwelling separation element. So these elements can only be used for inner walls and floors or compensating measures for noise reduction must be taken.

The extern walls (facade) of the old construction have a wood frame. Asbestos was also used in this facade. So, according the Dutch regulations, all the asbestos has to be removed before demolition or dismantling. The remaining of the facade cannot be used as a facade anymore so it will be demolished and the wood will be incinerated in order to re-use the energy of the wood.

The roof was made of concrete floor elements, a sand-cement layer for the slope, insulation material, bitumen and gravel. This construction must be dismantled separately. The gravel is contaminated with polycyclic aromatic hydrocarbon so it must be cleaned before it can be re-used. The insulation material and the bitumen will be incinerated and the concrete floor elements can be re-used.

The foundation, prefabricated concrete piles, can be re-used both as element (on site) or at material level.

2.2 Re-use options

In 1979, the Dutch government published an order for waste treatment called the Ladder of Lansink (Lansink, 1979). This order was a fixed top-down approach. Since 1980, more waste treatment options have been developed and therefore the Ladder of Lansink has been extended with five new options. This new order shouldn't be a fixed top-down order but it should be flexible. The order can change thanks to the results of calculation methods, such as Life Cycle Analysis (LCA) and Eco-cost Value Ratio (Vogtländer, 2000). This new tool is called the Delft Ladder (Hendriks, 2000). The two ladders are illustrated below.

Ladder van Lansink

1. *Prevention*
2. *Material re-use*
3. *Useful application*
4. *Incineration with energy recovery*
5. *Landfill*

Delft Ladder

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

The first, prevention, tries to prevent the production of construction and demolition waste. This can be done by a proper design in the early stages of the building project. It is clear that prevention in the early stages cannot be done here.

The second step is object renovation. This means re-use of a great part of the building at site; renovation. In this case object renovation is an option. The skeleton of the building can be re-used at site. In order to create dwellings with a bigger floor space, old apartments must put together. This can be done horizontally, vertically or both. Problems in noise reduction between dwellings have to be solved.

The third step, element re-use, is possible if the old elements can be dismantled without too much damage. These elements can only be re-used as inner walls and floors; not as a dwelling separation wall because of the noise reduction capacity. The foundation can be re-used for dwellings (at the same site).

The fourth and fifth step, material re-use and useful application are possible for almost all materials. The stony materials (including the foundation) can be crushed and used in concrete or as a road base material. The roof gravel can be used on roofs again.

Step six and seven, immobilisation with or without useful application, is for hazardous wastes. These materials were not present in these six buildings. So immobilisation is not an option here.

The next steps, incineration with or without energy recovery, can be used for the wood and the insulation materials. It is difficult to re-use these materials at another level because of the contamination and the (small) amounts.

The last step, landfill, is forbidden in the Netherlands for all reusable construction and demolition wastes. This landfill ban started in 1996. So only the materials that cannot be re-used can be dumped on a landfill. So there is only a very little amount of waste from these buildings that will end up on a landfill, except all the asbestos. This material is dismantled separately and dumped (special controlled) on landfills.

So technical possibilities and the current regulations result in the following options:

- Object renovation; re-use of the concrete skeleton
- Element re-use; re-use of elements at another site
- Element re-use; re-use of the foundation
- Material re-use; re-use of the concrete, roof gravel
- Incineration; recovery of energy from wood and insulation materials
- Landfill; all asbestos

3. BUILDING REGULATIONS AND MATERIAL REQUIREMENTS

The elements or components that are deemed reusable were built in an earlier period. In that period, other building regulations and material requirements were in effect. For example; in the 1950s there were no insulation regulations, and in the 80's a standard double glazed window had a k-value of 3.5 W/m^2K. Nowadays, the insulation regulations for elements or components are redundant because of the Energy Performance Coefficient (EPC). This EPC calculates the usage of energy for a certain building and how that will be accomplished is up to the architect; it can be realised by using single glazed windows and heavily insulated walls. Or with regard to deflection, can the structure still be re-used when it is a certain age and of limited deflection capacity?

3.1 Comparison between the old and new standards

The NEN 1009 is a standard for reinforced concrete and came into effect in 1962 and it is now outdated by the NEN 6720. But meet the old constructions the new standard? The elements used in the case-study Maassluis have been compared with the NEN 6720 (Luiken, 2000):

NEN 1009 states that the strength of reinforced concrete is 0,6 * the characteristic strength of reinforced concrete.
NEN 6720 calculates as follows:
$f'_b = f'_{b,rep} / \gamma_m$ $f'_{b,rep} = 0,72 \times f'_{ck}$ en $\gamma_m = 1,2 \rightarrow f'_b = 0,6 \times f'_{ck} \approx$ Which is almost equal to the old standard.

f'_b = the pressure failure of the concrete.
$f'_{b,rep}$ = the pressure failure of the concrete gained from experiment.
γ_m = the material factor
f'_{ck} = the cubic pressure failure of the concrete

The comparison for the steel:
NEN1009: QRn40 $f_s = 400$ N/mm^2 $f_t = 500$ N/mm^2 $\varepsilon_u = 11$ %
NEN6720: FeB400HWL,HK $f_s = 400$ N/mm^2 f_t = no standard $\varepsilon_u = 4$ %
The NEN 1009 is more strictly.

QRn40, FeB400HWL,HK = type of steel
f_s = the tensile failure of the steel
ε_u = elongation

So, after an element or component is dismantled it still has to undergo a few evaluations before the decision can be made for direct re-use. If the element or component does not meet the requirements and building regulations, then upgrading could be an option. In addition to the requirements and building regulations, the architectural features or even the colour can be deciding factors.

In the Netherlands the building regulations are summed up in the Building Decree. This means that every element or component, primary or secondary, must be certified. If a secondary element or component lacks a certification, it will not find its path to the construction site.

Two of the problems as for certification of a secondary element or component are: how will it be done and who is going to do it? Starting with the former, an independent institute should do this. Concerning the manner of how is it done: is every element or component examined or will a representative sample be taken and examined? An important aspect of these considerations is the costs associated with such a process. When a secondary element or component completes this process, then the next step will be the determination of the costs and environmental impact.

4. APPLIED RE-USE OPTIONS

The redesign of this neighbourhood can be shown in figure 3.

Figure 3: Artist impression, Componers neighbourhood Maassluis, The Netherlands (www.panagro.nl)

Five of the apartment buildings were renovated, but not all in the same way. Two of them were totally stripped, the apartments were connected horizontally in order to improve the floor area. An extra floor was put on top of these buildings (figs. 4, 5).

The top three floors of the other three buildings were removed. The remaining construction will be redesigned as single family dwellings. A special detail of this reconstruction is the demolition of the concrete cores. Therefore struts must be placed in the total construction.

All the walls in these five buildings have not enough noise reduction capacity. Extra walls will be put in front of the concrete walls with extra insulation. Also all the (new) wiring can be put behind these walls.

The last apartment building was demolished completely, except for the foundation. The foundation is re-used for dwellings. The original idea was to re-use the elements of the removed floors in the other single-family dwellings. But due to different reasons this wasn't done. The logistics of this re-use is very

Figure 4: Old apartment building

Figure 5: Renovated

difficult; disassembling starts with the roof, ending with the foundation and floors. Also the demolition techniques used caused damage to these elements. New demolition techniques for deconstruct these kind of constructions are under development.

So all these elements were crushed (on site) and used as a road base material. All other materials were removed from site to separation companies where it was processed and re-used or incinerated.

4.1 Deconstruction problems and the financial consequences

The dismantling of the three apartment buildings has just started and the experience will result in new solutions to the problems encountered, which then can be applied to future projects. One of the first and most important problems encountered is that the apartment building is not quite built as it was designed. During construction, the contractor changed the details without giving any notice of it. During dismantling we came across the different details, which made it more difficult to dismantle without damaging the construction (fig. 6,7). Firstly, when the project was just in the design-stage, the idea was to dismantle the third and the fourth floor. These remaining elements would be used to build single-family dwellings just across the street. It turned out to be very complex to dismantle and to build subsequently with the same elements. Moreover, in this stage it was not clear whether the elements were reusable, so the second thought was to dismantle the two upper floors and store them on a nearby location to catalogue and test them. Two things went wrong during the process. Firstly there wasn't enough time and knowledge available and secondly the government wasn't intending to subsidise the project, so, all the risk was for the housing association and the contractor.

Figure 6: On the left the correct detail, on the right the detail which gave problems during the dismantling.

Figure 7: The situation after dismantling and the solution.

The original building method is named after the factory where it was made: “Elementum”. It is a precast building system where the connections between the floors and walls should have been filled up with sand-cement grout, but during the construction a much stronger mixture was used. When a floor was removed with more force then initially planned, the whole construction moved a bit and it stood out of plumb. To prevent collapsing, more safety supports had to be added. One way to solve this problem is to saw the floor a few centimetres from the wall and remove the rest of the floor by hand. There is no need to say that solving these kinds of problems doesn’t make this project economic. Reusing the construction instead of building totally new houses gave a profit for the smaller dwellings of € 2,250 and for the bigger ones € 5,500. So far, for the first apartment building the extra costs were about € 45,000, which is € 2,800 per dwelling. For the next two apartment buildings, extra safety supports had been added before dismantling started and a different approach has been taken to tackle the problems based on the on site research and testing of the construction.

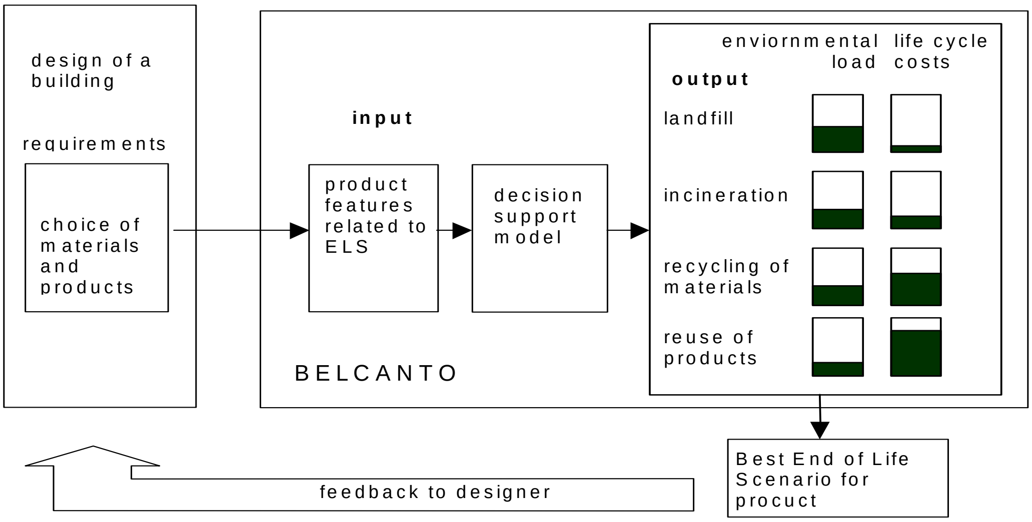

Figure 8: Scheme of the decision support system BELCANTO (Guequierre).

4.2 BELCANTO, Building End of Life ANalyze TOol

The discussed case showed an example of how a redesign of a neighbourhood can be handled taking a maximal re-use of elements and materials in account. This re-use was stated thanks to three enthusiastic partners: the housing association, the demolition contractor and the building contractor. No model was used to examine the environmental and financial aspects.

So a tool for an architect, or a building product developer, or a researcher is missing, to support the choice between re-use of products, recycling of materials, landfill or incinerating as the end-of-life scenario of a certain building product. Recently, we suggested a possible design for such a decision support system (Guequierre et al, 1999). Figure 8 shows a scheme of this system, called BELCANTO (Building End of Life Cycle ANalyse TOol). The output of BELCANTO will be at least the environmental load of a building product. However, decision-makers need also economic aspects, thus the life-cycle costs of the various ELS's must also be part of the output. Furthermore, some qualitative deliberations, like the ease of dismantling, are added to the output. The input of BELCANTO will be a building product.

5. CONCLUSIONS

The question that arises when reading the title of this paper is: “Is re-use of materials reality or utopia?” The answer to that question isn’t quite simple; it is a combination of four different aspects (technical, environmental, economical and regulations). Almost everything is dismantable with the current techniques, but will it be economically profitable? Or does it reduce the impact on the environment? A building meets certain regulations dated in the time when it was built, but when it or the elements will be re-used after 50 years, will they meet the standards valid in that period?

In the Maassluis case, there were three enthusiastic partners: the housing association, the demolition contractor and the building contractor, and all three had their own influence in the process. It was quite clear in the early stage of the dismantling process that the costs were estimated to low. The original drawings were on crucial points different than what was built. Consequently additional safety measures had to be taken. On the other hand, if there had been more time spent on researching the best way to dismantle the ‘Elementum’ building-method there could have been more reusable elements.

This project is the first of its kind in the Netherlands and so it is a learning project. About 2 million of these apartments were built during the period 1946-1980, and a lot of these apartments cannot meet the today’s standards. Because the housing association, the principal in this project, owns 2,500 of this same type apartment in the same condition as in this project, it can be expected that more of these projects will follow in the future.

Re-use of these old reinforced concrete elements is technically possible at different levels: object renovation, element re-use, material re-use and material re-use in a useful application. Material re-use in a useful application is common use nowadays in the Netherlands (almost all construction and demolition waste ends up as a road base material). A part of this material is used as an aggregate in concrete. The re-use of elements is the first in its kind in this case. Is re-use the best option or would it be economically preferable to choose another option? At this moment of writing we are building a decision making model called ‘BELCANTO’ (Building End Of Life Analyze Tool) (Guequierre et al, 1999) which can calculate which ‘End of Life Scenario’ is the best option to prevent construction and demolition waste.

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TOWARDS AN ESTABLISHED SECONDARY CONSTRUCTION MATERIALS MARKET IN SA: SOME BOTTLENECKS AND SOLUTIONS

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SUMMARY

The South African construction industry generates about 5 to 8 million tonnes of construction and demolition (C&D) waste per annum. Over a million tonnes reach landfill sites every year and the remainder is reused, recycled or dumped illegally. Of the portion that is reused, a large percentage finds low-level applications such as backfilling, landscaping, site levelling, landfill applications etc. Relatively less C&D waste finds high value applications such as in road applications, building construction, formal housing and in other recycled materials and products. Illegal dumping is becoming a serious problem in South African open spaces as perpetrators try to avoid transport and disposal costs of managing C&D waste. A recent study of the South African C&D waste practice revealed that there are a number of constraining factors to the use of secondary materials and products. This paper will highlight these constraints and propose some solutions to overcome them.

KEYWORDS

Construction and demolition waste, minimisation, secondary construction materials market

1. INTRODUCTION

The South African construction industry generates about 5 to 8 million tonnes of construction and demolition (C&D) waste per annum. This waste results from domestic and industrial construction activities that include new construction, renovations and demolitions. Landfill sites receive over one million tons of C&D waste per annum. A large proportion of C&D waste is reused. A smaller proportion of C&D waste is recycled for secondary use. The bulk of unaccounted for C&D waste is disposed of illegally in open areas. Of the portion that is reused and recycled, a large percentage finds low-level applications such as backfilling, landscaping, site levelling, landfill applications etc. Relatively less C&D waste finds high value applications such as in road applications, building construction, formal housing and in other recycled materials and products.

A recently conducted study into South African C&D waste practice revealed that there are difficulties relating to the estimation of quantities of C&D waste [1]. The quantities of C&D waste that are produced in South Africa per annum were deduced by comparative analysis, quantities estimated for C&D waste disposed in landfill sites were negatively affected by poor record keeping, non-uniform waste classification and the lack of weighing facilities at some landfills. In addition, reused C&D waste and illegal dumping could only be assessed qualitatively. This has increased the need for a national waste information system that will be able to capture data on waste generators, waste collectors and waste disposal facilities among others to enable accurate estimation of quantities that are disposed in landfills, reused and recycled and also to account for all waste that is dumped illegally.

South African legislation on waste management has undergone rigorous transformation in the past six years. Conditions have changed from a fragmented, ad-hoc type of waste control system to a more coherent, integrated management system that is driven by sustainability principles. However, there currently is no sectoral legislation on waste management (but government is apparently working on it).

The environmental legislative foundation was laid with the promulgation of the overarching Environment Conservation Act (ECA) no 73 of 1989. The ECA was followed by another overarching act, the National Environmental Management Act (NEMA) no 107 of 1998. The NEMA takes the environmental management process further by expanding on the environmental law reform programme. It also provides the enabling environment for the formulation of sectoral policy and legislation, including those for waste management [2]. The Integrated Pollution and Waste Management (IP&WM) Policy was promulgated in the year 2000. This policy sets out the vision, principles, strategic goals and objectives that government will use for integrated pollution and waste management in South Africa. A further development to the process was the preparation of the National Waste Management Strategy (NWMS) and its action plans. These form the basis for the translation of the goals and objectives of the IP&WM into practice.

Almost in parallel with the above process, the Construction Industry embarked on the Construction Industry Performance Improvement (CIPI) initiative. In line with international trends in the quest for sustainable construction, the construction industry has shifted the focus from performance criteria of quality, time and cost to sustainability oriented criteria of environmental preservation, reduced resource consumption and human development. There however, has been little development in terms of C&D waste practice so far i.e. in terms of management and minimisation, but the need for these has been realised by both government and the new Construction Industry Development Board (CIDB)[3].

In summary, large quantities of C&D waste are currently being produced in South Africa annually. There is a need for improved administrative processes to ensure effective waste management e.g. the need for a national waste information system. C&D waste management currently does not satisfy the tenets of sustainable development, however, potential has been seen for C&D waste minimisation through reduction, recovery, reuse and recycling. The biggest challenge was found to be the establishment of a viable secondary construction materials market. This paper will first look at some of the constraining factors to the recovery of C&D waste and the use of secondary construction materials and products in construction and then propose some solutions to overcome them.

2 SOME BOTTLENECKS

2.1 Policy and legislation

As there is no sectoral act on waste management yet, waste is managed primarily by the ECA no 73 of 1989. Being an overarching environmental act, the ECA does not and cannot be expected to go into detail on any specific type of waste. The ECA defines waste as effectively "unwanted or unused" material. Some types of waste are excluded from the definition because they are covered in more detail elsewhere (i.e. in other sectoral or general legislation) e.g. effluent, litter on roads etc [2].

According to the ECA, building rubble is excluded from the definition of waste if used for site levelling or backfilling. In cases where it is not, then general waste management principles apply. Other types of C&D waste that are not exactly "unusable" are covered by other legislation (sectoral or general). There is yet no uniform classification of C&D waste. This makes management difficult. Furthermore, the resources required to police compliance to legislation, in its present state, are just not available.

2.2 Resources

One serious limitation to the implementation of integrated waste management in South Africa is the shortage of resources, both financial and human, in government. In terms of financial resources, C&D waste minimisation and the establishment of a secondary construction materials market need financial investment. National budget and priorities determine the amount available for expenditure in the area of pollution and waste management. Issues such as awareness creation, technology development, start up costs of recycling ventures, operation and maintenance and SMME development all need funding. Clearly, government alone will not be able to meet these requirements.

Government currently has limited human resources dedicated to waste management (not to mention C&D waste). As was the case towards the end of year 2000, government is faced with a problem of staff turnover, which negatively impacts on progress in C&D waste related issues (or any other waste type for that matter). As much as there is a need for a complete waste regulatory framework, it will serve no purpose if the resources to monitor and enforce it are not sufficient.

2.3 Administration

There currently is no national waste information system. This means that C&D waste generators are not registered and thus do not have to account for the waste they produce, waste collectors do not have to account for their actions when handling waste (this is despite the good intentions of the "duty of care" and "polluter pays" principles of NEMA). Such a situation lends itself to abuse, hence the large quantities of illegal dumping and other forms of environmental degradation. C&D waste classification at landfill sites varies form site to site and regionally. This makes it difficult to keep accurate national records for management purposes.

Legislative measures should be packaged together with awareness creation. In the case of restrictions, alternative options should be provided. This is usually not done and results in the problem being shifted instead of being eliminated e.g. strict landfill site requirements result in increased illegal dumping if people are not given alternatives.

2.4 Stakeholders

In order to achieve integrated management of C&D waste, the various stakeholders involved in the life cycle of C&D waste need to play their part. For instance:

- *Designers* have traditionally not considered the implications of building designs on the amount of waste generated at the end of life of buildings. Many old buildings have been over designed or they lack the flexibility to be disassembled or adapted to a different use.

- *Contractors* generally do not practice waste management and minimisation on site. All generated waste is stockpiled and transported to landfill sites. The concept of source control is seen to be expensive to implement.

- *Demolishers* still believe that mass demolition and rapid site clearance are the best way to make money. The concepts of building deconstruction and waste minimisation are either not known or not taken seriously. Source control is considered expensive to implement (i.e. considering project constraints such as time and labour).

- *Waste generators* are by law responsible for the waste they produce from "cradle to grave". Their responsibility extends to the waste collection service providers they select and the waste disposal facilities where their waste ends up. With limited policing, this legislation is not well monitored. As a result, source control is not practiced and some waste collectors dispose waste illegally to avoid costs.

- Waste recovery in construction and demolition sites is usually carried out by formal and informal waste *salvagers*, demolishers and contractors. The lack of source control on site results in relatively high recovery costs that negatively impact on the financial benefits of the exercise.

- *Recyclers* and secondary material outlets generate revenue from the sale of secondary materials and products. One of the main determinants of the success of such services is the quality of the output. This depends on the quality of incoming raw waste material. On the other side of the scale, even if the recycler does produce good material, he still depends on consumers to buy it and at a good price. Unfortunately, the product price can sometimes be independent of its quality and just depend on market conditions.

- *Government* is probably one of the most important stakeholders in the establishment of a viable secondary construction materials market. Current financial and human resource constraints impact negatively on this role of government (hence government is currently not seen to be doing nearly as much awareness creation, promotion of secondary materials and financial investment as necessary).

2.5 Standards and specifications

South African standards and specifications currently do not accommodate the use of recycled C&D waste. Reasons for this include:

- *Willingness* - clients, designers and contractors currently have no incentive to use reclaimed materials in construction projects.

- *Risk* - reclaimed materials are perceived to be inferior. No one is willing to take a risk with secondary materials when there are established building materials on the market, even when the secondary materials have undergone the necessary quality control testing.

- *Awareness* - some building construction practitioners are not aware of the ongoing research of secondary materials, the international trends in the accommodation of such material in standards and specifications and the environmental benefits of using such material.

- *Nature of specifications* - current specifications are prescriptive in nature, giving details on the composition and type of materials to be used. This negatively impacts on the prospect of using alternative materials not covered by standards.

- *Nature of standards* - standards are based on the technical testing of materials to determine their fitness for purpose and long-term durability. By its very nature, this approach takes a long time and suggests suspicion if non-standardised materials are used. This negatively impacts on the use of secondary materials.

2.6 Market dynamics

The South African secondary construction materials market is currently not well established. C&D waste minimisation is faced with challenges such as:

- *Source control* – there is a dilemma of getting material supply from waste generators and practicing control on material quality. Source control sometimes acts as a disincentive for generators to bring waste to recyclers instead of transporting it to landfill sites

- *Authorities* - there is sensitivity and unwillingness to grant permission for C&D recycling in demolition sites within the areas of jurisdiction of some authorities. Reasons are usually concerns around noise and dust.

- *Secondary material use* - recyclers have difficulty selling their product because of the limitations imposed by standards and specifications for building construction and the traditional engineers who are generally unwilling to explore innovative materials.

- *Competition* **-** Market prices are usually set regionally and recyclers usually have little or nothing to say about them. This, together with the public perception of secondary materials forces recyclers to sell their product at a loss.

- *Quality assurance* - some tests have been conducted to determine the technical performance of secondary materials and products. These however have not influenced South African standards and specifications yet.

- *Funding* - the recovery and recycling of C&D waste is presently an expensive exercise that requires subsidisation. There currently is no clarity on who should take this responsibility especially with the risks involved.

2.7 Incentives

C&D waste minimisation is currently an expensive exercise. People have no incentive to separate waste at source and waste handlers generally have no incentive to salvage useful waste material. Waste disposal is typically funded by lump sum taxes usually hidden in property taxes or by flat fee payments. This type of pricing provides no incentive for waste generators to produce less waste or separate at source for reuse and recycling (i.e. a person can generate as much waste as they like and still pay the same fee). Some landfill sites in South Africa have started implementing "punitive levies" to those that generate large quantities of waste. As can be expected, people have resorted to illegal dumping as a cheaper option [4].

2.8 Targets

Waste management in South Africa is currently not driven by a collective national ideal. There is no national target for waste reduction or elimination. International trends indicate that such targets are necessary to increase commitment and monitor progress.

3. SOME SOLUTIONS

C&D waste minimisation in South Africa will be enhanced by the establishment of a viable secondary construction materials market. In turn, for the secondary construction materials market to be established, we need to have an enabling environment. How can this be achieved? The answer lies in the formulation and adoption of a C&D sector development strategy that will translate into an implementation plan in line with the NWMS and the CIPI initiative. Such a plan will require support from and should contain the following:

3.1 Government support

As indicated above, government is probably one of the most important stakeholders in the establishment of the secondary construction materials market. The government should visibly promote the use of secondary construction materials where possible and discourage the unnecessary use of primary materials. Where applicable, financial support must be given to the secondary construction materials market, but more importantly, the awareness level of the public needs to be raised. Firstly, people need to realise that "secondary" does not necessarily mean "inferior" and secondly, the environmental (non-financial) benefits of using secondary materials need to be emphasised.

3.2 Policy and legislation

Sectoral legislation on waste management needs to be formulated and promulgated to ensure effective management and compliance with the IP&WM policy objectives and the NWMS. Legislation relating specifically to C&D waste should discourage the abuse of natural resources and illegal dumping and promote C&D waste minimisation and secondary material use (countries such as Sweden, Denmark and the Netherlands have good examples of this [5]). Some steps that can be taken include the introduction of:

- High tipping costs at landfill sites that punish large quantity waste generators
- High taxes on raw material use
- Prevention of the disposal of C&D waste in landfill sites packaged together with awareness and alternative options
- Strict by-laws on illegal dumping
- Punitive measures for perpetrators and
- Strict environmental management policy requirements

3.3 IT based administrative systems

Having moved into the information age, many administration systems and operations could be improved by introducing IT based solutions in order to make waste management more effective. Such improvements could include the development of:

- A national waste information system that can register all waste generators by category of waste, register waste collection service providers and waste disposal facilities. This will help in the estimation of total wastes produced in South Africa, quantities disposed in landfills, quantities reused and recycled and help account for illegally dumped waste. Such a system will also help standardise waste classification.

- A web-based national secondary construction material information exchange service (or simply, the C&D waste exchange). This service will be of benefit to waste generators and secondary material consumers. Such a service will provide information on available and required waste material for secondary applications by type, source, quantities, location and available quantities. In addition, the service will provide information on waste minimisation, available technologies and possible applications for secondary materials and products.

3.4 Integrated C&D waste management

For C&D waste minimisation to be achieved, all the stakeholders involved in the life cycle of C&D waste need to play their part. For example:

- *Designers* must reduce the amount of waste that is generated in the first place. This can be done through design for waste reduction and design for deconstruction.

- *Demolishers* should use technologies like building deconstruction instead of mass demolition to maximise the recovery rate of useful waste material.

- *Contractors* need to incorporate waste management plans into their tender documents in order to improve waste management on site, save costs and generate revenue from waste.

- *The client team* needs to demand waste management plans with tender submissions. They also need to promote environmental construction practices and look at the possibility of demanding the use of a certain percentage of secondary materials in construction projects.

- *Recyclers* should keep a good reputation of material supply. This requires good source control, high quality production and sufficient material quantity availability.

- *National government* needs to promote initiatives aimed at sustainable resource use. It should also lobby for support of recycling initiatives and secondary material use at local government level.

- *Landfill sites* should provide stockpiling facilities where possible for C&D waste that they receive to allow for periodic sorting and crushing by a mobile crusher to produce secondary materials.

3.5 Standards and Specifications

There is a need to move away from prescriptive specifications as these have been shown to limit innovation in material use. A more appropriate form of specification would be a performance-based specification. This kind of specification details only the performance aspects of a particular material and not its composition. This will undoubtedly give opportunity to the use of secondary construction materials [5].

Ongoing research and development is needed with reference to types and methods of testing in order to ensure that all materials are tested on merit and accommodated by specifications where appropriate. Acknowledging the nature of standards, if well performing innovative materials were not used in pilot projects on a trial basis, we probably would not be using good materials like Pulverised Fuel Ash (PFA) and Ground Granulated Blast Furnace Slag (GGBS) today.

3.6 Incentives

Economic incentives

Variable cost pricing should be introduced as a substitute for flat fee pricing. Variable cost pricing has been introduced in a number of countries to increase the marginal cost of waste disposal, expose waste generators to the real costs of waste disposal (e.g. social costs, land occupation costs and opportunity costs) and to create an incentive for people to recycle waste [4]. Typical examples of such pricing mechanisms include:

- *Marginal cost pricing* - this pricing mechanism imposes costs per unit of waste generated. This approach targets the quantity of waste generated and thus provides incentive for people to generate less waste. Examples include quantity based pricing, unit based pricing and landfill waste tax.

- *Average cost pricing* - this mechanism estimates total waste volumes, costs and disposal units for the upcoming year. An average unit price is then derived and charged on everyone. The unit price will usually be higher than the flat fee and thus encourages waste reduction and recycling.

- *Two-tier pricing* - this mechanism uses a flat fee that is charged for an established minimum level of disposal service, beyond which a unit-based punitive fee is charged. In such systems, the unit-based fee can be anything from 40-100% higher than the flat fee.

General incentives

- *Landfill* - landfill sites can have incentives like the free disposal of clean recyclable waste in designated "green areas" or stockpile facilities for recyclables.

- *Environmental* - local authorities can organise environmental programmes that will leave consumers, households or companies with a good image e.g. spot-illegal-dumps programmes that will help identify, clean and monitor illegal dumps while acknowledging the participants etc.

- *Business opportunities* **-** government or donor funding can be injected into programmes that encourage creativity, art and resourceful use of waste material through entrepreneur and SMME development and support.

3.7 Showcase of good practice

There is a need to dissipate information on good practice examples in C&D waste management. Even with the constraints highlighted in Section 2, there have been individuals and companies that have made positive contributions to the cause. There is a need for a platform to be created where information sharing can take place. This could also present an opportunity for the "unconverted" to find out what the status quo is.

4 WAY FORWARD

To summarise, in order to achieve effective C&D waste minimisation and management in South Africa, the authorities need to dedicate effort into the establishment of a viable secondary materials market. The figure below gives priority and structure into the solutions proposed in section 3:

Integrated C&D Waste minimisation plan:

1. Provide an enabling environment

- Government support
- Legislation
- Awareness creation and change of public perceptions
- Funding

2. Stakeholder identification and involvement

- Designers
- Demolishers
- Contractors
- Waste collectors
- Landfill sites
- Salvagers
- Secondary material outlets
- Recyclers
- National government
- Local government
- Donor agencies
- Research institutions

3. Improve administrative systems

- National waste information system
- National secondary construction materials information exchange service (the C&D waste exchange)

4. Introduce alternative technology options

- Building deconstruction
- Construction site waste management plan
- Construction industry performance improvement initiatives

5. Incentives

- Economic incentives
- General incentives
- Punitive measures
- Quotas for secondary material use

6. Showcase best practice examples

- Construction projects
- Building deconstruction
- Source control
- Salvaging
- Reuse
- Recycling

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ASSESSING THE RECYCLING POTENTIAL IN BUILDINGS

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SUMMARY

An important goal for the building sector is to produce buildings with a minimum of environmental impact. Recycling can considerably reduce these impacts. An aim is therefore to produce new buildings with a minimum of environmental impact during their lifetime and with a high recycling potential. This paper presents a suggestion for assessing the recycling potential. The recycling potential can be used in planning a demolition, in the design of new buildings, etc. The paper will also discuss the issues related to comparison of the recycling potential to the impact from production, i.e. how to tell which of two is the best option considering different aspects of production and recycling potential.

KEYWORDS: Recycling, demolition, construction, reuse, landfill.

1. INTRODUCTION

Building 'waste', or rather leavings from a demolition, can be regarded as potential raw material for production of new materials. Recycling building materials can considerably reduce the use of energy and natural resources and reduce the use of land for landfill and extraction of resources.

Today most building materials from demolitions are either recycled with a considerable quality decrease or not recycled at all. The main part of the total embodied energy and used natural resources are then lost. Recycling can bring a considerable part of this back into use again. The scope for recycling building materials/components in the *future* depends to a very high degree on how buildings are designed today. Design for disassembly and recycling is therefore a major contribution to increased future recycling.

How much of all embodied energy and natural resources used in a building could, through recycling, be made useable after demolitions of today or after demolitions in the future is here called the recycling potential, R_{pot}.

The concept of recycling potential was previously presented and discussed in [1-4]. A similar way of thinking in terms of resource value, recycling potential etc has been discussed in [5, 6, 7, 8]. As showed in [4], an important problem with this approach is when to assess which one of two building designs is the best one.

This paper will be limited to a theoretical discussion of some aspects of the recycling potential and present a suggestion on how to compare buildings when using the recycling potential. The issue is discussed more in detail in [9]. The method has been applied in several case studies [1–3, 9–10].

2. WHEN CAN THE RECYCLING POTENTIAL BE USED?

The potential of recycling can be used in several situations.

- In the planning of a demolition. The way a demolition is performed will affect the benefits from recycling. Therefore it is a need to assess the potential benefits in order to decide how to undertake the demolition and to achieve the best environmental effects.
- In the design process of new buildings. The aim is to design buildings with a low total environmental impact during the lifetime, I_{tot}, and a high recycling potential, R_{pot}.
- A possibility in the future to incorporate demands on new buildings regarding I_{tot} and R_{pot} in the building code.
- In government subsidies for new buildings with a low I_{tot} and a high $R_{pot.}$ Buildings could for example be promoted by giving allowance of tax during the first years.

The above given examples of situations when the recycling potential can be used are considering whole buildings. If preferred, the recycling potential can of course also be assessed for a specific material or building component.

3. THE RECYCLING POTENTIAL

The total environmental impact from a building during its lifetime, I_{tot}, is commonly calculated as

$$I_{tot} = I_{production\ of\ material} + I_{erection} + I_{operation} + I_{maintenance} + I_{demolition} + I_{waste\ treatment} \qquad (1)$$

The total environmental impact, however, ought to be complemented with information on the potential for recycling, R_{pot}. R_{pot} could be calculated as

$$R_{pot} = \sum_{i=1}^{n} I_{pw\ i} \bullet Lt_i - I_{rec.proc\ i} \qquad (2)$$

where

n	is the number of material
i	material number
I_{pw}	is the environmental impact due to production of the material *for which the recycled product will be a substitute.*
Lt	is the remaining lifetime of the recycled material as a percentage of the predicted lifetime of the material for which the recycled material will be a substitute.
$I_{rec.proc}$	is the environmental impact from all recycling processes, i.e. additional impacts from demolition needed to make future recycling or reuse possible, the impacts from all upgrading or recycling processes and transports.

For combustible materials the energy saving is assumed to correspond to the heating value of the material minus the recycling processes.

In order to assess the recycling potential of a product, available recycling techniques and their energy requirement must be assessed. Further, the scope for dismantling, the amount of material to each form of recycling, the remaining service life time and amount of material discarded through dismantling must be assessed. In order to assess the recycling potential of a building to be demolished in the future, also the number of assumed recycling loops have to be assessed.

The recycling potential can be divided into a general, global level and a local level. A general level is valid when the recycling potential considers the future. A local level is valid when the recycling potential considers a demolition at hand. The recycling potential at a local level may vary between different regions as it is depending on locally available technology.

In order to avoid extensive speculations on recycling in a distant future, it is suggested that only one recycling loop should be considered. This will affect different materials in varying ways. For example, metals can actually be recycled numerous times. The problem of how many recycling loops to include has to be discussed further.

3.1 The future

The *needs* of future recycling can be analysed. This was done for four important resources used in the building sector; energy, timber, gravels and metals [10]. It was concluded that, assumed those materials will be used also in the future, there are strong indications that there also will be a need to recycle them.

Despite a *need* for recycling in the future, if a material or component actually *will* be recycled is dependent on a numerous amount of factors. Many of these factors in turn, influence or contradict each other. Besides, the probability of each factor is very different. Together the factors make up a complicated system. Part of this complexity is showed in Figure 1. From the figure it can be concluded that it might be more or less impossible to predict the future recycling.

Instead of making predictions of the future recycling, future recycling could be expressed in terms of a *potential* for recycling.

A fundamental question regarding the amount of recyclable materials that will be produced in the future is the amount of buildings that will be demolished. This will to a great extent depend on how 'old' buildings, components and materials are regarded. If old buildings are highly valued, they will be restored instead of demolished and the amount of recyclable materials will *decrease*. On the other hand, the reuse of valuable and actually dismantled components will *increase*. In regard of the environmental effects, these two factors can be regarded to coincide as reuse of buildings is, in general, the most valuable form of recycling. It seems reasonable to assume that the faster change in society, the higher will 'old' things be valued. Old things have a tendency to become a symbol of safety and security.

3.2 Allocation and recycling in the future

From the discussion in the previous section, it is obvious that there is a problem connected with allocation and recycling of building materials. Allocation can be defined as the process of assigning material and energy flows as well as the associated environmental discharges of a system to the different functions of that system. Recycling is a system where an allocation problem occurs, as the 'waste' from one function constitutes the raw material in a subsequent function.

There are several methods available for allocation. However, if parts of the impacts from the production and the waste treatment are allocated to the recycled product, no product is taking responsibility for these parts if no recycling occurs in future. My suggestion is that the following model should be tried [4]:

- All impacts from production and waste treatment of a material, I_{pw} , are treated as a separate quality allocated to the original product.
- The recycled product takes responsibility for the recycling processes.
- The potential benefits of recycling are treated as a separate quality, $R_{pot.}$

An advantage of treating I_{PW} and R_{pot} as separate qualities is that R_{pot} is made visible and that it facilitates an analysis of the constructions. This is important as R_{pot} is so closely dependent on the construction, its connectors and its scope for disassembly.

3.3 Assessing the scope for dismantling

Assessing the scope for dismantling a construction and separating the materials from each other is important for the assessment of the recycling potential. Both separation of materials, which disturb the recycling process and the amount of material, discarded through dismantling need to be assessed. The importance will vary with the form of recycling. The discarded material is for example only important for assessing the amount that can be reused.

Today there is no method for assessing the dismantling possibility of buildings. In methods used in product design, the evaluation is often based on the time required for the disassembly. The time is measured in case studies. To base an assessment of the ease of disassembly of building constructions on the time needed, appears to be to limited for building constructions, and to measure the time requirement in case studies is mostly not possible. Besides, there are other parameters whose inclusion seems important, for example risks in the working environment.

One way to assess the ease of disassembly of a building construction may be to give scores for some important parameters. It is here suggested that the parameters to be assessed are risks in the working environment, time requirement, tools/equipment, access to joints and degree of damage to the disassembled material caused by the disassembly process. An outline of such a method is presented in Table 1.

The outline comprises several unsolved problems connected with assessment of an individual construction and comparison of constructions:

- How to define the criteria for each individual assessment?
- Should a construction fulfil a minimum level in each individual assessment?
- Should the parameters be weighted against each other and in that case, how should it be made?

Table 1. An outline of a method for assessment of the ease of disassembly of building constructions.

Goal for the disassembly	Assessed parameter	Assessment	Score
Reuse	Risks in the working environment	Big	1
		Small	2
		None	3
	Time requirement	Long	1
		Medium	2
		Short	3
	Tools/equipment	Advanced	1
		Simple	2
		Manual	3
	Access to joints	Very little	1
		Acceptable	2
		Good	3
	Damage to the material caused by	Very much	1
		Acceptable	2

	disassembly	Very little	3
Material recycling	Relevant parameters.		
Combustion	Relevant parameters.		

3.4 Remaining service life time

The service life time and deterioration of a product are probably the most decisive factors for the assessment of sustainability and recycling. It has so far been difficult to find relevant data for life cycle assessment on the expected service lifetime for building materials.

Service lifetime can be divided into technical lifetime, economical lifetime and aesthetic lifetime. Which of these considerations will dominate will vary with different products. Whatever consideration is made, it will be connected with uncertainty and the uncertainty will of course increase with the applied time span.

In order to predict the reusability of a product, it is often suggested that if a product has been in use for a long time and is in good condition, the product is likely to be well suited for reuse. This is, however, connected with several problems, which can be illustrated with old roofing tiles. How to relate the present quality of an old tile to its original quality, i.e. how to assess its decrease in quality? Is the expected environmental damage on a tile from today different from the damage up to now? How many of the original tiles on the roof have been replaced, for technical reasons, over the years? As can be seen, this method for assessing the remaining lifetime has to be used with caution.

Regarding new products, it could be expected that the producer would provide the needed information. Available information from the producer, however, does not, in general, include aspects of recycling.

An introduction of an extended producer responsibility is likely to increase the information. For the moment it seems, that the assessment of reusability has to be based on available information and available test methods combined with ‘common sense’, and performed with great caution.

3.5 The degree of freedom

A quality so far invisible in the R_{pot} can be called *the degree of freedom*. It can be illustrated by two examples.

One example is *reuse* of beams. A wooden beam (solid wood, laminated wood, glulam etc), can be reused with great flexibility. Such beams can easily be shortened and can also be extended by joining two pieces. The same is valid for steel beams. Besides, wooden beams can be turned into fuel and steel beams can scrapped and the scraped can be turned into cars. A prestressed concrete beam, on the contrary, can be shortened but not lengthened. If the existing length is to short, downcycling is the only option left.

Another example is *material recycling* of metal products respectively mineral wool. A steel product can be remelted and turned into any other steel product. On the other hand, there is almost no other option for mineral wool than new mineral wool products.

From these examples it can be concluded that the probability of future recycling is very greatly dependent on the degrees of freedom. This quality could be made visible by introducing a probability factor.

4. HOW TO COMPARE OBJECTS?

A problem that arises with treating I_{pw} and R_{pot} as separate qualities is whether or not I_{pw} and R_{pot} should be weighted together and in that case, how a weighting could be performed. In other words, how to compare buildings and tell which is the best one?

Previous in this paper were given four examples of situations when the recycling potential can be used. It is first and foremost in the situation of the design process a comparison is needed. In addition, an official promoting of buildings would probably be simplified if the two factors were weighted together.

Incorporation of the I_{pw} and R_{pot} in the building code can be done using a maximum for I_{pw} and a minimum for R_{pot} based on reference levels.

In planning a demolition, the problem of comparison is not relevant as only the R_{pot} of different demolition options is to be compared.

4.1 The problem to compare

As mentioned before, a problem is how to compare buildings and tell which of the two cases in Figure 2 is the best option. The problem is obviously caused by the fact that we cannot predict the future and consequently we do not know whether or not recycling will take place. If recycling will take place, Case A is the best and if not, case B is the best one. Assessed in view of this uncertainty, the two cases can be said to have different qualities, here called IR-factor.

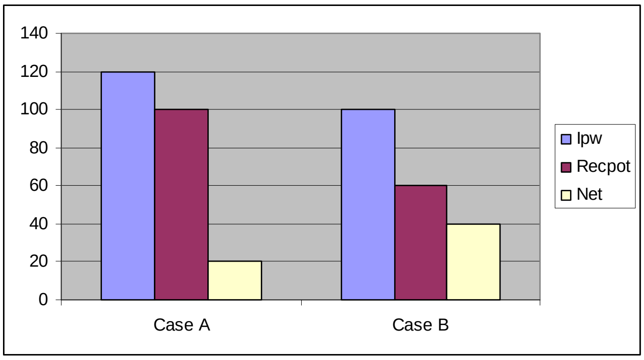


Figure 2 I_{PW} , R_{pot} *and Net, i.e.* I_{PW} *less* R_{pot},*, in two cases. The question is which case is the best one?*

The problem may partly and to a certain degree be tackled with the theory of probability. However, the problem remains if the probability is exactly the same in Case A and Case B. When the problem is analysed it can be seen that the aim is to define the IR-factor in such a way that it will promote a building design that has

- low impact in production
- high recycling potential
- low net impact whether or not recycling will occur

Further, it is desirable that calculation of the IR-factor from I_{pw} and R_{pot} is an easy process not requiring extra tools.

4.2 Suggestion to assessment of the IR-factor

The net energy use, Net, of a building can be expressed as

$$\text{Net} = \sum_{i=1}^{n} I_{pw\ i} - R_{pot} \qquad (3)$$

where

n	is the number of material
i	is the material number
I_{pw}	is the environmental impact from production and waste treatment of the *initial* material.
R_{pot}	is the recycling potential, defined above in equation (2)

It can be noted that Net can theoretically be of a negative number. This could for example be the case for reused clay bricks. I_{pw} for reused bricks is very low as it consists only of the impacts from dismantling, cleaning and some transport. If bricks are laid with a mortar that permits a second dismantling they can actually be reused again. From the definition of R_{pot} in formula (2) above, for the reused bricks R_{pot} will be considerably higher than their I_{pw} and consequently Net becomes negative.

If no recycling will take place, then Net = I_{pw}. The I_{pw} and the Net of a building can be marked on two parallel axes as in Figure 2. The x-axis can illustrate the probability of recycling, p.

If a product has a minimum of I_{pw} and a maximum of R_{pot} the Net will be minimised and consequently the perpendicular line from the x-axis to the line between the y-axes will be minimised.

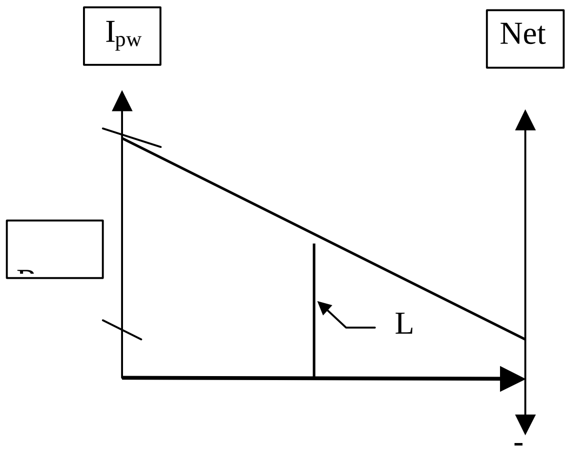
In this way, two objects can be compared by comparing the length of the perpendicular line from the x-axis to the line between the y-axes, L, for each product. The length of the perpendicular line can easily be calculated if the distance between the I_{pw}-axis and the Net-axis is set to 1. In other words, the length of the perpendicular expresses the IR-factor

$$\text{IR-factor} = R_{pot} \bullet (1 - p) + \text{Net} \qquad (4)$$

where

p	is the probability of recycling

The smaller the IR-factor, the better the product with respect to the relation between I_{pw} and R_{pot}.



No recycling (0% probability of recycling) *Recycling (100% probability of recycling)*

Figure 3 . *I_{pw} and Net are marked on two axes. The goal is to design a product with a minimum of I_{pw} and of Net. The IR-factor is expressed as the height of L.*

5. DISCUSSION

As mentioned earlier, determining the service lifetime of the product is, probably, the most decisive factor when assessing recycling. The greater the focus on recycling, the better data is likely to be provided. Limited access to data for the moment is not a weakness of the method itself even if it can affect the result.

Assessment of the scope for dismantling must for the moment be based on experiences from dismantling and theoretical estimations. It would be desirable if in the future the producer provided this information. Both the scope for dismantling and the amount of material damaged by dismantling can then be assessed with better accuracy.

It is here suggested that only one recycling loop should be considered in order to avoid extensive speculations on recycling in a distant future. As mentioned earlier, this will affect different materials differently, and the problem of how many recycling loops to include has to be discussed further.

Regarding the suggestion that demands for recycling should be incorporated in the building code and in government subsidies of buildings with high recycling potential, several questions can be raised. Firstly, can I_{pw} and R_{pot} be defined appropriately enough for such incorporation and subsidies? Secondly, is there a risk of an impoverishment and undesired simplification of the architecture or just a new challenge for better architecture? These issues are beyond the scope of this paper and they are therefore merely pointed out as issues that will have to be considered.

6. CONCLUSION

In the planning of a demolition as well as in the design process of new buildings, it would be useful to assess the recycling potential. Besides, recycling potential can be used in the building code and in government subsidies to buildings fulfilling certain requirements regarding the potential of recycling (for example through tax reduction during the first years of a building’s life time).

It is suggested that, in assessment of new buildings, all impacts from production and waste treatment are allocated to the original product and treated as a separate quality, I_{pw}. The potential benefits of future recycling are treated as a separate quality, R_{pot}. New objects can be compared by as follows: $(I_{pw} + (I_{pw} - R_{pot}))$ times the probability of recycling.

For new buildings, the potential benefits of future recycling are general, global. For buildings where a demolition is at hand, the recycling potential may vary depending on local circumstances depending on locally available recycling techniques.

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OBSOLESCENCE AND DEMOLITION OF LOCAL AUTHORITY DWELLINGS IN THE UK – A CASE STUDY

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SUMMARY

In the UK at present many local authorities are facing increasing numbers of undesirable dwellings in their area, which are proving to be very difficult or impossible to let. Some local authorities are incorporating demolition of selected properties into their overall strategy for tackling this problem.

The demolition of the Jespersen Street flats, part of the St. Mary's Estate in Oldham, North West England, began in June 2000. The 132 flats were contained in a five storey pre-cast concrete framed block, erected in 1967.

This paper first examines the issues behind the obsolescence of this building and the local authority's decision to demolish. It then continues by assessing the physical demolition process: the methods employed; the debris trails produced; and the level of reclamation and recycling on the project. Finally the paper examines the attempts made to 'close the loop' by finding new uses for the project's debris within the local authority area.

It is intended that this paper will illuminate whether a relationship exists between obsolescence and subsequent demolition and recovery of materials, or whether the two phases of the demolition process are mutually exclusive. Does the reason for demolition affect how it is carried out? And if so, to what extent?

KEYWORDS: Obsolescence; Demolition; Materials reclamation; UK local authorities.

1. BUILDING OBSOLESCENCE

1.1 Why demolish?

Building obsolescence has been termed "... the fourth dimension in building..." [1] and "... is the condition of being antiquated, old fashioned, outmoded, or out of date. The obsolete item is not necessarily broken, worn out, or otherwise dysfunctional, although these conditions may underscore the obsolescence." [1]. Obsolescence is the dimension that determines the timing of the demolition of the building. Demolition occurs generally, but not always, at the point at which those who have control of the building have no further use for it. It is in their terms obsolete and the fabric of the building is wasted. Components may be reused or recycled and the building may be capable of reuse, but for those in control the efficient way forward is the premature demise of the building. What are the perspectives that lead to this waste of resources?

A taxonomy of building obsolescence was posited by Golton [2].

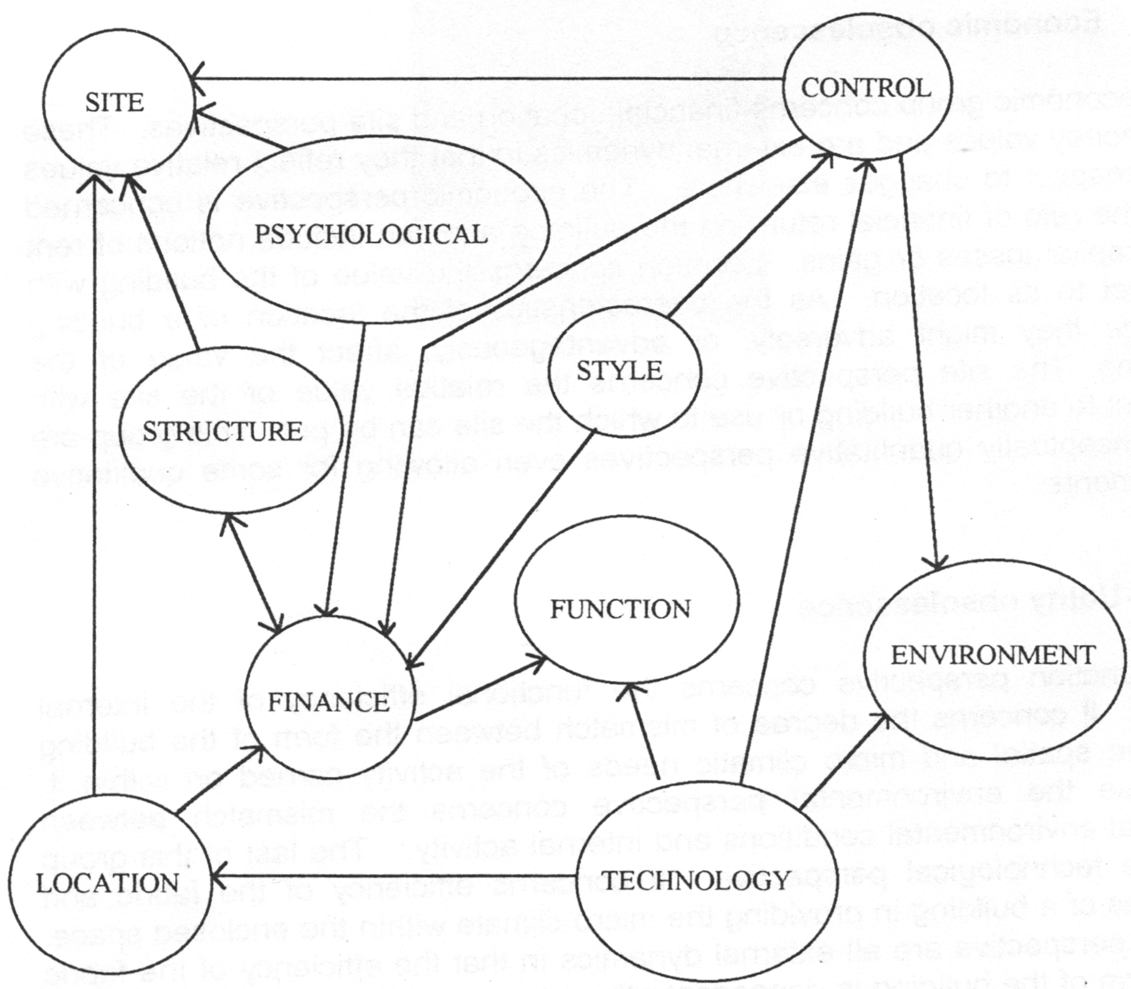

Figure 1. A taxonomy of building obsolescence [2]

The taxonomy suggests that there are ten perspectives that are interrelated and can be categorised into four groups of perspectives. Changes in one perspective iterate through other perspectives. They are dependent variables whose groups are; Structure that sits alone; the Economic perspectives of finance, site and location; the Utility perspectives of function, environment and technology; and the Social perspectives of psychology, style and control.

Structure concerns the fabric of the building. The rates of decay of the fabric of building can be measured, although the accuracy of the measurement may be questionable. It is an internal dynamic in that the measures are absolute change in the building. Conceptually it is a quantitative perspective.

The economic group concerns finance, site and location issues. These are money values and are external dynamics in that they reflect values relative to changes elsewhere. The financial perspective is concerned with the rate of financial return on the building and can include notions of rent and capital losses or gains. Location concerns the value of the building with respect to its location. As the characteristics of the location of building change they might adversely, or advantageously, affect the value of the building. The site perspective concerns the relative value of the site with respect to another building or use to which the site can be put. The elements in this group are all conceptually quantitative perspectives even allowing for some qualitative judgements.

The utility perspectives concern the functional efficiency of the internal space. Functional obsolescence addresses the degree of mismatch between the form of the building and the spatial and microclimatic needs of the activity carried on within it. Likewise the environmental perspective concerns the mismatch between external environmental conditions and internal activity. The technological perspective addresses the efficiency of the fabric and the services of a building in providing the microclimate within the enclosed space. These perspectives are all external dynamics in that the efficiency of the fabric and form of the building is dependent on relative efficiencies with other buildings. The efficiency is measured by quantitative and qualitative methodologies.

The social perspectives are those of psychological, style and control issues. Control addresses the legislative environment that is a political act of defining the obsolescence of buildings by decree. For example the building and fire codes define the technology of the fabric and services of buildings, and planning legislation defines the form and use of building. Style concerns the fashion of the time, essentially a qualitative value. The psychological perspective concerns an individual's reaction to the physical clues expressed by a building and the meaning of those clues conveyed to the observer. It is, as Rapoport [3] argued, about symbolism and psychological constructs. Whilst generic approaches exist to explore these issues, they are essentially qualitative.

Why then was it decided to demolish the building that is the subject of this study? Cole et al [4] reported that "Increasing concern is being expressed about the problem of low demand for housing and the consequences for social cohesion and community well-being of unpopular and obsolete properties... locked in a spiral of decline of which low demand for housing is both a key cause and effect." St Mary's, Oldham was such a development to which these observations could be applied.

On exploring the history [5] it can be seen that this epitaph in a similar form has been applied to developments at St Mary's on many occasions. In 1820 the site was farmland with a sparse scattering of cottages. By 1850 the site had been developed with terrace and courtyard housing for miners and mill workers with an occupation rate of five persons per house in 1871. By 1880 the whole area had been developed on a gridiron pattern and all floor surfaces were cobbled, paved or covered in brickwork. In 1886 the Medical Officer of Health is reported as saying "The special insanitary form which poverty takes in... St Mary's is unhealthy dwellings." The key problems at this time were dampness and bad ventilation. In 1962 the Ministry of Housing and Local Government Report [5] on the area was revealing similar problems relating to the lack of satisfactory sanitary facilities. Where occupiers were spending money on the properties it was for furnishing and decorations and not for resolving structural problems or providing sanitary facilities. The approach was adopted irrespective of tenure. In 1962 it was an area of steady demand due to low housing costs, a supportive social community close to the town centre, and the properties being houses.

The local authority of the day decided that the best way to resolve the unsatisfactory housing conditions was by redevelopment. The comprehensive redevelopment approach required the complete clearance of the area before rebuilding could begin and so the community would have to be dispersed. 75% of the residents expressed a desire to stay in St Mary's. There was also an overwhelming desire to be rehoused in houses or bungalows and not in flats. “The opposition to living in flats was not... based on the experience, but it is worth considering in detail as a record of what people felt (in so far as they could be explicit about their apprehensions).” [5]. In the event the area was redeveloped mainly with flats. In a social survey 18 months after the occupation of the last flat, 93% of the tenants were very or fairly satisfied with their dwelling [6].

By the mid-1990's St Mary's was again cause for concern. "...tenant turnover was 35%, considerably higher than the borough wide figure of 15%. Demand for properties on the estate is low evidenced by the fact that over 20 percent of those housed last year had no points and were therefore not assessed as in housing need." Technically the dwellings were generally sound and were capable of being refurbished but the cost of the works demonstrated that the estate had a negative value [7]. It was economically obsolete.

The development of choice in the social housing market meant that the preferences expressed by the tenants some 30 years earlier could now be exercised. The prospective occupiers considered them obsolete from utility and social perspectives. Exercising choice determined the obsolescence of the properties for the landlord from an economic and functional perspective. The appropriate decision was therefore to demolish the buildings.

Having decided to waste the buildings a key decision concerns the maximisation of recovery of resources in the obsolete structures. This is the focus of this study.

2. ST. MARY’S ESTATE, OLDHAM: THE JESPERSEN STREET PROJECT

When the St. Mary’s Estate was redeveloped in 1967, Jespersen Street was one of a number of low-rise blocks of flats that were built alongside terraced houses. The blocks of flats were originally linked with ‘sky-bridges’ to provide easy access from one to another. At the time of this demolition, all other flats had already been removed as part of previous demolition projects, and Jespersen Street stood isolated. The terraced houses are still occupied and there are no plans to demolish these in the foreseeable future.

Photo 1. A section of the north elevation of Jespersen Street before demolition.

2.1 General Building Description

1 – 133 Jespersen Street consisted of a linear block of one-, two- and three-bedroomed flats and bedsits, with raised deck access on alternate floors. The block was aligned east-west with access from the rear (north) elevation. The eastern end of the building was five storeys in height, reducing to three storeys at the western end; this arrangement was dictated by the sloping site which has gradients of up to 1 in 8. The eastern end of the building also had a short length of basement below.

2.2 Construction Technology

The St. Mary's Estate redevelopment used the 12M Jespersen method [8]. This prefabricated system of building was developed in Denmark, and brought to the UK by John Laing and Son. The system relied on prefabricated medium weight concrete panels for cross walls and floors, and other factory techniques for external cladding and internal partitions. The size of the St. Mary's Estate (originally 495 dwellings) made it an ideal project on which to use a prefabricated system; the larger the scheme the greater the savings in both cost and erection time.

Walls

Load bearing cross walls were a standardised height of 8ft 4ins (2.5m), in lengths of 4ft (1.2m) or 8ft (2.4m), and had a thickness of 7ins (180mm). These were not reinforced. Gable walls had a standard load bearing inner leaf with a layer of bonded polystyrene insulation and the outer cladding panel applied (see below). Special 'goalpost' panels [9] were used to frame the access deck.

Floors

These were also formed of 7ins thick concrete, but this time reinforced, and came in a standard width of 4ft. Lengths could vary from 6ft (1.8m) to 18ft (5.4m) in 1ft (0.3m) increments. The floors were finished with a screed and domestic floor finish to the ground floor flats and tongue and groove (T&G) boarding on battens to upper floors.

Cladding and Partitions

Infill cladding comprised dense-aggregate concrete panels between cross walls with continuous glazing over. Internal non-loadbearing partitions were unplastered pre-cast lightweight concrete slabs.

Stairs and Deck Access

Public staircases were pre-cast concrete with metal handrails, whilst internal staircases were timber. The access decks were finished with a layer of asphalt, and had polystyrene tiles adhered to the soffits. Here concrete handrails were provided, with a lightweight composite panel spanning between columns beneath.

Windows and Doors

Originally painted softwood exterior doors were provided, and metal framed single glazed windows. However in some flats these had been replaced with PVC doors, windows and fascias. All internal doors were hollow-core.

Heating

The St. Mary's Estate operates a district heating system to remaining houses, which initially supplied ducted warm air heating and hot water to Jespersen Street as well. The ducted warm air heating was later altered to radiators in the flats.

The overall dimensions of the building were 200m long by 11m deep. To achieve this depth nine floor panels and five wall panels (four large and one small) were used per structural bay. Jespersen Street comprised 50 structural bays, containing 5 staircase/refuse bays and 45 accommodation bays, (the accommodation bays provided two flats per level for every three structural bays, see Figure 2 below)

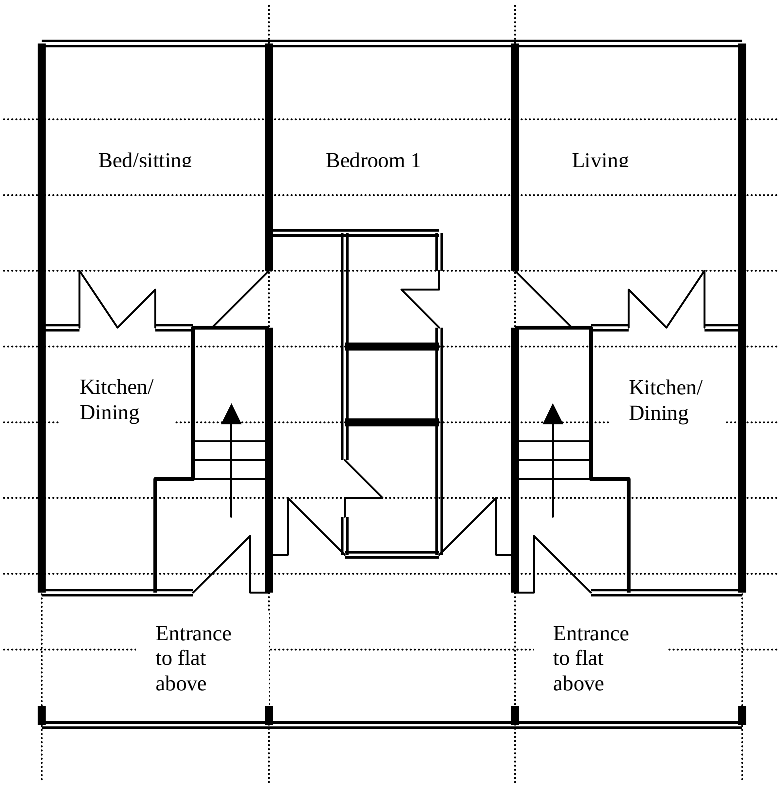

Figure 2. Typical flat layout on access deck level. Left: Bed-sitting room flat. Right: 1 bedroom 2 person flat. (Not to Scale)

All the floor and wall panels (not external cladding) were produced in steel moulds to give a smooth finish. Fixings were moulded into the panels at the factory, and joints between panels were concrete filled in-situ.

2.3 The Demolition

Martin Flynn Demolition of Manchester bid £10,000 less than their nearest two competitors to win the contract to demolish Jespersen Street from Oldham Metropolitan Borough Council. The contract period ran for eighteen weeks from 22nd May 2000 to 22nd September 2000.

Hoardings were erected around the site during the first three weeks of the contract. These consisted of chipboard panels screwed to a framework of timber posts and rails. Since these were screwed instead of nailed, this allowed them to be dismantled and either be reused by Flynn or sold on to another user. Screw fixing is more expensive initially, but not only can the boards then be reused, they are also more resistant to being kicked through by vandals than the nailed equivalent. The hoardings on this project cost £15,000.

At the beginning of the fourth week, a sub-contractor started to strip out the building. From the first week of the strip out, two types of skip were on site: one from a local timber recycler that produced chipboard; and one of Flynn's own for debris to be landfilled. Except for the T&G boards, all solid wood removed from the building was placed in the chipboard skip. Some of the fittings removed from the flats could not be recycled in this manner, for example hollowcore doors and kitchen unit carcasses, and these were landfilled. The T&G boarding was stockpiled on site, and all reusable boards were taken by H & J Reclaimed Timber at the end of the project. The remaining off-cuts and damaged boards were then put in the chipboard skip.

In flats which had been unoccupied for a long period before demolition most of the heating system, radiators and pipework had already been removed, but in those more recently vacated, some remained. Any copper found was kept in one of the site huts until the end of the project when enough was collected to send to a dealer. All the sanitaryware and radiators went to a scrap dealer to be sold on. The protective boards from the windows in good condition went to Flynn's yard, although ten were sold to a member of the public for £10. The rest were scrapped.

Asbestos panels were found in the airing cupboards of some flats. An asbestos removal firm was brought in from the sixth week, and once the flats were cleared of asbestos they were marked so that in the event of a fire the fire brigade would know which flats still contained asbestos and act accordingly. Flynn use the same asbestos removers on all their contracts in the region.

Attempts were made to find a recycler willing to take PVC window frames, but when this proved to be impossible (recyclers were unwilling to take post-demolition waste, and only really dealt with waste from the manufacturing process) the windows were removed from the north side of the building. This allowed other materials such as the timber to be dropped from upper storeys, whilst leaving the windows on the southern elevation meant better site security. (This elevation looked directly over a main road, and was considerably nearer to the boundary of the site than the northern elevation).

Some of the infill panels on the deck fascia of the flats turned out to be good quality timber with insulation behind. Once the insulation was stripped from these panels they were sent for chipboard. Polystyrene tiles from above the deck were removed with a hoe and bagged as work progressed to prevent the wind taking them. This proved to be quite a time consuming job, and could only be carried out after materials stripped from the flats had been removed from the deck (see photo 2), and sorted into the appropriate skips.

An asphalt roofing company came to the site and enquired about taking up some of the decking surface. Flynn agreed that they could have the asphalt free of charge if they took it up themselves. This helped both parties, as the amount of timber in the flats meant that Flynn were getting behind with the stripping out, and the asphalt company brought their wagon on site and fed the removed material straight into the boiler.

Demolition of the actual structure began on 18th July. This was initially carried out with a long-reach excavator with hydraulic breaker attachment. However, as demolition progressed it was found that an ordinary excavator with bucket claw attachment sufficed.

Photo 2. Materials stripped from flats are left on access decks for sorting.

The sloping nature of the site, and the proximity of the building to the site boundary in some places meant that demolition could not simply start at one end of the building and proceed linearly. A section had to be taken out of the centre of the building, so that the excavator could get into the line of the building. Demolition then proceeded westerly to the end of the building, and the excavator was turned around to complete the demolition in the other direction.

Photo 3. The 75 tonne excavator gains the height it needs using the debris pile.

It took two days to reach the western end of the building, where an operative had to be constantly watching the footpath just outside the site boundary to make sure pedestrians didn't walk too close whilst demolition was in progress.

When the demolition doubled back, the 75 tonne excavator could be used. All the concrete was going to be crushed offsite but was initially stockpiled on the site. This debris pile was banked up so that it would give the smaller excavator the height it needed to reach the top of the building. See Photo 3 overleaf:

The final section of the building at the easterly end had to be demolished at a quiet time of day in terms of traffic (early in the morning on a Saturday), because it was so close to the road there were concerns about debris falling on the carriageway.

Once all the building was demolished, sorting of the rubble began. Reinforcing bars were sent for recycling, and all the concrete went for crushing off-site (Oldham MBC wouldn't allow crushing on the site).

2.4 Debris Trails

The following table provides a summary of the debris that was removed from Jespersen Street in terms of type, quantity and destination and ultimate fate:

Table 1. Summary of Debris Trails from Jespersen Street

Material Type	Quantity	Destination	Fate
Concrete	9400 tonnes	Off-site crusher	Recycled
T & G floorboards	3000 sq. m	H& J Reclaimed timber	Reclaimed
General timber	92 tonnes	Chipboard companies	Recyced
Asphalt	10 tonnes	Roofing company	Recycled
Copper pipe	2 tonnes	Scrap merchants	Recycled
Aluminium	0.25 tonnes	Scrap merchants	Recycled
Reinforcing steel	140 tonnes	Scrap merchants	Recycled
General waste (including plastics and chipboard)	45 tonnes	Landfill	Disposal

In addition to the above, the hoardings and protective covers from the windows of Jespersen Street were also taken for reuse, and small numbers of toilets, washbasins and other fittings such as boilers and radiators.

2.5 Closing the loop

Overall Oldham MBC were very impressed with the level of reclamation and recycling that took place on the Jespersen Street project. No previous demolition contractor had recycled as much as Flynn on an Oldham contract. This could partly be due to the fact that there was no redevelopment taking place immediately on the site, so the time period for the demolition was longer. However, the lack of redevelopment did mean that Oldham MBC had no demand for recycled concrete for use on their own site. They also refused planning permission for a mobile crusher in a yard close to Jespersen Street, making the recycling and sale of the aggregate difficult. Flynn had to find other outlets for the material.

Although the idea of screw fixing the hoardings was good, when panels were removed (either by vandals or by the operatives) they were replaced using nails.

In this case the level of reclamation and recycling is high given the circumstances. Oldham MBC could have given more thought to their role as a possible recipient of some of the recyclate and this would have helped to close the loop still further. Apparently, although the council did not need to use the crushed concrete on their site at Jespersen Street, they were completing another project at a school in the area for which they were importing virgin aggregates. Unfortunately this site was for the Education Department, not the Housing Department as at Jespersen Street, so the connection had not been made before tendering. This shows the need for organisations to realise that when demolishing properties, resources are being released. These resources may be of use to other sections within the organisation and there is a need to establish appropriate communications to disseminate that information. A new culture needs to be developed.

3. CONCLUSION

This paper has introduced a study of Jespersen Street in Oldham to try and illuminate whether a relationship exists between the reason for a demolition and the way in which that demolition is carried out.

In the case of the flats on the St Mary's Estate, although they were structurally sound and offered substantially larger accommodation than in many modern homes, prospective tenants had deemed them obsolete from social and utility viewpoints. The demolition of Jespersen Street was the final stage in the systematic removal of all the flats built on the estate in the 1960s. The whole process was partly instigated by the residents association who were worried about increasing incidences of drug abuse, arson and unsociable behaviour. Many of the estate's residents liked the area and wanted to remain in the vicinity, but believed that the blocks of flats were attracting the "wrong sort" of tenants. One of the reasons for the demolition from Oldham MBC's point of view was there were too few tenants to support the amount of housing available on the estate.

Although outline plans are in place to introduce a lower density of housing (possibly pensioners' bungalows) on the site in the future, there were no immediate plans to replace the quantity of accommodation demolished. The demolition contract period was therefore longer than if the site was to have been built on immediately, and meant that the proportion of materials reclaimed or recycled was greater than could have been expected otherwise. Unfortunately, the lack of imminent redevelopment also meant that there was no obvious outlet for some of the recycled concrete, and the contractor had to explore other avenues for recycling in consequence.

Although this case study does not prove a direct link between obsolescence of a building and the demolition method employed, it does show that an indirect relationship between the two may exist. The reason for obsolescence influences decisions made with regard to demolition and/or rebuilding a structure. These decisions can in turn influence the contractual terms for a demolition, for example the time period allowed. Ultimately this can affect the method chosen for a particular demolition and thus the amount of reclamation and recycling carried out.

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DECONSTRUCTION AND THE REUSE OF CONSTRUCTION MATERIALS

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SUMMARY

BRE are in the process of determining the methodologies, tools and products that need to be put in place to optimise materials recovery from existing buildings and product recovery from future construction.

This report will give an overview of the waste arisings in the construction and demolition (C&D) industries, the legislative, strategic, fiscal and policy issues relating to deconstruction.

It will also investigate how the deconstruction process can work effectively within the C&D and recycling industries.

KEYWORDS: Deconstruction, demolition, construction, design, recycling, reclamation.

CONTEXT

At last year's deconstruction *closing the loop* conference held at the Building Research Establishment (BRE), the definitions of deconstruction, disassembly, demolition, refurbishment, retrofit and adaptable were discussed. A consensus was reached and these are the definitions that will be used throughout the text.

- *Disassembly* - taking apart components without damaging, but not necessarily to reuse them.
- *Demolition* - a term for both the name of the industry and a process of intentional destruction.
- *Deconstruction* - Similar to disassembly but with thought towards reusing the components.
- *Refurbishment* - Improving building performance through partial or complete replacement and/or upgrade of components and services.
- *Retrofit* - Change of use or purpose after construction from which a building was designed (term *retrofit* rarely used in UK, predominantly a US term).
- *Adaptable Building* - A multi-use building which allows for an easy change in its use.

1. INTRODUCTION

The construction industry is the largest consumer of resources of all UK industries both directly and from its supply chain of material producers, fabricators and stockists. Approximately 6 tonnes of materials are consumed per person per year. At the same time the construction and demolition industry produces large quantities of waste components and materials. This resource inefficiency is coupled with environmental, economical and social impacts that are rapidly becoming unacceptable.

The source, type, quantity and true cost of demolished components and material are mostly unknown. Despite this, every year in UK approximately 3.3 million tonnes of architectural and ornamental components, 24 million tonnes of recycled aggregates and an unknown quantity of steel and timber is recycled back into production. However, large volumes of potentially reusable components are landfilled and lost to the system only to be replaced with similar components.

With this lack of national and site data, academics and researchers need to be conscious that they don't try to reinvent the wheel or propose impractical solutions. The demolition industry has known for decades about the key factors that affect the choice of the demolition method and particular barriers to reuse and recycling of components and materials of the structures. The demolition industry itself is best placed to guide current deconstruction and contribute to future technologies.

In recent years there have been an array of current and proposed legislative, fiscal and policy framework affecting the demolition industry, and this will become ever more stringent in the future. To respond in the short term requires integrated waste management systems that are supported by the inherent skills and technologies of the construction, demolition and waste management industries. Longer term solutions need to be incorporated into today's construction. This is where designing for deconstruction and innovative solutions is a vital key to unlock the potential of mass reuse of components that are shown to be fit for use or purpose.

The BRE Deconstruction group believes that digests, information papers, protocols, quality control schemes, tests for strength, quality and durability, and demonstration projects can help provide the necessary confidence and opportunity in reusing components or recycling materials. The two key areas requiring further investigation and demonstration in order to overcome barriers and factors will be performance-based specifications and the design of deconstructable joints and fasteners.

The future development of a sustainable, efficient and prosperous demolition industry that sees material and component reuse as a key facet, will require considerable investment in terms of time, money, skills, tools, technologies, standards and risk. There are far reaching benefits to more sustainable construction, demolition and waste management industries, not least in terms of employment, market networks and regional/national storage and distribution centres.

2. COMPOSITION OF CONSTRUCTION AND DEMOLITION WASTE.

2.1 Overview

From the numerous attempts to identify UK and European waste arisings in terms of construction and demolition, it is difficult to propose any figures with much confidence.

What is apparent is the complex nature of the wastestream in terms of amounts, composition and waste management routes. In general terms, construction and demolition wastestreams are distinctly different with refurbishment waste forming a grey area in between.

Construction waste: small quantities generated over a long period of time as a by-product of the main process. Opportunity to avoid waste. Some opportunities to reclaim and recycle materials and products.

Demolition waste: large quantities generated over of short period of time as a main part of the process. Little opportunity to avoid waste. More opportunities to reclaim and recycle materials and products.

The area of deconstruction becomes interesting when these two processes are linked into an integral system. When this occurs it is possible to consider the fate of the building at the end of its useful life, i.e. design for deconstruction and adaptable buildings, and consider the reuse of demolition products in new construction and refurbishment, i.e. reuse and recycling within the same site.

A recent survey sponsored by DETR (Department of the Environment, Transport and Regions) and the EA (Environment Agency) will be published in Spring 2001[1]. This survey consisted of a postal questionnaire sent out to all known crusher operators, licensed landfills, holders of relevant exemptions. The response rate varied between 20 to 30%. Once these results were extrapolated the following conclusions were made:

- Total production of C&D waste (including excavated soils) in England and Wales estimated to be 72.5 million tonnes (69.2 Mt in England). *This figure excludes road planings and materials re-used without processing i.e. crushing and/or screening. The overall waste arisings including all these materials is likely to be between 90 to 100 million tonnes per year.*
- 33.8 Mt of C&D waste (mainly hard demolition waste such as concrete and bricks).
- 23.7 Mt of soil (including stones and rock, and coming mainly from excavation).
- 15Mt of mixed C&D waste and soil, plus minor amounts of other inert materials.
- Recovery rate including recycling (35%), landfill engineering (13%), spreading on exempt sites (28%) was estimated to be 76%.

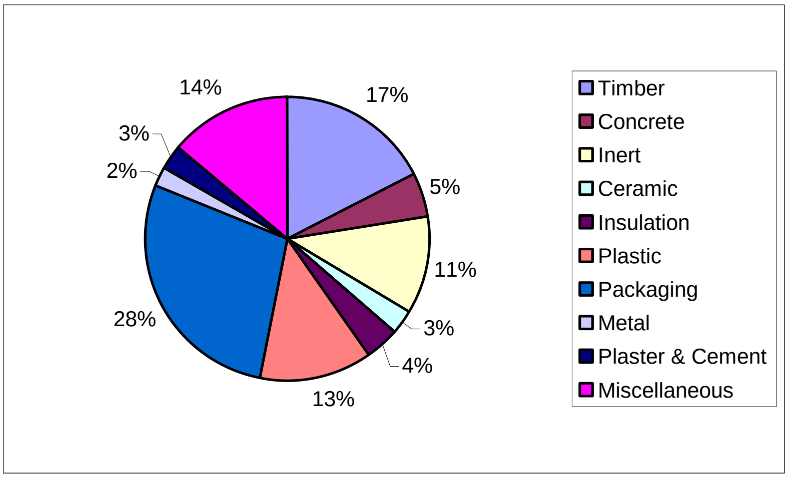
It has to be said that the emphasis of the survey was to determine the inert materials available for recycling and the current methods of waste management. The information on other components of the wastestreams such as timber, plastic, glass and packaging is limited; and information on products and materials suitable for reuse was not collected.

2.2 Construction waste

Obtaining reasonably accurate figures for the composition of construction waste has so far been elusive. 10 million tonnes of UK construction waste per annum is often quoted from various sources, themselves estimated and extrapolated from disparate investigations. More recently, the BRE Centre for Waste and Recycling has been gathering detailed benchmarks of waste arisings from different types and sizes of construction sites. Six of these sites are detailed in *Table 1* according to project type. *Graph 1* shows the varying composition of construction waste material group based on data collected on the composition of construction waste to date. Incidentally, core inert waste only accounts for 20% of this waste, much less than packaging at around 25%. Further implementation of SMARTWaste™ on various sites is expected to provide a more accurate picture.

Table 1 – Construction Waste by Material Group and Project Type[2]

Project Type / Waste Group	Office A %	Housing (1) B %	Housing (2) C %	Leisure D %	Housing E %	Restaurant F %	Avg %
Timber	8	33	25	3	15	20	17.3
Concrete	2	18	0.5	3	10		5.6
Inert	1		0.5	11	27	27	11.1
Ceramic	2				11	4	2.8
Insulation	9	2	1	9	1		3.7
Plastic	4	17	37	4	5	10	12.8
Packaging	47	8	22	49	9	32	27.8
Metal	6	3	0.5	3	1		2.3
Plaster & Cement	10	1	0.5	3	2		2.8
Miscellaneous	11	18	13	15	19	7	13.8
Total	100	100	100	100	100	100	100



Graph 1 – Average Composition of Construction Waste by Group

2.3 Excavation waste

30 million tonnes per year of excavated soil/clay waste are estimated to arise from construction site preparation. This could be minimised by appropriate architectural, structural and landscape design. At present, this is not a serious consideration even for environmentally sensitive design teams. Landscaping often provides important opportunities to utilise this type of waste on site, with the added benefit of reduced transport, environmental and social costs including noise, dust and vibration nuisance.

2.4 Demolition waste

Crushing and separation of demolition waste

Demolition waste is taken to include waste from the demolition of structures and parts of structures and include recycled/reclaimed materials where appropriate. The breakdown of the estimated 30m tonnes of demolition waste arising each year is shown in *Table 2*, itself from a range of sources.

Table 2 - Demolition Waste, Estimated Annually [2]

Material	Quantity
concrete	12 million tonnes
masonry	7.2 million tonnes
paper, cardboard, plastic and other	5.1 million tonnes
asphalt	4.5 million tonnes
wood based	1.0 million tonnes
other	0.2 million tonnes

2.5 The recycling industry

Approximately 24 million tonnes of inert C&D waste is recycled per annum. This figure is substantiated by three separate investigations by the Quarry Products Association (QPA), BRE[3] and more recently the EA & DETR[1] survey. The survey by BRE suggests that the average transport distance to the recycling site and back to customer is 50km.

Crushing and grading of concrete components into recycled aggregates

Timber recycling is now a common route for large amounts of untreated timber waste generated in built up areas. The main market is wood panel product manufacture with virgin feedstock being replaced with up to 30% recycled wood fibre in chipboard. Constraints to this market are the location and quality of the material arising.

Construction timber waste is in the form of timber pallets, crates, cable drums and formwork. Most of this can be reused or recycled, formwork presents problems in the concrete and oil contamination.

Typically materials such as plastics, cardboard and paper are not reaching the recycling sector from C&D. This would require greater segregation and the creation of collection systems that are currently not available. *Table 1* and *Graph 1* identify that as much as 40% of construction waste is from plastics and packaging alone.

Metals recycling involves traditional recycling routes such as scrap yards. Metal from construction and refurbishment is far less likely to be recycled than that arising from demolition. However, offcuts of copper and aluminium components and pipes may provide a source of revenue under the right market and recycling conditions.

2.6 The reclamation industry

Buildings currently undergoing deconstruction are typically supplying the reclamation market. The main end users of these products are householders and small builders carrying our renovations and extensions to older properties. This is reflected in the disparate nature of the reclamation industry, with around 1500 organisations involved.

Approximately 3.3 million tonnes of C&D waste is reclaimed as per *Table 3*. This excludes concrete that is accounted for elsewhere. 30% of these components are reclaimed within 30km of its source, 60% within 150km and 10% beyond 150km distance (including import and export). Greater reuse of components in mainstream construction would further increase the amount being reclaimed.

Table 3 - Size of UK reclamation industry and market[3]

Sector	Sales £ million	Employment	Tonnes 000's
Architectural antiques			
Stone	17	2100	69
Timber	4	1100	7
Iron & steel	4	800	7
Clay	1	800	2
Ornamental antiques			
Stone	16	1170	22
Timber	36	1740	22
Iron	9	1000	9
Clay	1	100	1
Reclaimed materials			
Timber beams	42	3600	133
Timber flooring	29	2960	101
Clay bricks	31	4300	443
Clay roof tiles	63	3600	306
Clay and stone paving	19	1300	672
Stone walling	29	2450	1083
Salvaged materials			
Iron and steel	11	2800	75
Timber	36	7800	371
Antique bathrooms			
Sinks, baths, taps, WCs	41	1900	1
TOTAL	389	39520	3324

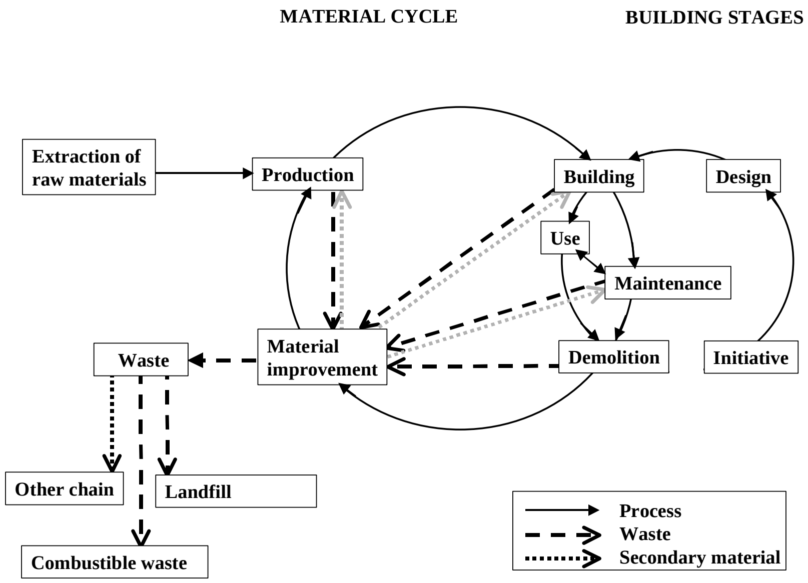
Reclamation involves less processing, greater employment and is often a more efficient use of resources than recycling. For deconstruction, and therefore reuse to increase, there needs to be greater markets for lower value reclaimed materials than is the current scenario. This is where use in main stream construction of reclaimed components and materials are an essential part of creating markets to facilitate further deconstruction.

2.7 Integral waste management

The Netherlands implements an integral waste management system that attempts to reduce as much as practicably possible the extent of C&D waste going to landfill, and encourages the reuse and recycling of components and materials.

Figure 1 shows the integrated resource use and waste management cycle i.e. a closed loop. This approach to waste management is bolstered by the government's Ladder of Lansink (Delft Ladder), which includes more options than the UK waste hierarchy. The Delft Ladder sees prevention, construction reuse, element reuse, material reuse, useful application, immobilisation with useful application, and finally Immobilisation before any of the other options including incineration with energy recovery, incineration with no energy recovery and finally sent to landfill.

Figure 1 – The Netherlands Waste Management cycle[4]



The Delft Ladder re-interpreted in UK terminology might be:

- Waste reduction
- Adaptable buildings
- Components/ module reuse
- Materials reuse
- Recycling/ composting to similar grade application
- Site engineering/ lower grade application
- Incineration/landfill with energy recovery
- Incineration/landfill without energy recovery

In the context of construction and demolition waste, BRE are also distinguishing between on site and off site reuse and recovery (proximity principle) in the determination of BPEO (best practicable environmental option) for waste management. In terms of deconstruction this basically means the on site markets for demolition products are generally preferable, in environmental and costs terms, than off site markets.

3. LEGISLATIVE, STRATEGIC, FISCAL AND POLICY FRAMEWORK AFFECTING DECONSTRUCTION

Current and future legislation can be a key driver in sustainable waste management. The following sections will describe the European and UK legislative, strategic, fiscal and policy issues that may have an impact on the deconstruction process.

3.1 Current EU waste management and legislation

Overview of EU C&D waste management

There are increasing restrictions on the disposal of active (mixed) C&D waste in Europe that ought to increase the amount of mono landfills for future recovery. Current mono landfills containing only C&D waste are very limited. Despite a range of Council Directives and Decisions, there is still no common theme. The recent Landfill Directive provides the necessary measures to address the lack of a common theme, and encourages reuse and recycling of components and materials through various means including growing disposal costs.

Subsidies to assist this change are few and far between, however a positive response has been witnessed by member states implementing waste management plans. In some member states, these plans have served to set targets and increase levels of reuse and recycling. In others, there is a growing wealth of information available to help them improve performance.

There is increasing use of tools to facilitate change including waste exchanges to transfer reclaimed components, but the network required to market the materials is predominantly patchy. Funding from the EU and member states helps support R&D in new techniques and technologies, and more recently dissemination of established knowledge.

Project group on C&D waste

Most European environmental legislation takes a long time to evolve, normally with plenty of time for input from interested parties and EU member states, similarly for comment on draft European Directives. In 1992 the Commission set up the "Priority Waste Streams Programme" and, following consultation, 6 priority waste streams programmes were initiated. These were:

- Used Tyres
- End-of-Life Vehicles
- Chlorinated Solvents
- Healthcare Waste
- Construction and Demolition Waste
- Waste from Electrical and Electronic Equipment

Project groups were set up for each of the six waste streams to discuss and recommend ways that member states could improve methods of waste management. These needed to respect the objectives and principles of sustainable development, preventative and precautionary action, shared responsibility, and the concept of life-cycle management of products and processes in the most cost effective way.

In April 2000 a working document produced by the C&D waste project group described the measurement of the C&D waste stream in member states, and detailed the aims and instruments that are likely to improve C&D waste management. The document also includes a selection of recommendations which member states need to consider when developing their own waste management policies.

Working group on sustainable construction

As one of the fourteen priority actions for improving competitiveness within construction, a Working Group on Sustainable Construction was established in 1999 which included three Task Groups, one of which was TG3 on C&D waste management. The main function of TG3 is to provide a document of recommendations on how to improve C&D waste management through improved planning, prevention and reclamation. One of its main findings was that "optimal separation of C+DW must take place to maximise recovery of material for reuse and recycling"[5].

The scope of the document focused on whole construction process including design, pre-construction, construction, demolition, reuse, recycling, final disposal, research and education. Its output was to make recommendations to three core sectors of construction, building on and making use of both the Symonds report and the Priority Waste Stream report. These three core sectors are Industry, Member states and their public authorities, and the European Commission. The recommendations are suitably lengthy and incorporate other requirements of industry and member states that include:

- Waste management plans for C&D waste
- Design for deconstruction, reuse and recycling
- Annual reports
- Appropriate management of hazardous wastes
- Environmental assessments of manufactured materials and products
- Education to the whole supply chain about waste prevention and reclamation
- And many more, relevant recommendations

European waste management plans

Member states are requested to provide waste management plans to facilitate self-sufficiency, reduce movements of waste materials and establish inspections of disposal and reclamation. Reports to the Commission by individual States are submitted every three years, and agglomerated into a single report by the Commission thereafter. Annexes of Waste Categories (Annex I), Disposal Operations (Annex IIA) and Recovery Operations (Annex IIB) are included in the Landfill Directive.

European Waste Catalogue

The European Waste Catalogue (EWC) applies to all wastes whether for disposal or reclamation, and is a harmonised, non-exhaustive list using common terminology across the Community. However the inclusion of a material in the EWC does not mean that it is a waste, only when the relevant definition is satisfied is it considered waste. The EWC is indexed by waste ids, for example:

ID= 01 04 02 waste sand and clays
ID= 08 01 05 hardened paints and varnishes
ID= 08 04 03 waste from water-based adhesives and sealant
ID= 17 01 01 concrete
ID= 17 04 05 iron and steel

Hazardous wastes 91/689/EEC & 94/904/EC

Member states are required to implement controlled management of hazardous waste. These indicate the appropriate means necessary to collect, transport, store and manage hazardous wastes. These are defined in Annexes covering generic types of hazardous waste including pigments, paints, resins, and plasticisers, and properties of waste which render them hazardous including oxidising, harmful, carcinogenic and corrosive substances, as well as substances that yield damaging leachates or ecotoxic risks.

3.2 Current UK waste management and legislation

UK law

Prior to 1972 there were minimal controls over the disposal of wastes. The Public Health Act 1848 was the first attempt at national legislation in the UK. It was this Act which created the term "Statutory Nuisance" in relation to any accumulation or deposit which was prejudicial to health or a nuisance. The Act enabled local government to take action on behalf of the public. Between 1848 and 1936 a series of Acts were enacted before the consolidating Public Health Act 1936. This Act gave local authorities the powers to police and inspect waste arisings. It also gave authorities the power to remove household and trade waste and to inspect for, and require the removal of, noxious materials.

The Environmental Protection Act 1990

The Environmental Protection Act 1990 (EPA 90) was the culmination of a long period of discussion of amendments to environmental law. The Act covers a wide range of environmental topics, not all of which are relevant to waste management. Part I of the Act introduced the system of Integrated Pollution Control (IPC) which is applicable to the release of pollutants to air, water and land from certain processes, establishing the important new criteria of Best Available Technology Not Entailing Excessive Cost (BATNEEC). Part II of the Act deals specifically with the deposit of waste on land (most waste management activities fall under the provisions of Part II). Many of the provisions of the EPA 90 have been implemented by Regulations made by the Secretary of State for the Environment.

The Environment Act 1995

The Environment Act 1995 established the Environment Agency and the Scottish Environment Protection Agency. The creation of these Agencies represented a major step towards truly integrated environmental management and control, as they brought together the regulators responsible for Integrated Pollution Control, water management and waste regulation. The 1995 Act makes numerous amendments to the EPA 90 and the other major environmental statutes. Many of these amendments relate to the powers and duties of the regulators, who now have greater scope to take preventative action when there is a likelihood of pollution.

Development of UK waste classification scheme

Working in partnership with the waste industry, the EA is developing an UK system of classifying waste. The UK system will contain more information about the polluting potential of wastes than the existing EWC. It also differs from the European system in that it presents separate information on:

- the composition of the waste (with 341 available codes)

- the industrial process that produced the waste (classified according to the 586 standard industrial classifications).

The aims of the classification scheme are:

- to provide the Agency with better quality data on waste arisings and disposal
- to provide waste holders with better and more consistent hazard information, as part of the existing Duty of Care system.

Once the classification system has been formalised, there is likelihood that waste producers will be given a statutory duty to enter the code on the Duty of Care transfer note.

Scottish National Waste Strategy

In May 2000 the Scottish Environment Protection Agency (SEPA) published the Scottish national waste strategy. It contains proposals for meeting the targets in the Landfill Directive as well as covering wider issues of waste reduction, reclamation and recycling and the planning of waste management facilities. The main objective of the waste strategy is to achieve integrated waste management system and services. The strategy also identifies four priority waste stream projects; newsprint, tyres, future (WEEE etc) and C&D waste. The latter C&D project will require the development of a C&D Waste Action Plan that will reflect three key objectives and tasks:

- comprehensive review of volume and location of C&D waste
- levels of C&D waste reclamation, key players and barriers to reuse
- future management and market development of C&D waste

UK Waste Strategy 2000 (England and Wales)

The DETR published a statutory waste strategy for England and Wales in May 2000. This strategy describes the government's vision for managing waste and resources better. It sets out the changes needed to deliver more sustainable development. The strategy stresses that the quantity of waste produced must be tackled by breaking the link between economic growth and increased waste. The main theme of the strategy is 'where waste is created we must increasingly put it to good use – through recycling, composting or using it as a fuel'. The strategy also recognises the need to develop new and stronger markets for recycled materials. To address this, a major new Waste and Resources Action Programme will be set up. This Programme will deliver more recycling and reuse, help develop markets and end-uses for secondary materials, and promote an integrated approach to resource use.

Sustainable construction strategy

The need to reduce waste at all stages of construction was central to the message of *Rethinking Construction* the 1998 report of the Construction Task Force on the scope for improving the quality and efficiency of UK construction. Improving the efficiency of the construction industry is a key objective for the Government, as set out in its strategy for more sustainable construction 'Building a Better Quality of Life'. The strategy published in April 2000, identifies priority areas for action, and suggests indicators and targets to measure progress. It sets out action that the Government has already taken, further initiatives that are planned, and highlighted what others can do. The Government will use the strategy as a framework to guide its policies towards construction, and will encourage people involved in construction to do the same.

The sustainable construction strategy emphasises the importance of reducing waste at all stages of construction by focusing on the need to consider long term impacts of design, construction and disposal decisions so that materials and other resource use is optimised. The strategy encourages the industry (including clients) to consider refurbishment or renovation as an alternative to new buildings and structures. It highlights the need to avoid over-specification in materials and the scope for standardisation of components.

3.3 Adopted EU directives to be implemented by UK legislation

Integrated Pollution Prevention & Control (IPPC) (OJ L257 10.10.96)

The purpose of this Directive is "to achieve integrated prevention and control of pollution" arising from the industrial activities listed in Annex I to the Directive. Also, to "prevent, or where that is not practicable, to reduce emissions in the air, water and land…including measures concerning waste, in order to achieve a high level of protection of the environment taken as a whole". It is very similar in concept to the UK's Integrated Pollution Control (IPC) system, and this Directive will therefore have less impact on the UK than on other member states.

The Landfill Directive 99/31/EC

The Directive defines three classes of landfills: for hazardous, non-hazardous and inert waste. The following wastes are banned from landfill:

- explosive, oxidising or flammable wastes
- infectious clinical waste
- tyres (whether whole or shredded)
- liquid wastes, except those suitable for disposal at an inert waste site

The aim of the Directive is to provide measures, procedures and guidance to prevent or reduce negative effects to the global environment and all its cycles from landfilling of waste during the whole lifecycle of the landfill site. All hazardous waste is to be treated before landfilling, although the term "treat" can be taken to mean merely sorting, provided the hazardous character of the waste is reduced. The Directive states that hazardous waste may only be landfilled in a hazardous waste site and therefore rules out co-disposal which must cease by 2004 at hazardous waste sites.

Article 3 of the Directive excludes inert waste suitable for reuse or recycling in redevelopment, restoration, fill or construction purposes. Article 6(a) excludes inert waste requiring treatment prior to landfill, but in Article 6(d) stipulates that landfill sites designed for inert waste are reserved for inert waste. Similar legislation is evident at Member State level, where inert waste (including concrete) in UK is often exempt from landfill tax when used for constructing landfill cells and roads, agricultural road improvements, construction purposes (including high- and low-grade applications) and filling-in disused quarries. Approximately 40 million tons of recycled aggregates are used in the UK each year.

European lists and tests

Annex II of the Landfill Directive requires that a uniform waste classification and acceptance procedure is required. The waste acceptance criteria is to be complete by April 2001, and the waste acceptance procedures by April 2002. In the interim, preliminary waste acceptance procedures are used to separate inert, hazardous and non-hazardous wastes into groups. Eventually this uniform European list will assist member states to define national lists, that individual landfills will use to define site-specific lists. A three-level hierarchy to characterise and test wastes will also be required to validate that waste entering a landfill meets these lists. This hierarchy will include an initial test, an annual test and an at-the-gate test for all loads. It is early days in the development of these lists and tests and there is much scope to influence the final outcome. Yet by April 2002 there may be significant change regarding what type of waste or materials you can dispose of in which landfill, and what preliminary, periodical or spot tests are required.

3.4 Proposed directives

Draft commission white paper on environmental liability

The European Commission has been considering the introduction of a Community-wide scheme of environmental liability since 1989, following a draft Directive issued on civil liability for damage caused by waste. This controversial draft was subsequently dropped, to be replaced by a wider-ranging set of proposals in the 1993 Green Paper on remedying damage to the environment. The current thinking within DGXI is set out in a draft White Paper, the most recent version of which was produced in October 1998. If the Commission accepts the White Paper it will be reissued as a draft Directive, possibly in the year 2000.

3.5 Fiscal

Landfill tax

The landfill tax was introduced on 1st of October 1996 and it applies to waste that is disposed of in licensed landfills. Exemptions for the tax have been provided for dredged waste, mineral waste from mines and quarries, and wastes arising from the clearance of contaminated sites. Exemptions also apply to inert materials that are used for landfill restoration or filling former quarries. The tax seeks, as far as is practicable, to ensure that the price of landfill fully reflects the impact which it has upon the environment. It provides an incentive to reduce the waste sent to landfill sites and to increase the proportion of waste that is managed at higher levels of the waste hierarchy.

There are two rates of tax, a standard rate of £11 per tonne (increased from £7 per tonne in April 1999) and a lower rate of £2 per tonne. The higher rate for mixed waste will increase £1 every year from 2000 until it reaches a rate of £15 per tonne in 2004. The categories of waste to which the lower rate of tax apply – generally inert waste – are set out in the Landfill tax (Qualifying Materials) Order 1996 (SI No 1528). The landfill tax (Contaminated Land) Order 1996 (SI No 1529) sets out the provisions for exempting waste from the clearance of historically contaminated land.

The landfill tax credit scheme was established to permit up to 20% of the taxes collected by landfill operators to be used for the purpose of implementing social and environmental projects complying with specific 'approved objects' in the regulations. The revenue must be used to encourage the use of more sustainable waste management practices and technologies, or to establish partnerships between landfill operators and local communities. The Scheme therefore, benefits both the community and the waste industry by providing opportunities to enhance social and environmental conditions and services at the local level. The landfill tax scheme is managed by ENTRUST and individual projects and funds that are approved by ENTRUST have to be managed by an authorised waste and environment body.

Aggregates tax

In April 2000 the Treasury agreed to introduce an aggregates tax of £1.60 per tonne on primary aggregates from April 2002. Secondary and tertiary aggregates will not be subject to the tax, which should encourage a greater use of recycled aggregates in low- to high-grade applications. A large proportion of the tax will be used for a Sustainability Fund that will be used to support various initiatives that are currently out for consultation. This will include developments, improvements and R&D within the industry, its facilities and its impacts to the local populations. Similar to the landfill tax, it is envisaged that a competent authority will oversee the management and approval of the fund and projects. However, until the aggregates tax is implemented and the fund structure is agreed, there is little benefit in speculating the outcome.

3.6 Policy

New Demolition Code of Practice BS 6187: 2000

This British Standard concerns the process of demolition from initiation, through planning, to the execution stages. The new version of BS 6187:1982 is essentially a re-write which takes into account the advances in technology and equipment that are available to the demolition industry. The application of new techniques and the effect of new legislation that has been introduced, particularly health and safety, and environmental legislation, including the Construction Design and Management (CDM) Regulations 1994, the Construction (Health, Safety and Welfare) Regulations 1996 and the Environmental Protection Act 1990 have been taken into account. The document is written for all – including Clients - involved in demolition (which include partial demolition) projects and gives emphasis to responsibilities from concept stage to completion, starting with clients. The Standard addresses the safety of both those engaged in the demolition process and also those members of the public who may be affected by the demolition activities.

The new edition of BS 6187 has been expanded to cover project development and management, site assessments, risk assessments, decommissioning procedures, environmental requirements and facade retention. Deconstruction techniques are considered, including activities for re-use and recycling. Principles relating to exclusion zones, their design and application have also been added.

3.7 Training

General

The National Demolition Training Group established in 1990 is a recognised body for professional training of the demolition industry that has regional and national outposts in order to satisfy the demand for safer and efficient activities in the construction and demolition sector. Today's operatives, supervisors and management need to be competent in a range of skills including first aid, specialist plant, asbestos removal, demolition supervision, demolition management, demolition techniques, explosives, scaffolding, product design, working at heights, chainsaws, abrasive wheels, personal protection equipment and other daily skill requirements. Most of these activities require specialist training and testing that is often mandatory and occasionally highly specialised.

Scheme for the certification of competence for demolition operatives

The scheme for the certification of competence for demolition operatives was established in January 1990 and covers training for the three craft levels; demolition 1 (Topman), demolition 2 (Mattockman), demolition 3 (Labourer). The scheme was jointly initiated by the NFDC and the Construction Industry Training Board (CITB), and discussed with the Demolition Industry Conciliation Board (DICB). The essential objectives of the scheme are to ensure that all operatives in the demolition industry are assessed and registered according to their competencies, and that they have received appropriate safety training. The standard of competency is based on a Training Specification as defined by the CITB.

Scheme for the certification of competence for demolition supervision

The scheme for the certification of competence for demolition supervision was developed in May 1997 and is complementary to the scheme for demolition operatives. This scheme offers a natural career progression from the scheme for demolition operatives. It is completed through distance learning by completing twelve modules, a one-day appraisal and final examination.

Scheme for the certification of competence for demolition management

The scheme for the certification of competence for demolition management was developed in May 1998 and is complementary to the scheme for demolition operatives and the scheme for demolition management. The fourteen-week course has been designed for people with more than seven years practical experience in demolition who require training in management. Together these three schemes afford an effective, contemporary and well-trained force in demolition.

Certificate of training achievement (plant) card

The certificate of training achievement (plant) card demonstrates that a plant operative has achieved a level of competence and health and safety in the use of plant on demolition sites as opposed to road building or construction. New health and safety test centres have been established along with driving theory test centres to replace the one-day safety awareness course. An innovative part of the new test is a bank of questions covering all aspects of plant operating duties that is sent to candidates prior to their test.

A random selection of questions from the bank is asked during the theory test and candidates are expected to answer them accordingly. This method of testing requires that operatives are knowledgeable in all areas of plant operation.

4. THE CURRENT INDUSTRY POSITION OF DECONSTRUCTION AND REUSE OF COMPONENTS AND MATERIALS[2]

This section summarises the opinions of BRE experts in their chosen field that is relevant to this report, i.e. steel, masonry, concrete and timber.

4.1 Steel

The steel industry has, for many years, been aware of the environmental and economic impact of waste from C&D processes. Demolition contractors have extensive experience of recycling steel both from structural sections (beams and columns) and reinforcement. The challenge will be to increase the amount of steel re-used rather than recycled. There remains a need to incorporate design for deconstruction for new buildings and to develop new tools and techniques to maximise the re-use of material from existing buildings through deconstruction.

Standards and Specifications

There are no specific national or international standards relating to the disassembly, deconstruction or demolition of steel structures. Design standards make no reference to the re-use of steel members from demolition of existing buildings. The Steel Construction Institute (SCI) and BRE have drawn up proposals to develop a model specification.

Health and Safety

For the reclamation of structural steel members existing techniques are generally remote. Beams and columns are either partially or totally flame cut or, alternatively, cut up using shears attached to a modified excavator. Bolts are rarely removed prior to reclamation. Methods to promote an increase in the amount of steel to be re-used are likely to involve removal of bolts from areas where access and space is restricted. This is likely to involve a greater risk of injury to operatives. The National Demolition Training Group will be of help in this area as they are responsible for the scheme for the certification of competence for demolition operatives which includes health and safety on site. Guidance is also available in BS6187 demolition code of practice.

Building and Planning Control

There are no known restrictions imposed by Building Control or Planning Authorities on the use of steel recovered from existing structures or from demolition sites. Building Control will require evidence that components recovered from one project are capable of meeting the requirements for the new application. This relates to methods for verifying performance.

Deconstruction Tools and Techniques

A number of specialist processes are available for the reclamation of steel from existing structures either for recycling or re-use. Heavy-duty magnets are available to extract reinforcement from floor slabs during crushing the concrete for recycled aggregate. Developments in this area may be restricted by the availability of suitable tools. The provision of a tool for the automated removal of bolts from connections could greatly improve the number of sections available for re-use rather than re-cycling. Current methods for removing beams are likely to lead to distortion in the proximity of the connection, with a subsequent requirement to flame cut the steel on the ground. The demolition industry has developed crushers and pulverisers to allow reinforcing bar (rebar) to be removed from reinforced concrete structures. There have also been recent developments in the rotating crane attached shear that allows the shear to rotate through 360 degrees. This was developed for the demolition of tall buildings. The NFDC (National Federation of Demolition Contractors)and IDE (Institution of Demolition Engineers) are organisations that can assist the development of new and future technological solutions, tools and techniques.

Material Tests to Verify Performance

There are no specific standard tests that have been developed for reusing reclaimed steel components. As long as they have not been highly stressed (inelastically), and do not show any visible signs of plastic deformation, they should be fit for re-use in structural applications. Any out of plane deformations such as buckling in the web of column sections could lead to instability in use. The only source of information on this topic is the ‘Appraisal of existing iron and steel structures’ published by the SCI which gives information on methods of investigation and guidance on calculations for checking structural adequacy.

4.2 Masonry

Standards and specifications

Generally the standards on bricks and blocks are BS3921/85 and BS6100, but most bricks and blocks reclaimed during demolition will possibly not be able to satisfy these standards. There is no official standard that controls the quality of reclaimed bricks and blocks, and generally suppliers of these materials work under the unofficial standard ‘one good face, one good end’. Similar standards apply to slates, tiles and paving stones. Reputable firms that supply reclaimed bricks can attain ISO accreditation under ISO9002 if they set up a Quality Management System of their own to class the bricks, for example premier quality, average quality and below quality. This type of system allows clients to know what to expect and gives potential for customer satisfaction. It allows builders to determine ‘fitness for purpose’.

Health and safety

There are minimal health and safety implications to those already covering demolition sites in Construction (Health, Safety and Welfare) Regulations 9, 10, 11.

Building and Planning control

If buildings on a historic site with special significance to the community are deconstructed and re-built using some of the reclaimed materials and components it gives a feeling of continuity to the area as well as improving it for the future. Nevertheless, there is still a growing need for local plans and planning approvals to include instructions to reclaim and reuse construction and structural components where practicable. Without specifications, the need to assure components are ‘fit for use or purpose’ will be required.

The Planning Policy Guidance (PPG15) and the Planning Act (Historic Buildings and Conservation Areas) 1992 are both responsible for making the re-use of old bricks big business. They encourage a policy of ‘like-for-like’ replacement of materials when repairing a historic structure and the reclamation industry has grown from this need. They don’t specifically enforce the ‘reuse of reclaimed bricks’ but they encourage (i.e. “you will get listed building consent if you agree to use bricks that are similar to these old ones”) using similar old bricks and discourage using new ones. Also under PPG15 if planning officers are considering a development plan anywhere around a listed building they are advised to consider whether it affects the setting of the listed building. One thing that may help an applicant get permission for their development is to create a new building that has similar features or is built of the same material or in the same style as an historic/listed building nearby. This helps the harmony of the street, and will therefore not adversely affect the historical feel of the area.

Deconstruction tools and techniques

It is in the best interests of demolition companies to perform deconstruction in the most careful way possible that leads to the least damage to the components of a building. It is therefore likely that deconstruction is performed by hand. This allows the demolition company to maximise profits through selective demolition so that components are sold to reclamation yards and recycling facilities. This has been a gradual realisation on the part of demolition firms and therefore the quality of bricks for example, which arrive at the reclamation yard has continued to improve over the years. If the demolition company makes more money from hand-cleaned, whole bricks then it will take care in demolition. Some demolition companies clean (remove the mortar) the bricks before selling them on, some supply to established reclamation yards that undertake the cleaning themselves. However one of the limitations to reclaiming bricks is the growth in the use of ordinary portland cement (OPC) rather than lime-based mortars which are easier to separate than OPC. There is need to investigate practicable and cost-effective removal techniques for OPC mortars.

Material tests to verify durability / specification

The same tests that are carried out on new materials and products to determine strength and durability can be carried out on reclaimed products but it is currently not required. Any enforcement of these tests would limit the uptake of reclaimed products. However, practicable and cost-effective tests that demonstrate ‘fit for use or purpose’ would be welcomed and perhaps encourage clients, architects and LA’s to recommend their use.

4.3 Concrete

This section summarises the current issues affecting re-use of concrete components in the construction industry. Concrete constitutes a large proportion of construction waste in the UK and around the world but traditionally little of this has been re-used, or even reclaimed and this has been restricted to use in low-quality sub-base or foundations. A small amount is now crushed and used as aggregate, mainly in bases and in-fill. On rare occasions recycled aggregates are used in high-grade applications, for example the concrete floor slabs of the BRE Environment building and the strong floor at the BRE Cardington test facility[6].

The demolition industry is becoming increasingly sophisticated but the construction of concrete structures is also becoming increasingly complex with the different types of concrete and construction techniques available to the designer increasing at a rapid pace. Consideration therefore needs to be given to the deconstruction of a structure at the design stage. Clients are also demanding more flexibility from their buildings, as the use (and/or ownership) of a building is likely to change over the life span of a building. The need for partial deconstruction of a building is becoming increasingly important. There is also an increasing amount of interest in countries such as the Netherlands in partial deconstruction of concrete structures and in the use of 'demountable buildings' to reduce the amount of concrete waste produced.

The idea of leasing concrete framed buildings has also been discussed, with the frames being deconstructed at the end of their required use and reassembled at a different location for a different customer. However, further work would be needed to develop strategies for assessing the quality of the concrete elements in addition to the financial aspects involved (e.g. maintenance guarantees, insurance etc.).

Standards and specifications

There are no current national or international standards relating to the specific deconstruction and re-use of concrete structures. However, guidance has been published on the demolition of concrete structures by several trade organisations. Significant guidance also exists on the reuse of crushed concrete as aggregate in new concrete, including BRE Digest 433[7], The DETR (Department of Environment Transport and Regions) Quality control for the production of recycled aggregates and more recently the DETR Protocol for the use of reclaimed product in precast concrete.

Health and safety

Existing health and safety legislation mostly covers the demolition of concrete structures. Some of the international standards mention concrete specifically. Special care has to be taken with pre- and post-tensioned beams and slabs. Health and safety on construction sites is increasingly becoming a political as well as legal and economic issue, with the Deputy Prime Minister John Prescott recently devoting a large proportion of his key note speech at the Labour Party conference to attack the construction industry on their poor safety record.

Building and Planning control

There is no mention of deconstruction in building or planning controls but minimum *de factor* standards are laid down for the reuse of aggregates in concrete.

Deconstruction tools and techniques

Most commercial concrete buildings are cast in-situ concrete frames and therefore need to be destructively demolished. The concrete components cannot therefore be reused in their original form. Concrete frames incorporating pre-cast concrete beams, columns, stairs and hollowcore floor slabs are simpler to deconstruct if the joints are simply supported. However, these joints are frequently cast in place, usually with concrete or mortar that is stronger than the actual concrete elements. One barrier is that no standard jointing system exists and the joints are not designed with deconstruction in mind, although new and innovative jointing methods are being developed and would hopefully include deconstructable jointing systems.

Pre-cast flooring systems are frequently used and are perhaps the simplest of concrete components to deconstruct and reuse. However, they are sometimes covered with a 50 mm cast-in-place concrete layer to provide a monolithic slab, meaning destructive demolition is then required. Pre-cast beams are often pre- or post-tensioned and can be very hazardous to demolish requiring special care.

High-pressure water-jetting is frequently used to cut concrete in repair situations and it leaves both the reinforcing steel and the surrounding concrete clean and reusable. Thermal lances and other heating methods could be more widely used in the future as the technique develops as they can cut through reinforced concrete whilst leaving the majority of the concrete element intact.

Material tests to verify durability / specification

The main problem with reinforced concrete as a reusable construction material is that it naturally deteriorates with time due to carbonation, although techniques (such as coatings) can be used to extend this finite life span. No specific standard tests have been developed for the assessment of reclaimed concrete components that are to be reused in their original form. However, many standard tests exist to assess the strength, quality and durability of reinforced concrete which could be used together to provide an assessment of the condition and the potential life span of a concrete element.

A potential problem is that many of these tests require a sample of the concrete to be taken (e.g. a core) and the total cost of the range of tests required may negate any financial benefits of reusing the element. Also, many of the problems encountered with reinforced concrete are not immediately apparent and are ‘hidden’ within the element e.g. reinforcement corrosion. Full-scale load testing is possible although it is likely to be prohibitively expensive. However, an approximate (and therefore cheaper) assessment could be made of the quality and strength of the element and the element used in a lower-grade application (with a higher factor of safety). There are also non-destructive testing methods that can be used to determine in-place strength of concrete elements.

General

The industry's perception and reticence are perhaps the main barriers to the reclamation and reuse of concrete components, unlike the steel industry where steel components are sometimes salvaged and reused. It is also more difficult to assess the quality of a concrete element (whether reinforced or not) compared with a steel element as defects are not immediately apparent without detailed (and expensive) examination and/or testing. Designers are also very wary of specifying reclaimed concrete components in new structures due to safety (and the resulting legal) reasons and no guidance or standards exist to aid them in this task.

The cost savings are also minimal (at the moment) for the reclamation and reuse of concrete components compared with new construction, and until relevant fiscal measures are imposed it is likely to remain this way. On the other hand, the concrete industry is increasingly moving towards the use of more standardised components in order to increase productivity and reduce costs and this will in turn increase the potential for deconstruction and the reuse of concrete components in the future.

One growth area however does exist for the reuse of concrete components in their original form. This is concrete block paving which is being increasingly used in private and commercial driveways and car parks and in the pedestrianisation of town centres. These can be quickly and cheaply dismantled and reused when required.

4.4 Timber

Although timber is a natural renewable resource and as such can have a very low environmental impact, a greater amount of recycling and reuse will obviously benefit the overall environmental audit for building components. Timber product manufacturers already adopt sustainable practices for use and processing of the raw material with any waste being consumed through space heating. This has been driven mainly by sustainable timber certification schemes such as the Forest Stewardship Council (FSC) and customer pressure. The C&D industries have not been influenced by the same economic and customer pressures, and as such have not responded to current national and European initiatives for the reduction of waste. There is however current reuse of high value items such as large section beams and timber flooring, although a potential to greatly increase the amount of timber suitable for reuse in construction still remains.

Standards and specifications

Structural timber for use in construction, be it new or reclaimed, must be strength graded to either BS 4978 for softwoods, or BS 5756 for hardwoods. Machine grading of timber may also be adopted which conforms to BS EN 519. If the timber has been graded then a stamp should provide information on the strength class, species group and origin. This information can be used to ensure that the timber meets an architect's specification. Engineered wood products such as glulam and some decorative large section beams are not marked with grading stamps even though the lamina or overall beam will have been graded in the past. For the structural reuse of these materials either a paper trail proving the beams origin and strength will be required or the species will need to be determined for allocating a minimum grade stress provided in BS 5268. Non-structural timber may also be reused in non-structural applications but is not subject to the same stringent rules governing the fitness for purpose. In this case, durability and appearance may be established from the timber species.

Health and Safety

The deconstruction of timber structures is generally covered by the CDM Regulations for ensuring the safe working practices of operatives. Nailed connections used frequently in timber construction offer potential for accidents. Safety clothing such as steel mid-sole boots and protective gloves for handling help to reduce such risks. There is no particular H&S risk that should bar the increased reuse of timber from the deconstruction of buildings.

Building and Planning Control

Some Planning Authorities may be sceptical about the reuse of construction materials on a large or ‘innovative’ scale based on the building industry preference for established products and techniques. This healthy but sometimes restrictive approach should favour increased reuse of materials in the future providing the long-term performance of materials is proven.

Deconstruction Tools and Techniques

Many timber components that are reclaimed from existing structures contain nails and screws that must be removed or made safe for handling before reuse or recycling. This is done by hand which can be time consuming and generally only proves to be economically viable for high value items such as large section beams. Many lower value components such as small section joists and studs will need to be free of nails and screws if they are to be recycled by chipping for the production of boards products. Since nailed and screwed connections should be made into virgin wood to attain the codified values for shear and pullout, either larger diameter nails or reduced capacities should be adopted for the reuse structural. Either option would require research to establish basic rules for reuse performance. An economic way around this problem has been adopted by the Scandinavians. Their approach is to specify ‘connector free zones’ within the timber cross section. This enables any areas containing nails or screws in the reclaimed timber to be easily removed with a rip saw, thus providing defect free timber that may be reused or recycled.

Material Test to Verify Performance

In principle the strength of reclaimed timber can be verified from stress grading. Although the type of defects that may be experienced in reclaimed timber may not be covered by the codes, an experienced visual grader should be capable of determining a suitable strength class for damaged structural timber. Alternatively, component tests could provide data for the reuse of wall panels, trussed rafters, composite beams and studs. These tests only require a few repetitions and may be used to provide generic rules for reuse of timber components.

5. UK CASE STUDY – 2, MARSHAM STREET

The redevelopment of the former Department of the Environment (DoE) HQ offices at No.2 Marsham Street will include the demolition and removal of the current structures. A BRE pre demolition audit made the following recommendations.

The demolition of the former DoE is expected to generate over 250,000 tonnes of concrete alone, and a range of other valuable resources including steel, glass, aluminium and numerous fixtures and fittings.

Possibilities include:

- To recycle 97% by volume and 99% by weight of the former Department of the Environment building at No.2 Marsham Street
- To maximise recovery of materials and products from demolition
- To maximise the use of demolition materials in construction of the Home Office and other high profile projects
- To demonstrate cost-savings

This process could be assisted by use of the following tools and services:

SMARTWaste

SMARTWaste (Site Methodology to Audit, Reduce and Target Waste) has been developed by BRE to provide a robust and accurate mechanism by which C&D wastes arising during the project life-cycle can be benchmarked and categorised by source, type, amount, cause and cost. This data is a springboard to identifying and prioritising actions to reduce waste arisings (producer responsibility), re-use at source (proximity principle), and maximise recovery to extend materials' life-cycle. The benefits of the tool are to identify the potential true cost savings of projects, and to maximise the reduction, reuse, recycling and recovery of materials over landfill. Current development of the tool will incorporate key performance indicators of material waste arisings from data collected across the industry.

Materials Information Exchange (www.bre.co.uk/waste)

One of the key barriers to the increased use of C&D wastes is the absence of information on the availability, quantity and type of waste. It is this problem which the DETR Materials Information Exchange (MIE) seeks to address, by matching the suppliers of waste with potential users. The MIE provides a free internet site where the user can advertise materials available by geographical location, search for materials wanted, identify where upcoming demolitions are, and access links to other relevant organisations and resources including a searchable database of C&D research.

Speculative recycling targets include.

100% In-situ and precast concrete including mullions, columns, beams, stairs, panels, stilts, slabs and walls
100% Reinforcing bar
100% Assorted furniture
100% Non-asbestos insulation

100%	Bomb-shield net curtains
100%	Bricks and blocks
100%	Steel frames
100%	Fire fighting equipment
100%	Window frames
95%	Assorted metals including aluminium, copper, and cast iron
80%	Internal timbers
80%	Glass from the windows
80%	Boilers, radiators and associated piping
75%	Sanitary ware
50%	Timber panelling
50%	Door and window furniture
50%	Internal electrical fixtures and fittings
30%	Control equipment

Previous UK demonstration projects have managed commendable recycling rates:

IBM's office at Hursley	=	95% by volume
BRE's Environment Building	=	96% by volume
Therefore Marsham Street target	=	97% by volume/99% by weight

The use of recycled aggregates (RCAs) in high-grade applications such as structural concrete is feasible with the introduction of BRE Digest 433 and the BRE/DETR Quality Control Scheme for RCAs. The use of these RCAs should be encouraged in high-grade applications rather than low-grade applications such as sub-base fill. Using RCAs from the demolition of Marsham Street would reduce the need for volume and cost of primary aggregates (South East England has few quarries), reduce vehicle movements to and from site, extend the life cycle of reclaimed materials, and offer employment opportunities for the local population.

There is potential to use a nearby site as a staging ground for the crushing, grading and testing of RCAs before using the material for in-situ concrete, pre-fabricated components or other high grade applications. There is also opportunity to establish a temporary plank casting yard for prefabricating components of the new structure, and temporary mixing yard for preparing in-situ concrete. These temporary measures would reduce the need to import materials and components with associated environmental impacts, reduce the distance of vehicle movements, and create employment opportunities for the local population.

Conclusion

The demolition process is yet to take place and at this point BRE are not certain of any involvement in a project to maximise materials recovery from these structures. In any event, the concrete panels that make up the four towers will need to be taken apart carefully due to the built up nature of the area. Whether these recommendations are taken up or not, it will be interesting to see what the effect of deconstructing the buildings will have on recovery rates.

6. FUTURE OF THE INDUSTRY

Demolition in the UK is likely to follow the lead being taken by the Dutch. Landfill is becoming gradually more expensive and landfill taxes are continue to increase. There will continue to be a requirement for inert material in landfill engineering and restoration, but this is likely to tail off as landfill space diminishes. This will encourage selective demolition and so increase reuse and recycling rates. The innovations within the industry are likely to come from new mechanical plant, which are rapidly becoming more sophisticated and specialised. The next growth market for plant is likely to be in the area of the soft strip, which is still labour intensive.

A key component to the future of the industry will be free exchange of ideas and technologies, adoption of other proven industrial techniques, best practice guides, demonstration projects and sound auditing/benchmarking of processes. Central to this will be dissemination of gathered information.

Some information sources are listed below:

The International Council for Research and Innovation in Building Construction (CIB) http://www.cibworld.nl/ Task Group 39 on Deconstruction (1999-2003) held its annual meeting in the UK last year. The report of this meeting and relevant information relating to CIB TG39 can be found at http://www.cce.ufl.edu/affiliation/cib/. Similarly, the Conference Proceedings of 'Deconstruction – Closing the Loop' held at BRE in May 2000 are also available from BRE gettlesonv@bre.co.uk.

The UK EA waste handbook is an excellent source of information and contacts of the waste management industry http://www.recycle.mcmail.com/content.htm. Similarly, the Symonds report http://europa.eu.int/comm/environment/waste/report.htm is of some relevance to the industry although tends to focus on 'core' C&D waste. The Salvo website is very popular for reclaimed components www.salvo.co.uk. Finally, the DETR Materials Information Exchange www.bre.co.uk/waste is of great value for exchanging components and materials at no cost.

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BUILDING DECONSTRUCTION ASSESSMENT TOOL

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SUMMARY

Deconstruction is a means to "un-construct" buildings for the maximum recovery of reusable and recyclable building materials in a cost-effective manner. It also provides feedback for the design of new structures to extend their longevity through cost-effective maintenance, repair and adaptation. In order to assist the Owner or Contractor in determining the economic feasibility of deconstruction under real-world conditions, a model for use as a computer-based estimating tool is described in this paper. The tool may also be used for modeling macro-economic variables to assist in determining labor and disposal costs, and salvageable and recyclable materials values, that are necessary to make deconstruction cost-effective on a regional basis. The tool that is currently in development is for use with wood-framed one- and two-story structures and will provide a template for other kinds of structures, including masonry residential structures, multi-family residential structures and eventually commercial structures, as more real-cost data is available for these building types.

KEY WORDS: deconstruction; selective dismantling; C&D waste management; building salvage; pollution prevention; assessment tools.

1. INTRODUCTION

The purpose of the Building Deconstruction Assessment Tool is to facilitate the estimation of costs, revenue potential, and project management of the deconstruction of a wood-framed residential building. Deconstruction is the process of dismantling a structure, generally in the reverse order of its construction, in order to recover the maximum amount of reusable and recyclable materials. The priority is on reusable materials. It also results in the separation of hazardous materials for proper disposal. Deconstruction can be characterized as: dependence upon hand labor; and an environmentally preferential management of the whole building removal and its materials, as opposed to "cherry-picking," which is a form of selective demolition, removing only the highest value materials prior to conventional mechanical demolition, materials reduction, and disposal. As an economic matter, many demolitions include varying degrees of recycling of metals and concrete, with minimal to no reuse. As the proper data is developed on the deconstruction and materials types of larger commercial structures, the tool will be adaptable to any building type. The basis for the default data in the model and the structure of the model came from the "Building Deconstruction: Reuse and Recycling of Building Materials" project, funded by the Florida Department of Environment Protection (FDEP). This project consisted of the deconstruction and analysis of six (6) residential structures in Alachua County, Florida, USA during 1999-2000. Deconstruction was determined to be economically feasible using a price competitive with demolition, and accounting for revenues from resale of recovered materials. The average "gross" deconstruction cost was 21% higher than the average demolition cost for six (6) houses. The "net" cost of deconstruction (including salvage revenue) was 37% lower than demolition and 10% lower using "wholesale" prices. The salvage revenue is based on retail used materials prices, which are 50% to 25% of equivalent new materials. Wholesale used building materials prices are in turn one-half of the retail used material prices. The savings in disposal costs between gross deconstruction and demolition were on average 41% per house of the six (6) houses that were used to develop the model baseline data. Total net savings between no salvage (demolition) and salvage (deconstruction) were on average 53%. Therefore, there is a greater opportunity to realize further savings through increasing disposal costs (100-41 = 59%), than in increasing salvage value (100-53 = 47%) (1).

Attempting to increase salvage value per building will have a point of diminishing returns as the more valuable items are stripped more efficiently than harder-to-access materials, and labor costs remain constant even for removing low-value materials (2). Based on this analysis, the local disposal fees in a geographic area are an important "indicator" of deconstruction potential and will encourage more "whole house" deconstruction in lieu of selective "cherry-picking" of materials. One of the principal markets for salvaged building materials is as "low-end" building material. If the savings from deconstruction are principally from avoided disposal fees, rather than attempting to receive a high profit from the salvaged materials, then materials resale prices can remain affordable to do-it-yourselfers. More lower costs salvage materials would also increase the total amount of materials being diverted from landfills rather than a small fraction of high-value architectural salvage.

The six (6) buildings used to develop baseline data were randomly selected based on availability during the research grant period and resulted in a range of costs and revenues per square foot. The deconstruction assessment process that is presented in the model was developed from experience and was augmented by research on other projects and interviews with a long-time deconstruction specialist, Pete Hendricks from Chapel Hill, North Carolina, U.S.A. Another computer-based estimating tool for "selective dismantling," has been developed at the French-German Institute for Environmental Policy - University of Karlsruhe, Karlsruhe, Germany (3).

The net income of a deconstruction from the Contractor's perspective is the expression:

(Price Paid by Owner + Salvage Value) - (Pre-Deconstruction + Deconstruction + Processing + (Transportation + Disposal)) = Net Income

The net income for demolition is:

(Price Paid By Owner) - (Pre-Demolition + Demolition + (Transportation + Disposal)) = Net Income

Figure 1 - Economic Equations for Demolition and Deconstruction

Key factors in the feasibility of deconstruction are allowable time to deconstruct, labor costs, local disposal costs, and the salvage value of the building materials. Additional costs include the pre-deconstruction costs of environmental and worker health protection measures, estimating, and salvage materials marketing costs. Transportation costs can also be a significant cost to remove and redistribute materials. Optimization of building deconstruction will depend in the future on the commercial transfer of salvaged materials as close to the building site as possible. The Building Deconstruction Assessment Tool will aid most directly in reducing estimating and materials marketing costs, by reducing the time to estimate costs and the salvage materials inventory. The materials inventory can be used in conjunction with digital photographs and the Internet to market salvageable materials before the deconstruction takes place. Scheduling the sale of materials before the deconstruction is to take place, for “just in time” and “point-of-deconstruction” resale, will aid in the avoidance of additional storage and transportation between the point of removal and the point of reuse. Salvage materials values can be extremely variable, from dimensional lumber (which may be much less valuable than new lumber) to architectural salvage (which may have a unique value).

1.1 Defining Deconstruction

Deconstruction has arisen as a formal means to increase the salvaging and reuse of building materials from renovation and demolition activities. Deconstruction is also sometimes called salvaging, but for the sake of clarity is not "cherry-picking," or salvaging which imply a removal of only the highest value materials, leaving the remainder for disposal. Deconstruction is a comprehensive whole-building strategy for dismantling a structure to recover the maximum amount of reusable materials. Deconstruction is a reverse form of construction, i.e. the careful disassembly of a structure. Reuse is the use of materials without altering their form except for minimal processing, i.e. removing fasteners, cleaning, and reshaping. Reuse has the potential for an infinite number of cycles, whereas recycling is the reconstitution of a material into a new form, requiring greater amounts of energy and material inputs to reconstitute the material as a new product. The potential for reuse from new construction is also present from over-estimates, mis-orders, and damaged materials. The waste produced from leftover modular building materials such as bricks and concrete masonry units (CMU), and form work, can be diverted by reusing these products in future construction projects. Historic preservation and adaptive reuse is the ultimate in reuse of land, infrastructure and the building materials in situ. Reuse can occur on-site in renovation construction, by the removal and rehabilitation of individual building components, and their return to the building.

2. STATEMENT OF THE PROBLEM

The US Environmental Protection Agency (EPA) has estimated that there was 136 million tons of construction and demolition (C&D) waste produced in the Unites States in 1996. C&D waste includes new construction, renovation and demolition. Renovation waste is from improvement and repairs of existing structures. Ninety-two percent (92%) of the total C&D waste, or 125 million tons, was from renovation and demolition, leaving only eight percent (8%) by weight resulting from new construction (4). While estimates vary, total C&D waste is generally estimated to comprise between 25 and 35% of all solid waste produced in the US. Wood has been estimated to compose 25-40% of the C&D waste stream in the United States (5). An unfortunate lack of systems to recover and reuse lumber from demolished buildings contributes to waste and environmental degradation. The preponderance of waste from renovation and demolition indicates a critical need to address this portion of the total C&D waste stream. For example, there is an increasing concern over the potential for groundwater contamination from leaching of chromated copper arsenate (CCA) treated wood, formaldehyde-based resins used in engineered lumber, paints and other treatments, from demolition waste. In Florida, as the building stock ages, it can be expected that the total volume of landfilled renovation and demolition waste will continue to grow over time unless viable alternatives to landfill disposal are investigated and implemented. There are many influencing factors in deconstruction work, such as: labor scheduling and costs; tipping fees at C&D waste landfills; hazardous characteristics of demolition waste; markets; materials grading systems; time and economic constraints; contractual agreements; and public policies. These conditions affect the potential for deconstruction to develop into a long-term, economically viable sector of the construction and demolition industries for waste reduction, resource conservation, and job creation.

3. BENEFITS OF DECONSTRUCTION

Successful strategies for implementing deconstruction can reduce the energy use, land consumption, groundwater degradation, deforestation and greenhouse gas production associated with wasted wood resources. An analysis of demolition permits in the Metro Portland region showed that 944,000 board feet (BF) of lumber could be removed from the solid waste stream in that area each year through salvage operations (6). The specific benefits of deconstruction over conventional demolition will vary from project to project. Broadly, however, experience has shown that there are clear environmental, economic and social advantages to recovering and reusing building materials. One project found that 1,000 BF of salvaged lumber could replace up to 10,000 BF of standing timber (7). Deconstruction projects have demonstrated that the intensive but relatively low-skilled hand deconstruction work can provide new jobs that require minimal training and can act as a practical entrance point for labor force development throughout the construction trades.

3.1 Environmental Benefits

The most common and most reusable material that results from deconstruction is lumber. Salvaging lumber for direct reuse has multiple environmental damage avoidance components. These include the preservation of forest resources for storm water and soil erosion control, maintenance of bio-diversity and CO2 sequestration, and reduced energy use and pollution from the harvesting, milling, and transportation of new lumber. It is estimated that the construction of a 1,100 square feet (SF) wood-framed home will require approximately 10,000 BF of structural lumber. The reuse of approximately10, 000 BF of lumber will result in avoiding the clear-cut harvesting of approximately 55 trees on about 2 acres of forest (8). The deconstruction of a typical 1,500 SF wood-framed structure in Florida, greater than 50 years old, can result in the reclamation of approximately 4,500 BF of structural lumber (2). Therefore, the deconstruction of 2+ older residential structures will produce approximately enough lumber to build a new home. Two acres of managed forest will produce a net storage of about 8 tons of CO_2 per year. The Massachusetts Public Utilities Commission has placed a value of \$20/ton on CO_2 stored in new forests. When these factors are accounted for, deconstruction and reuse has multiple environmental cost-effective, i.e. environmental cost-avoidance, benefits.

3.2 Toxicity

At the present time, some demolition, especially at the scale of residential buildings, does not fully account for all hazardous materials, and in fact is not required to do so depending upon the type of asbestos, for example. Deconstruction, by its reliance on hand labor, requires a stringent environmental health and safety protocol to manage any hazardous materials and to protect worker health. This greater attention to hazardous materials management insures that future impacts such as disposal of materials with lead-based paint (LBP) in an improper manner is reduced. Because deconstruction is a gentler version of demolition, the release of hazardous materials from breaking, crushing, abrading and grinding commonly associated with mechanical demolition is eliminated. The ability to reuse materials back into new construction in such as way as to eliminate human health risks from LBP exposure for example, extends the life of the valuable reused material and keeps the LBP out of the natural environment for as long as possible.

3.3 Economic Benefits

Whole-house deconstruction is more labor intensive than mechanical demolition. It is also a different set of skills more closely aligned with the labor skills required to build new wood-framed homes. Skills such as job safety, tool-use, teamwork and basic carpentry can be assimilated in a more forgiving environment at the scale and pace of a residential deconstruction project. These skills can translate into greater efficiency of deconstruction or eventual transition into the labor-short construction market that currently exists in many parts of the US. Research by the CCE and others has shown that resource recovery and reuse/recycling in general and deconstruction for reuse specifically, can require up to 10 times more labor hours than resource collection and disposal. These labor hours are at a lower pay rate, for example a laborer versus a heavy machine operator, but more jobs are created. The very premise of deconstruction is to create reusable materials by protecting the condition of the materials in the removal stage. With an understanding of, and alignment of, market users and uses to the deconstruction process, the materials are handled in a manner most appropriately, and therefore most effectively, for achieving their highest value in reuse.

With a current population of 16 million and an estimated population of 20 million within the next 20 years, several things will result in the State of Florida, for example. The extent of new developable land will decrease, landfills will become filled and the ability to open new ones will be reduced, both because of land area and siting constraints, and by the increasing financial burden of closing and monitoring closed sites, combined with costs for new start-ups. As the infrastructure of Florida ages and need for housing increase, there will a greater trend towards renovation and redevelopment in existing urban areas. The combination of increased availability of salvageable materials, increased disposal costs, increased need for housing, and eventually, increased costs of gasoline and concerns for global warming via fossil fuel use, and its impacts on Florida, will all drive a greater need to reuse materials of all kinds. These conditions will increase the economic and environmental viability of deconstruction and reuse as a “sustainable” business enterprise. A current impediment to deconstruction is the requirement for Davis-Bacon Act requirements for wages on Federal projects, and the possibility of labor union wages in certain geographic areas. Because labor is such as large portion of the costs of the deconstruction, areas of high labor costs, or increases in labor costs will have a significant impact on the economic viability of deconstruction.

4. BASIS FOR MODEL

Because deconstruction generally requires more time than conventional demolition, this constraint must be overcome to implement deconstruction on a widespread basis. Methods to overcome this constraint include decreasing preparation time, and increasing information on labor time and scheduling requirements. Other constraints are the uncertainty of resale markets and the ability to pre-sell materials, in order to make a deconstruction project economically feasible. A deconstruction estimating tool that can be used to quickly estimate both potential salvage value and deconstruction costs will assist in making a rapid assessment and facilitate “pre-sales” of materials before the deconstruction process begins. The purpose of the Building Deconstruction Assessment Tool is to facilitate the decision-making process for determining the most cost-effective and environmentally sound method(s) for removing residential wood-framed buildings from existing sites. This does not pre-dispose that preservation, adaptive use, and rehabilitation in-situ are less cost-effective or environmentally sound from the perspective of the building itself. Many building removals occur for factors unrelated to the building itself, be it cultural, functional, or land-use considerations. This model does pre-dispose that the decision to remove the structure has been made and that a tool for realizing the least environmental damage while balancing real world costs constraints within the current US regulatory climate will be beneficial. The full range of options for removing a structure includes: moving the structure; deconstruction or selective dismantling; and total demolition. The tool may also be used for modeling hypothetical economic variables that in turn may assist in the development of policies to make deconstruction a more cost-effective alternative to demolition on a regional basis.

The traditional demolition of buildings is based upon mechanical labor and disposal in landfills. There may be some selective salvaging of the highest value materials that are readily accessible with hand tools and without diminishing the structural integrity of the building. Items such as antique plumbing and electrical fixtures, finish work, and flooring are examples of these items. As landfill space becomes more restrictive due to economic and environmental constraints, the economic value of salvage and reuse will go up as an alternative to the costs of demolition and disposal.

The creation of a model for planning for deconstruction, salvage and recycling will facilitate the deconstruction process which is currently a largely unknown quantity for most Owners, Developers, Building and Demolition Contractors. There are many attributes of deconstruction which are similar to demolition, including environmental assessments and removal of hazardous materials, and the permitting process. The principal difference is in the time that is required to dismantle a structure for the purposes of salvage and recycling. Before significant capital investments are made, it is helpful to have the ability to assess the economic viability of deconstruction of the structure, or in the case of multiple opportunities, the relative feasibility of different types of structures at one location such as a military base or housing project.

A model which can include variable local conditions such as disposal costs and estimated value of materials, some as generic building materials and other as architectural salvage with relative values, will both encourage the choice of deconstruction and enable the planning of a cost-effective deconstruction for both Owner and Contractor, since the ultimate goal is the complete removal of the structure, and not a highest benefit/cost “cherry-picking” operation.

4.1 Scope and Limits

The deconstruction assessment tool described in this paper is principally developed for wood-framed structures. In order to keep the model as user-friendly as possible it was decided to use laypersons terms, a non-technical format, and provide options for the user to use either default data or input their own data. The model does not use the Construction Specification Institute (CSI) numbering system. It was felt that the CSI Format did not provide an intuitive framework for the deconstruction process, partially because it was created for the construction of buildings, and also because the level of complexity of a one or two-story wood-framed building would not necessarily require the detail of CSI formatting. It was a critical concern in the development of the model that it be practical and has levels of complexity in order to minimize the time needed to develop preliminary estimates. It is envisioned that for the sake of uniformity, the model could be arranged in CSI Format in the future and for use with commercial and large-scale projects.

4.2 Methodology and Data

The data for determining default values was collected by time, task, location/component in building, material type and quantity. The model is set up to be a series of scenarios such that the user can select options for deconstruction or demolition for either the entire building or the major components of the building. Basic defaults include costs for abatement of asbestos, labor productivity rates for the components of the building, quantity calculations based on building square footage and construction types. Input data includes the size of the building, the type of construction, local tipping fees and wages, and other more specific information on the value of the material as reused, recycling, or re-manufacturing feedstock.

5. DESCRIPTION OF MODEL

The deconstruction tool has three major sections. The first section is a preliminary evaluation of the candidate building for its suitability for deconstruction. The second section of the model is the calculation of regulatory costs such as permitting and environmental assessments. An additional variable cost is the degree of asbestos containing materials (ACM) abatement may be

required, and the degree of additional effort (cost) that may be required to address the presence of lead-based paint. The third section of the model is to make a detailed assessment of the building-by-building component categories. Based upon this estimate, several other factors can be developed such as salvage percentage and salvage value. From the inventory of the total structure and the subtraction of the estimated quantity of salvage, the estimated amount of disposal material can be calculated. From the quantity of materials by their use in the building, a labor cost for removal can be calculated. All of these estimates can be a default value and the model user can make changes for each category. See Figure 2 for an outline of the model.
The preliminary assessment section of the model uses a series of "indicators" of the building's deconstructability, which are compiled into a score.

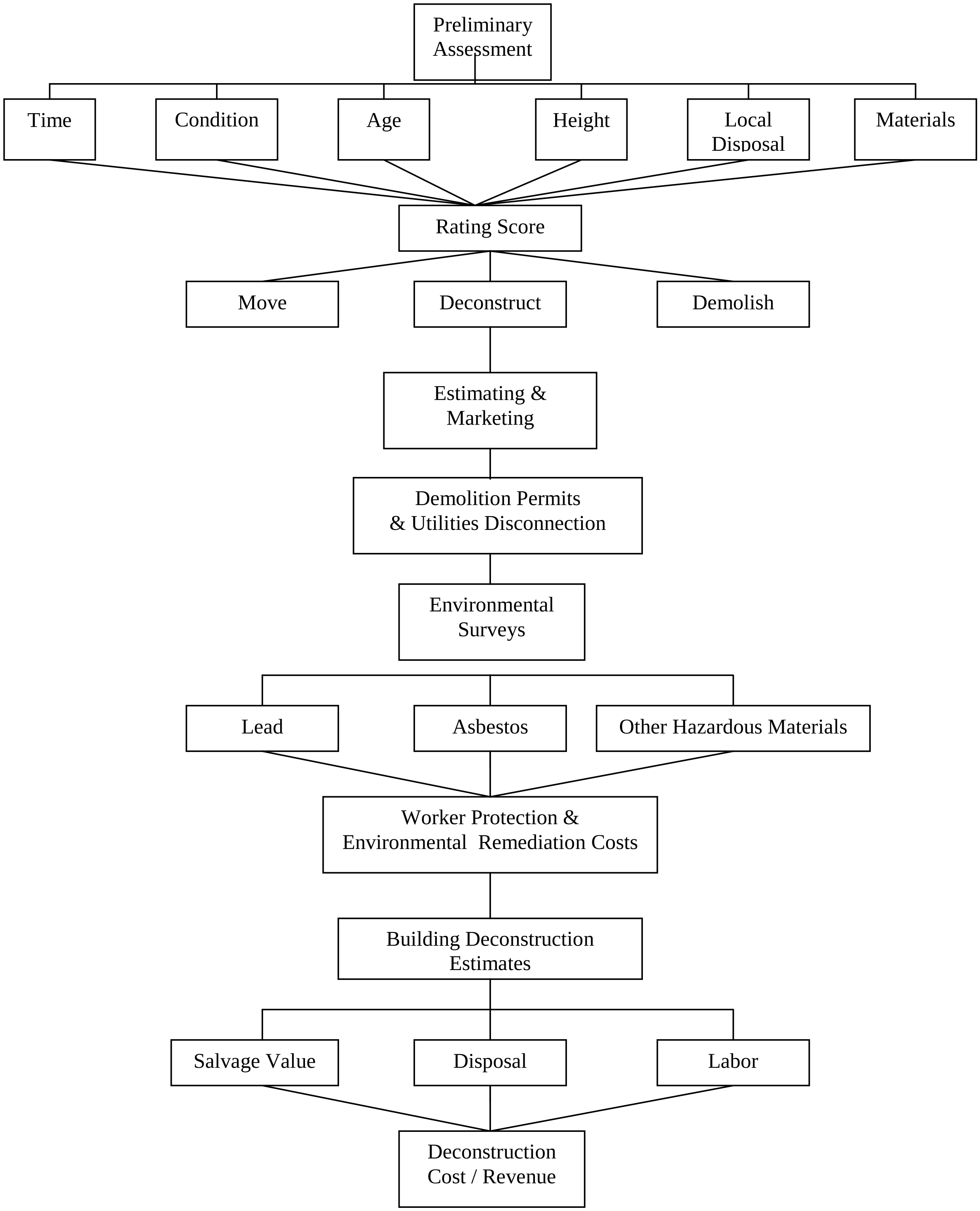

Figure 2 - Diagram of Building Deconstruction Assessment Tool Structure

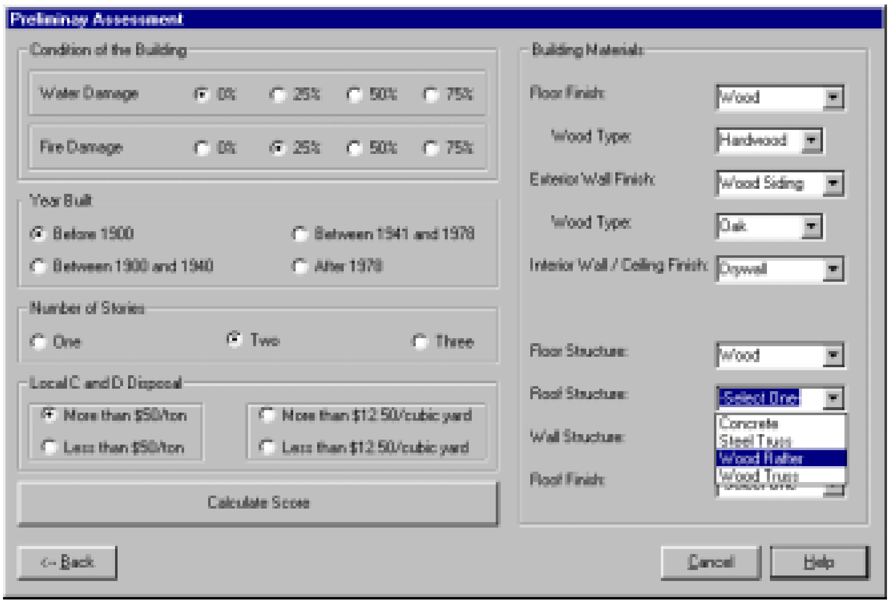

Figure 3 - Preliminary Assessment Using "Indicators" of Feasibility

"Bonus points" are given for a high local disposal fee and use of high-grade species lumber in the structure. Upon determining that the building has a high "score" for deconstruction, (Figure 4) the user will proceed to a more detailed quantification of the materials of the building and assign a base dollar value on the salvageable materials. The building is broken into major and minor components, under these categories, the specific elements and materials types are listed for the user to increase the specificity of the assessment as they wish. The main element categories are:

1. Appliances and Equipment
2. Hardware and Fixtures
3. Interior Casework
4. Windows and Doors
5. Interior Walls and Ceilings
6. Roof
7. Exterior Walls
8. Floor
9. Foundation
10. Site

The building is assessed in two ways, by the entire building and each subsequent addition to the original building, and then by room. For some elements such as exterior siding, the perimeter exterior walls can be estimated as a component of the entire building. For other elements such as interior finishes, each room is assigned up to 6 wall surfaces, 2 ceiling surfaces, and 2 floor surfaces, and the finishes are estimated by room.

Building major categories and sub-categories include for example:

5. Interior Walls

5.1 Wall structure

5.1.1 2 x4 wood 24” on center
5.1.2 8” Concrete masonry unit

5.2 Wall Finish
5.2.1 Gypsum drywall

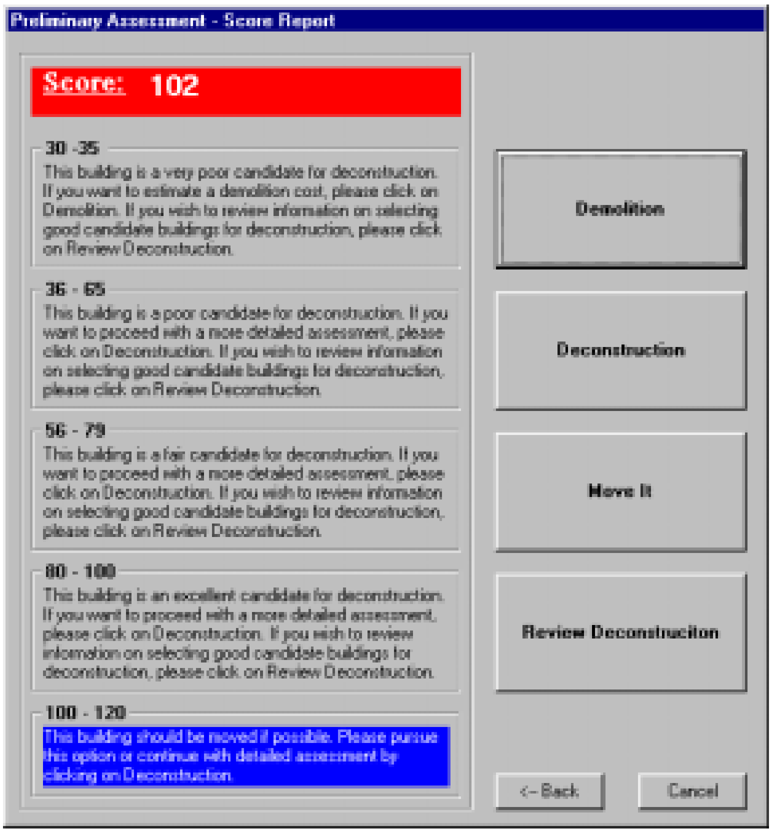

Figure 4 – Preliminary Scoring Summary

Upon completion of the materials quantity estimates, a salvage rate or percentage is assigned to each sub-element category to estimate the actual salvage value that can be expected. The salvage factor will first be based on the general level of deterioration as determined in the preliminary assessment, and then further refined with each element of the building. For example, in the case of a window or door, the user will assign a salvage factor of 1, since the window only has value as an entire unit. For a wood framed wall, the salvage factor will be a percentage of the wood in the wall.

Upon completion of the detailed materials and salvage estimate, the user will then be able to estimate costs based on unit deconstruction rates, estimated labor costs rates, estimated disposal and disposal costs, permitting and environmental assessment costs, and asbestos abatement costs if required. The final report will combine these estimates and variables to determine the cost-effectiveness of a deconstruction. In addition, the user will have the flexibility to change any variable such as salvage values for components, labor rates and disposal fees, in order to understand macro-level costs and specific materials revenues which most effect the economic viability of deconstruction in a particular geographic locale. This modeling capability will have use for determining local policy options to increase the feasibility of deconstruction within a particular municipality.

6. CONCLUSIONS

The Building Deconstruction Assessment Tool is meant to reduce the time and cost of estimating costs and salvage revenues that may occur from a wood-framed residential building deconstruction. As a consequence, it can be used to model macro-economic variables such as labor costs and disposal costs, in order to determine the threshold values for making deconstruction economically viable within a region or municipality. There are many other variables which can affect the cost of this environmentally preferable means of building removal, particularly hazardous materials remediation and worker safety protection. The costs of processing and transfer to condition and point of reuse can include additional processing, which will bring a marginal increase in value, marketing costs, transportation and storage costs. At the current time, many locations in the United States have disposal and labor costs that inhibit the economic viability of deconstruction and materials reuse. Lead-base painted materials are commonly found in residential structures in the United States built before 1978 and the reuse of these materials poses a human health hazard, liability concern, and additional cost for remediation. By qualifying and quantifying the materials, types and quantities and costs associated with bringing them to the market place, it is expected that a computer-based estimating tools can reduce the risk and uncertainty associated with building deconstruction.

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GRADING AND MECHANICAL PROPERTIES OF SALVAGED LUMBER

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SUMMARY

Decommissioned buildings were until recently demolished and deposed of in landfills. Current trends now focus on material recovery and reuse as a means to conserve our natural resources and promote environmentally acceptable disposal methods. This research was conducted to evaluate the mechanical properties of lumber salvaged from two residential buildings in Gainesville, Florida. Compared to virgin lumber tested under the same conditions, the salvaged lumber was on average 50% denser and of such strength as to merit its structural use in building construction. Results of visual grading of lumber salvaged from six residential buildings deconstructed in Gainesville Florida are also presented. It was found that more than half of the pieces (57%) had damages due to use and deconstruction, which resulted in reduction of their grades. Trimming the ends of damaged pieces resulted in grade increase, but of course reduced the length of the salvaged lumber pieces.

Keywords: Salvaged lumber, Lumber grading, Tests of salvaged lumber, Deconstruction, Damage, Reuse options, Demolition, Waste reduction.

1. INTRODUCTION

Wood has for many centuries remained the principal building material for the construction industry. It is a natural material and the only renewable structural construction material in general/mainstream use today. Lumber production in the United States increased by 34 percent from 81.7 million cubic meters in 1970 to 109.5 million cubic meters in 1994. Unchecked harvesting and fire ravaged US forests for many years until the first decades of the twentieth century when replanting of trees was undertaken on a massive scale to avoid depletion of the forests. The first European settlers in the US found half of the land covered by forests. Today forest area has been reduced to 32 percent with the volume of wood in the forests 25 percent more than what it was in 1952. Harvesting of wood has increased by 40 percent since 1952 [1].

Harvesting of wood and production of lumber have many adverse effects on the environment and, without effective measures to ensure sustainable practices, the negative impacts will increase and be carried well into the future. Environmental concerns during the harvesting of wood include loss of biodiversity, loss of plant and animal habitat, species extinction, soil erosion, deforestation, and increase in atmospheric carbon dioxide with a resultant increase in global warming. Conduction of water from the soil to the atmosphere is eliminated when trees are cut, leading to a decrease in atmospheric moisture. During the production of lumber, fuels used in mills pollute the air through the emission of toxic gases such as carbon monoxide (CO) and sulphur dioxide (SO_2). Environmental and health hazards associated with these gases include global warming, decreased visibility, smog, eye irritation, and lung damage.

Every year in the United States, an average of 146 million cubic meters (60 billion board feet) of virgin lumber is consumed. One source of readily useable lumber and timber for building construction, which remains untapped, is the 7.3 billion cubic meters (3 trillion board feet) of lumber and timber sawn in the United States since the turn of the twentieth century and still residing in structures [2]. When these structures reach the end of their service lives, become obsolete, or change use, the lumber and timber can be salvaged and reused, utilizing little energy. The traditional practice of demolition used to dispose of these buildings results in a mixture of different materials only fit for use as mulch, compost, disposal in landfill, or incineration with energy recovery (except chromated copper arsenate pressure treated wood or painted wood, which are harmful to the environment). Demolition methods allow for little or no possibility of salvaging the lumber in these buildings. With the increasing cost of landfilling, the construction industry is turning its focus to deconstruction or building dismantlement to salvage reusable components of the deconstructed buildings and to minimize the waste sent to landfills.

Deconstruction is the careful dismantling of buildings with the goal of maximizing the reuse potential of the components and minimizing the amount of materials that are landfilled. Typically, deconstruction involves more handwork and careful use of heavy equipment, and takes more time than demolition. The choice between demolition and deconstruction depends on many factors such as:

- the potential amount and quality of materials which can be salvaged;
- the market for the salvaged material;
- the hazardous materials present and their impact on the process and products;
- the available time for building removal.

For deconstruction to be profitable, the recovered materials must be sold in order to help defray the additional costs of more manual and time consuming effort associated with salvaging materials. The average home has much to offer: toilets, sinks, bathtubs, cabinets, windows, doors, flooring, plumbing parts, and on average, 13,000 board feet of lumber.

The Unites States Department of Agriculture (USDA) Forest Service estimates that if 2% of existing wood buildings are decommissioned each year and 25% of the lumber reclaimed, this will supply one-quarter of the overall lumber requirement for 50 years. Salvaged lumber has distinct advantages such as being tight grained, dense, and generally free of knots. After being in service, the salvaged lumber is generally dry and dimensionally stable. However, there is little known about its quality and the effect of damage and age on its grade yield and engineering properties. Damage to the salvaged lumber can be categorized under three sources [10]:

- damage during the construction process, which includes nailholes, boltholes and notches;
- damage during usage of the building which includes decay, warping and termite attack; and
- damage during the deconstruction process to salvage the lumber from the building. Deconstruction damage includes edge splitting, edge damage and gouges.

Salvaged lumber has traditionally been successful in markets for larger timbers (150mm x 150mm cross-section and larger), dense grain material, and heart redwood. Typical products include flooring, architectural millwork, furniture, and small manufactured items. The predominant use for salvaged dimension lumber is for agricultural needs and storage with very limited structural use as primary or secondary members in wood-framed construction (e.g., studs, joists, rafters, siding, flooring).

The major barrier to the structural reuse of salvaged dimensional lumber is the lack of up-to-date grading or certification stamps. While some salvaged lumber may still have grade stamps on them, these have been invalidated by the alterations to the lumber and are not acceptable to building inspectors. Some owners have had salvaged lumber regraded for use in their buildings. The grades are assigned based on existing grading rules for virgin lumber. Existing grading rules do not adequately consider or sometimes inappropriately disallow defects commonly found in salvaged lumber. This is because these listing rules do not specifically address the use of salvaged lumber or the characteristics that distinguish it from virgin lumber. As a result, much of the salvaged lumber is downgraded or disallowed and is not used for its highest value use

To expand the use of salvaged lumber, new grading standards (grading rules, engineering properties, and a grade stamp) needs to be developed. Existing grading rules do not reflect the characteristics of salvaged lumber, its particular advantages, and its common defects. The new grading criteria must be based upon technical research that substantiates the effect of age, exposure, and defects on the structural integrity and performance of salvaged lumber. Experimental testing needs to be performed on different grades of salvaged lumber to determine their engineering properties. Based on the results of these tests, a new industry grade stamp must be approved for salvaged lumber.

Developing acceptable grading standards and a stamp for salvaged wood will allow salvaged lumber to move readily through distribution channels to the market, and then through the permitting and construction process. It will significantly expand the value, volume, and types of salvaged wood that flow through the system. Recovery operators will have much clearer product specifications and will be able to optimize their operations. Overall unit costs will come down, while acceptance of this product by designers, builders, inspectors, and consumers will rise. This paper reports the results of structural tests and visual grading of salvaged lumber from several residential buildings in an effort to provide some data on this issue.

2. LITERATURE REVIEW

2.1 The Riverdale Case Study (1997)

The Riverdale case study involved the deconstruction of a 2,000 square foot, 4-unit two-story residential building in an urban area of Baltimore County, Maryland. The building was part of a 27-acre, 600-unit housing development owned by the Maryland State Office of the U.S. Department of Housing and Urban Development, Baltimore, Maryland. The Urban and Economic Development Division of the U.S. Environmental Protection Agency, Washington D.C., sponsored the project. The owner's interest to use this new approach to building removal was to address how and under what conditions building disassembly and salvage can be cost competitive with standard demolition.
The Riverdale case study had the following objectives:

- to identify major issues hindering deconstruction as an alternative to conventional demolition;
- to determine labor requirements for specific deconstruction activities;
- to evaluate jobsite practices such as sequencing, layout of operations, tools and workers required, and flow of materials;
- to determine market opportunities and values of salvaged building materials; and
- to disseminate information on building disassembly and salvage.

The project sponsors for the pilot deconstruction project considered the Riverdale buildings ideal for the study for the following reasons:

- the buildings were built prior to 1950 and did not have engineered wood products such as plywood and OSB, which characterize Post World War II construction technology, and composite materials that are difficult to disassemble or have low salvage value;
- the buildings had exterior structural brick and interior stick-frame with wood. An important project objective was to provide information on salvage value and labor requirements for brick and light-framed structures;
- the buildings were structurally sound. Riverdale units were generally tight so that rot and decay of building materials were essentially non-existent.

Lumber salvaged from buildings

The building was deconstructed in the reverse order of construction with the last components installed removed first. The structural lumber was salvaged from the floors, interior walls, second level ceiling joists and the roof. After removal from the building, the lumber was denailed, stacked and banded outdoors in piles according to their sizes and length. The sizes of the lumber salvaged were 2x4, 2x8 and 2x10. No grade stamps were found on the salvaged lumber and no effort was made to regrade them before they were sold. Approximately, 10 to 20% of the framing lumber exhibited warping, splitting or severe crowning. This resulted in a reduction of its value to 10-25% that of their new component. Table 1 shows the amounts of lumber sold and corresponding sale prices.

Table 1. Results of Riverdale Site Sale

Salvaged Material	% of total amount of item sold	Sale price as a % of estimated retail
Framing – 2x4 higher quality	75%	45%-50%
Framing – 2x4 lower quality	15%	~25%
Framing – 2x8 higher quality	50%	45%-50%
Framing – 2x8 lower quality	40%	~25%

The Riverdale study identified several factors, which affected the salvage value and marketability of the materials including:

- type of materials; the framing lumber, which had wide application and used in large quantities was relatively easier to sell than finished materials such as windows and hardwood flooring which have specific dimensions, specific uses and require more targeted marketing;
- time of year; depending on the geographic location, construction firms and do-it-yourselfers are more interested in building materials in the summer or spring than in the winter;
- condition of the local economy; demand for building materials is stronger when construction and remodeling activity is strong;
- retail building material prices; the value of used material is strictly a function of new building material prices. Salvaged lumber becomes an attractive alternative to conventional lumber when lumber prices go up.

Conclusion and Recommendations
In an organized site sale, customers had more interest in buying the lumber and bricks, which required little marketing or established location/reputation for used building materials. For more finished or use-specific materials such as flooring, doors, and windows, many customers commented that they needed time to check on dimensions, retail prices, and their spouses' reaction before purchasing. These use-specific materials required a larger investment of marketing time and resources when compared to the commodity materials–lumber and brick. Framing lumber sold for approximately 50 percent of new retail and windows sold for as little as 10 percent of new retail. The absence of grade certification for the lumber did not make it appealing to customers who wanted to use the lumber for structural applications. A recommendation from this study for the industry was the need to develop a grading methodology for salvaged lumber. The building industry needs guidance on how to advise buyers on structural reuse of salvaged lumber.

2.2 Fort Ord Deconstruction Project (1994)
In 1994, the Fort Ord U.S. Army Military Reservation in Marina, California, was closed. This closure left more than 28,000 acres and more than 7,000 buildings to be programmed for civilian use. Additionally 1,200 buildings had to be demolished because they did not meet current code standards or contained hazardous materials. The Fort Ord Reuse Authority (FORA) developed the deconstruction project to test the feasibility of a sound environmental approach to building disposal other than landfilling. Four buildings

were deconstructed for this study. The buildings were representative of 740 other buildings requiring disposal on site and are as follows:

- building 21 was a 2,300 square feet single-story wood-frame building that had served as a dental clinic. Approximately 150 buildings of this type exist at Fort Ord;
- building 1807 was an 11,500 square feet single-story wood-frame building that had been used as a classroom and similar to 180 other buildings on site;
- building 2143 was a 4,720 square feet single-story wood-frame barracks built in 1940. It is estimated that 385 buildings of this type still remain;
- building 2252 was a 22,000 square feet single-story wood-frame shop. Only one bay (about 10%) of this building was deconstructed because the other bays were similar. This building was representative of approximately 25 buildings at Fort Ord.

Sale of Salvaged Lumber

All the lumber salvaged from the buildings was preserved. Structural lumber represented about 40% of the total lumber in the buildings and this percentage was consistent regardless of the building type. Some of the lumber was sold in the local market and most of the buyers were predominantly college graduates. The major reasons for purchasing the lumber were superior quality of material, perceived value of material for the cost of the material, environmental concerns and past success with buying other salvaged material. The predominant use for the lumber was agricultural needs and storage. The bulk of the consumers considered a price of 50% of virgin lumber as reasonable for the salvaged lumber. Bids from contractors were typically low because the materials needed to be trimmed to standard sizes and the volume was not large to merit their interest. Moreover the contractors could not use the salvaged lumber as structural components due to the absence of grade certification.

Lumber Grading

Falk et al (1999) reported on a further study developed to determine the effect of damage on the grade yield of the deconstructed lumber. This was considered as a first step to determine reuse options for reclaimed lumber. This study involved the USDA Forest Service, Forest Products Laboratory (FPL) and the West Coast Lumber Inspection Bureau (WCLIB). The objectives of the study were as follows:

- assess the quality of lumber salvaged from the deconstructed buildings through a grade yield evaluation;
- investigate the effects of damage on grade yield.

Only the structural lumber salvaged from the buildings was used in this study. The dimensions of lumber used for the study were 2x4, 2x6, 2x8 and 2x10. 1009 pieces of the lumber were selected for grading. About 30% of the pieces came from building 2252, 38% from building 2143, 21% from building 21 and 11% from building 1807. Douglas Fir was the predominant species, making up 92% of the pieces. The rest of the pieces were 6% Hem-Fir and 2% Sugar Pine. Table 2 shows the selected lumber pieces.

Table 2. Lumber size distribution for the FORA study

Size	Pieces	Percent
2x4	184	18.2
2x6	275	27.3
2x8	504	50.0
2x10	46	4.5
Total	1009	100

The lumber was visually assessed for structural grade according to Standard No. 17, Grading Rules for West Coast Lumber. The lumber was graded twice in this study, in the first grading, the full length of each piece was graded and the type of defect or grade determining characteristic such as knots, slope-of-grain, wane, warp or damage was noted. For those pieces where damage was the grade-determining defect, the grader also made an estimate of grade assuming the damage was not present. This provided an estimate of average grade reduction as a result of damage. For each piece with a localized grade-determining defect, an evaluation was made to determine if trimming would increase grade or if multiple pieces of higher grade could be cut from the graded piece. Damage in the lumber was classified as follows:

- type 1 damage included those resulting from the original construction process such as nail holes, bolt holes, saw cuts and notches;
- type 2 damage resulted from the use of the building such as drying defects, decay and termite damage; and
- type 3 damage was attributed to the deconstruction process and included edge damage, end damage, end splitting and gouges.

Ninety-six pieces of 2x4 were shorter than 7 feet and these were not graded since they were considered to be of limited market value, a total of 910 pieces that were graded.

Results of Visual Grading

Table 3 shows the results of the visual grading performed for the 910 lumber pieces. The 2x4 lumber was graded as light framing. The light framing designation applies to lumber 2 to 4 inches thick and 2 to 4 inches wide. Four grades exist under this designation (listed from highest to lowest): construction, standard, utility, and economy. The 2x6, 2x8, and 2x10 lumber was graded as Structural Joists and Planks. The structural joists and planks designation applies to lumber 2 to 4 inches thick, 5 inches and wider.

Table 3. Grade distribution, accounting for damage, 910 pieces

Grade	All sizes (%)
Structural Joists and Planks	
Select Structural	5.5
No. 1	17.9
No. 2	46.8
No. 3	13.0
Economy (< No. 3)	7.9
Light Framing	
Construction	2.4
Standard	6.5
Utility	0.7
Economy	0.1
Total	100.0

Four grades exist under this designation (listed from highest to lowest quality): select structural, no.1, no. 2 and no. 3. A second grading of the pieces was performed to determine the grade yield with end trimming. For each piece with a localized grading defect, an evaluation was made to determine if trimming the lumber would increase grade or if multiple pieces of higher grade could be cut from the graded piece. For the second grading, the 2x4 was graded as structural light framing with the same grade designation as the structural joists and planks. The grading for the other dimensions remained the same.

Conclusions andRrecommendations

The prevailing grade-determining defects among the pieces were knots (40.9%) and damage (37.9%). The most frequent forms of damage to the lumber were nail holes (36.2%) and edge damage (26.7%) out of a total of 345 damaged pieces. Trimming of the lumber resulted in having a single piece of a higher grade or two smaller pieces of higher grade. In some instances trimming the piece would yield a piece of length less that 7 feet and this was not considered to have a market value and was not done. Although only about 1 percent of the members yielded two lengths of lumber after trimming, and average increase of one grade was possible with a required length reduction of between 1.0 and 3.0 feet. Trimming increased the grade of about 18 percent of the lumber. To minimize lumber degrade from deconstruction damage the study recommends careful removal of the floor underlayment and roof sheathing as well as careful removal of end nails from joists and rafters rather than prying them free.

2.3 The Twin Cities Army Ammunition Plant (1996)

The Twin Cities Army Ammunition Plant (TCAAP) case study (Lantz and Falk, 1996), involved the deconstruction of two large timber-framed buildings. This case study was undertaken to determine if salvaging the lumber for reuse is a feasible alternative to conventional demolition and landfilling. With the end of the cold war in the 1990's, many military facilities were classified as excess to the Nation's defense requirements. As a result, the U.S. Army made a decision to discontinue military manufacturing operations at their Twin Cities Army Ammunitions Plant in Arden Hills, Minnesota. Two of their large World War II era wood-framed industrial buildings (501 and 503) that had been used for manufacture of small-caliber ammunition manufacturing was deconstructed and used for this study. Although opinions about timber recycling were more often quantitative than qualitative, the following conclusions were reached prior to beginning the deconstruction process:

- at the very least, the very large timbers were recyclable. It was unclear if there would be a ready market for the smaller timbers or the dimension lumber. Quotations on purchase price ranged from $50 to $200 per thousand board feet (MBF) for the standing timber members;
- the absence of a grade stamp for the salvaged lumber will limit its use for structural purposes.

Some characteristics of both buildings are presented in Table 4. The range of nominal timber dimensions included 2x8 to 2x14; 3x10 to 3x14; 4x10; 6x12 to 6x18; 8x14 to 8x18; and 10x18.

Table 4. Characteristics of dismantled at TCAAP buildings

Characteristics	**Building 501**	**Building 503**
Floor space	377,000 ft^2	548,000 ft^2
Timber	1,250MBF	1,875MBF
Wood recycled	750MBF	1,500MBF

Visual Grading

To address some of these pertinent concerns, an experimental test program was developed to evaluate the grades and engineering properties of the lumber salvage form the TCAAP project (Falk et al. 1999). The West Coast Lumber Inspection Bureau graded 500 pieces of 2x10x18 foot dimensioned lumber from building 503 according to Standard Rule 17 for both visual stress grade and the visual requirements of mechanically graded lumber. The pieces graded had originally served as either floor joists or roof rafters. Unlike freshly sawn lumber, which is graded based on the natural defects, the grader took into consideration defects to the pieces due to service use or the deconstruction process. In grading the recycled lumber, it was assumed that 1 foot would be trimmed from both ends of each piece therefore any defect in the 1-foot end zones was ignored. In addition, dynamic Modulus of Elasticity (E) was measured for each piece using a portable DynaMOE transverse vibration device. As can be seen from Table 5, twenty-eight percent of the 500 pieces were graded as select structural. Fifty-six percent were graded as No. 2 or better and forty-four percent were graded as No. 3 and lower. The major reason for downgrading the lumber was the presence of knots, end splits and primarily gouges that occurred during the deconstruction process. Observations made from the visual grading showed that about half the grade-limiting splits were due to prying the lumber loose from the structure. It was estimated that as much as thirty percent of the lumber was downgraded as a result of the deconstruction process.

Table 5. Results of visual grades of 500 2x10 pieces.

Grade	Number in grade	Percentage
Select Structural	142	28.4
No. 1	42	8.4
No. 2	97	19.4
No. 3	78	15.6
Economy (<No. 3)	141	28.2

Mechanical Grading

100 pieces of 2x10 joists that met the visual requirements of Machine Stress Rated (MSR) lumber were randomly selected from the 500 pieces for Mechanical grading. Mechanical grading combines visual assessment of growth features with direct measurement of modulus of elasticity to sort individual pieces into grades. The mechanical testing was performed at the USDA Forest Service, Forest Products Laboratory. The 100 pieces were conditioned at 65 percent relative humidity and 74 degree Fahrenheit for 2 months prior to testing. Species identification found 53 of the species to be Douglas Fir, 25 pieces of Hem Fir and 22 pieces to be of the Southern Pine species. The joists were tested in a third-point bending test loaded on edge over a 16-foot span that resulted in a span-to-depth ratio of approximately 21. A constant rate of loading with a mid-span deflection of 0.2 inch per minute resulted in failure in about 10 minutes.

Conclusions andRrecommendations

The stiffness of the recycled lumber measured by its Modulus of Elasticity (E), was found to be approximately equal to that of current production. The lumber will be suitable for applications where resistance to excessive deflections are of primary importance. Bending strength of the lumber salvaged from building 503 measured by its Modulus of Rigidity (G) was somewhat less than the bending strength of lumber produced today. Because of the historical use of the facility to produce magazines for explosives, it is possible that some form of chemical contamination may have weakened the members in the building although a chemical analysis could not prove or disprove this possibility. This fact coupled with a small sample size, prevents the general adoption of the findings of this study. Reuse options for the lumber investigated in this study included ceiling or floor joists. More finished or use-specific materials such as flooring, doors, and windows required a larger investment of marketing time and resources.

3. MECHANICAL TESTS OF SALVAGED LUMBER

3.1 Materials

The salvaged lumber tested was obtained from two decommissioned buildings in Gainesville, Florida. Building 1 was a 2150 ft^2, single story timber-framed residential building constructed in 1915, and located at 2930 NW 6th Street. Building 2 was a 2200 ft^2, two-story timber framed residential building constructed in 1900 and located at 14 NE 4th Street. Prior to the deconstruction, a certified contractor abated the siding and interior tiles, which were contaminated by asbestos.

Figure 1 shows the site layout during the deconstruction of building 1 [see Reference 3 for deconstruction details]. A determination was made as to what to do with the specific material when removed from the structure. Based on the material type and condition, items were immediately reused, processed further, or disposed of. For this reason it was important to have the storage space, processing space, and dumpsters close to the structure. The denailing and processing station was an area designated for such activities as denailing and sawing off damaged ends of salvaged lumber to get pieces of better quality and higher value. In some instances, the pieces were discarded when sawing them would have resulted in unmarketable pieces of length shorter than 2.1m (7 feet).

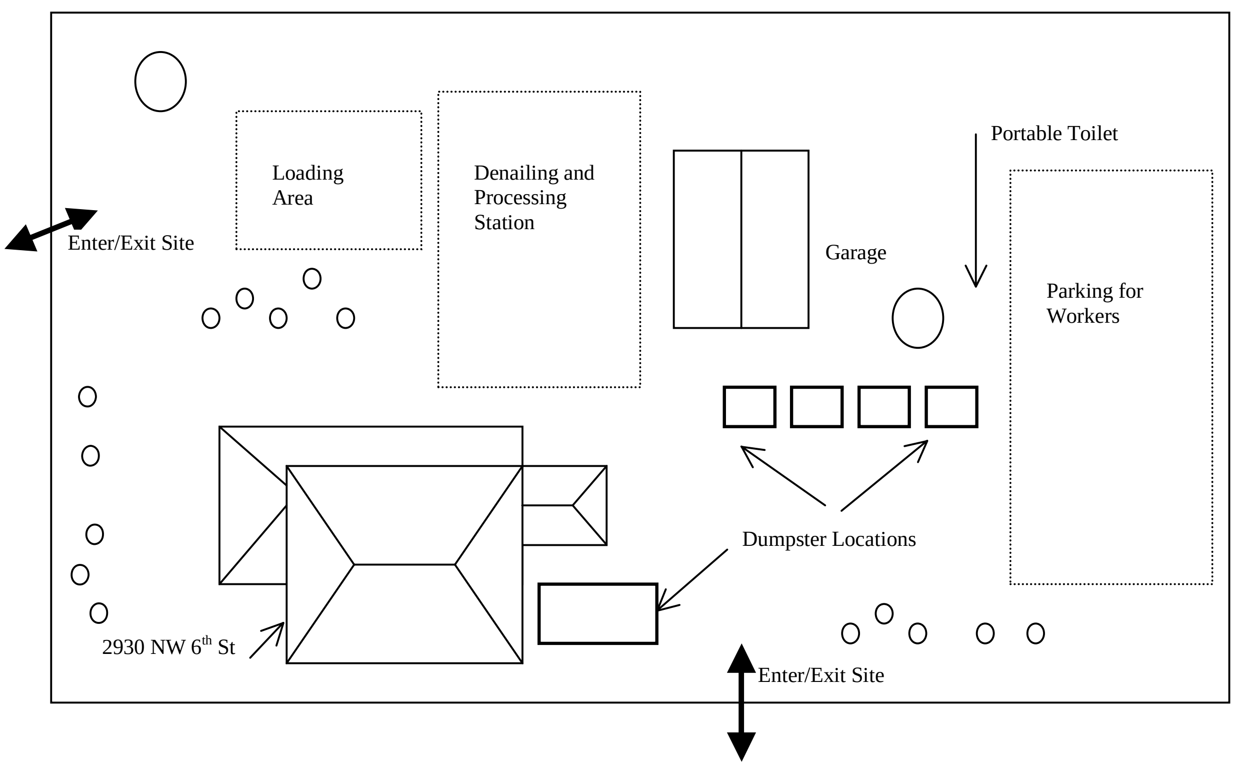

Figure 1. Diagram of deconstruction field organization [Ref. 3]

The main damage requiring the pieces to be discarded was decay caused by water infiltration. The deconstruction process proceeded in the reverse of construction with the last items in place removed first. The roof, wall and floor covering were carefully removed to get to the structural lumber and timbers. The structural lumber components of this building consisted of the studs, floor joists, ceiling joists, and rafters. The lumber species was Southern Pine. There were no grade stamps on the lumber salvaged. The nominal cross-sectional dimensions of the salvaged lumber were 50 x 100mm (2x4), 50 x 150mm (2x6), 50 x 200mm (2x8), and 100 x 150mm (4x6). The stud wall skeleton after removal of the roof and wall coverings is shown in Figure 2. Figure 3 shows salvaged dimensioned lumber deconstructed from building 1.

Figure 2. Stud wall skeleton, building 1.

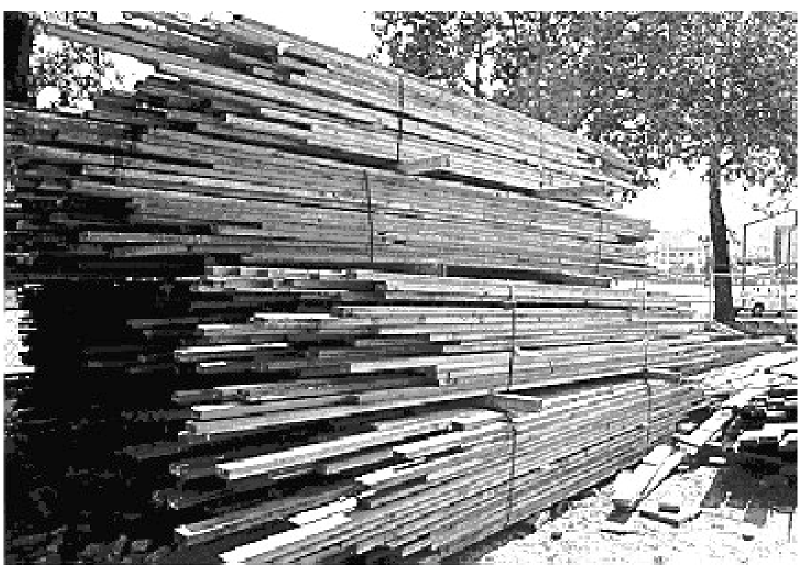

Figure 3. Dimension lumber from building 1

3.2 Testing

Test samples were classified according to usage in the old building as studs or rafters. Selected lumber from both buildings was cut into lengths of 600 mm (24 inches) for the tests [4]. Eight pieces from each category were randomly selected for testing. Virgin lumber of Southern Pine species was also tested to provide a basis to compare the results obtained from the salvaged lumber tests. To determine the cross-sectional dimensions of the samples, measurements were taken at three points, both ends and in the middle. Table 6 shows the dimensions and number of samples for each group.

Table 6. Salvaged and virgin lumber test samples

Lumber source	**Description**	**Average Dimensions (mm)**			**Number**
		Width	Depth	Length	
Building 1	Studs	45	92	600	8
	Rafters	56	110	600	8
Building 2	Studs	45	93	600	8
	Rafters	54	102	600	8
Virgin lumber	Studs	38	89	600	8

Bending Test

Three point bending tests were performed based on procedures outlined in the American Society for Testing and Materials (ASTM) D 198 [5]. The distance between supports was 47 mm. A Tinius Olsen machine of 270 kN capacity was used for the test. The load was applied through a load cell and a computer recorded the load and deflection throughout the tests. The load was applied through a 12-mm thick steel plate to avoid exceeding the sample's bearing stress. Two 12-mm thick steel plates supported the samples. Failure of the test samples during the bending tests occurred at the middle and was characterized by either a tension failure at the bottom or compression failure at the top of the specimen. Figure 4 shows tension failure in a test specimen. Some of the samples in building 2 had low bending resistance values due to the presence of 6-mm diameter holes in the bottom center of the specimen.

One-inch thick pieces were cut off from each piece after testing and used to determine the sample's moisture content and specific gravity. The moisture content was determined in accordance with procedures of ASTM D 4442 [6] method A and the specific gravity was determined in accordance with procedures of ASTM D 2395 [7] method A.

Results of the bending test are shown in Table 7. A 5% exclusion limit for the average bending values was obtained for each set of specimens. These values were then divided by an adjustment factor of 2.1 to give the allowable bending stress. The factor includes an adjustment for normal duration of load and a factor of safety. The calculated allowable bending stresses for the salvaged lumber were between 71% and 125% of the value obtained for the virgin lumber tested. The highest allowable bending stresses were obtained from the studs salvaged from building 2.

The allowable modulus of elasticity for each category was calculated by dividing the calculated mean value by an adjustment factor of 0.94, which accounts for normal duration of load and a factor of safety. The allowable modulus of elasticity was least in the virgin lumber. The values for the modulus of elasticity obtained for the salvaged lumber tested ranged from 109% to 137% that of the virgin lumber tested.

The virgin lumber was the least dense of the samples tested. The average density of the salvaged lumber was 50% higher than the density of the virgin lumber.

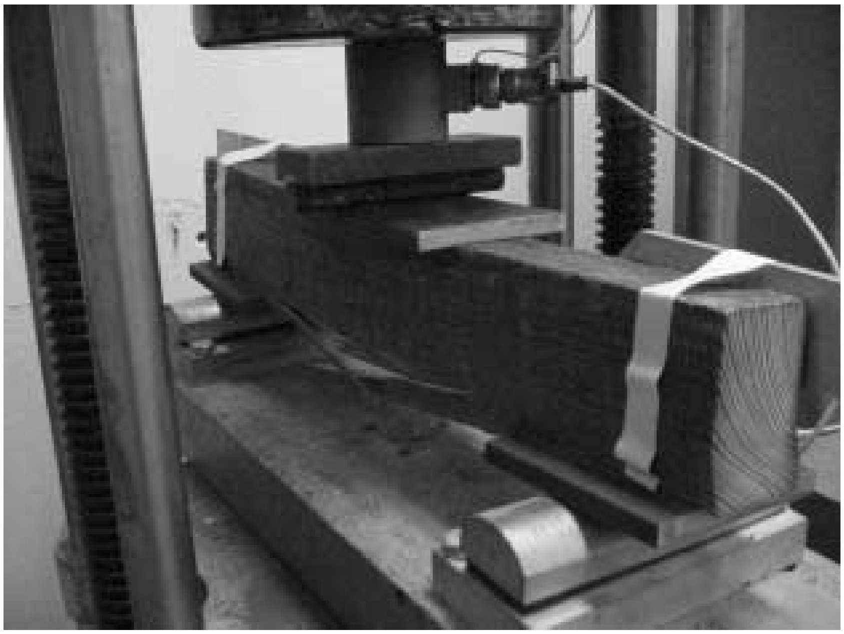

Figure 4. Tension failure at the bottom of a sample during the test

Table 7. Summary of bending tests

Member	**Building**	**Bending stress, F_b (MPa)**			**Modulus of elasticity, E (GPa)**		**Density (Kg/m^3)**	**MC (%)**
		Avg	Sta. Dev. (σ)	F_b (Allow)	Avg	E (Allow)	Avg	Avg
Studs	1	68.7	15.3	20.8	9.24	9.79	673	9.8
	2	64.4	2.7	28.8	8.07	8.55	683	10.6
	Virgin	71.1	11.9	24.6	7.03	7.45	418	10.1
Rafters	1	57.5	14.0	16.4	7.65	8.14	632	10.5
	2	87.7	4.2	38.5	9.58	10.20	612	9.1

Shear tests

Shear block specimens were made according to procedures of ASTM 143 [8]. The thickness for the salvaged studs was on the average 45 mm (1.75 inches), for the virgin lumber 38 mm (1.5 inches), and for specimens from the salvaged rafters was 50 mm (2 inches). In all tests, the shear plane was 50 by 50 mm (2 by 2 inches) (see Table 8).

Table 8: Shear test samples

Building	Description	Specimen dimension (mm)			Area of shear plane (mm)		No of samples
		Length	Thickness	Height	Length	Width	
1	Studs	50	45	64	50	50	8
	Rafters	50	50	64	50	50	8
2	Studs	50	45	64	50	50	8
	Rafters	50	50	64	50	50	8
Virgin	Studs	50	38	64	50	50	8

The shear specimens were tested with a 270 kN (60,000 lbs) Tinius Olsen universal testing machine. The specimens were placed in the shear tool with the crossbar adjusted so that the ends rested evenly on the support over the contact area as shown in Figure 5. The maximum load at failure was recorded. The portion of the specimen sheared off during testing was used to determine the moisture content. The moisture content was determined according to procedures of ASTM D 4442 method A.

A 5% exclusion limit for the average shear values was obtained for each set of specimens. These values were then divided by an adjustment factor of 4.1 to obtain the allowable shear stress. The adjustment factor accounts for normal duration of load and a factor of safety. The results of shear tests exhibited in Table 9 showed that the allowable stresses for the samples tested were highest for the new lumber. The allowable shear stresses for the salvaged lumber range in value from 50% to 95% that of the virgin lumber. This lower shear resistance of the salvaged lumber may be due in part to the existence of boltholes and nail holes near the supports.

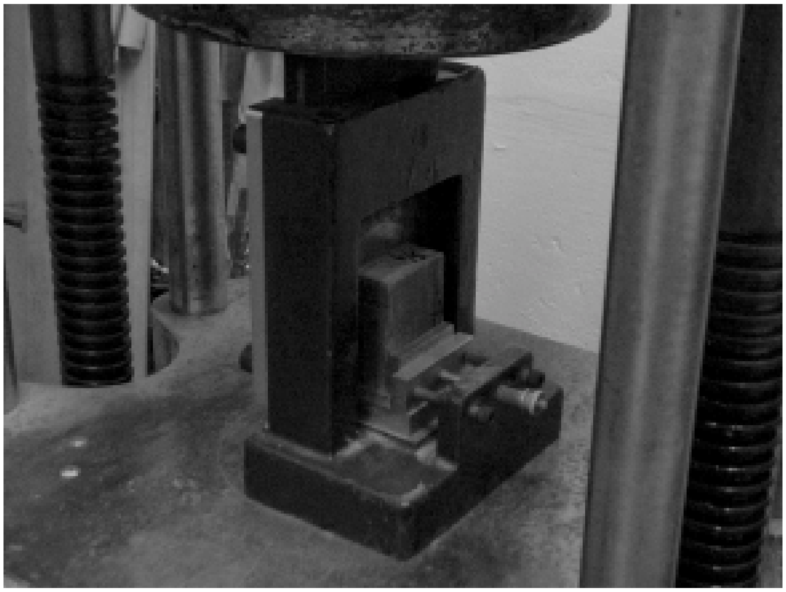

Figure 5. Shear parallel-to-grain Test Assembly

Table 9. Summary of shear test results

	Building	**Shear stress (MPa)**		
		Average	Sta. Dev. (σ)	F_v (allow)
	1	7.29	2.56	0.76
Member	2	8.44	1.53	1.45
	Virgin	7.54	0.79	1.53
	1	7.16	1.37	1.20
	2	7.10	1.54	1.12

4. VISUAL GRADING OF SALVAGED LUMBER

A lumber grade, and the grading rules that stand behind it, are critical elements in the trade of lumber products. The grade assigned to a piece of lumber verifies its quality and adherence to national grading standards criteria and rules. This quality assurance allows for its widespread acceptance by engineers, architects, and building officials at a building site. The Southern Pine Inspection Bureau (SPIB) performed visual grading of lumber salvaged from six timber-framed residential buildings deconstructed in Gainesville, Florida [3]. The grading was in accordance with SPIB, Standard Grading Rules for Southern Pine Lumber [9]. The houses had been in use for the last 50-100 years having been constructed between 1900 -1950. The grading was performed over two grading sessions.

The visual grading of salvaged lumber was undertaken to evaluate the quality of lumber and determine the effects of damage on grade yield. The modeling, analysis, and presentation of the results reported here are after the work of Falk, et. al [10]. As can be seen in Table 10, most of the lumber graded was 50 x 100 mm (2 x 4) making up 40% of the pieces. The rest of the 521 pieces consisted of 36% of 50 x 150 mm (2 x 6), 22% of 50 x 200mm (2 x 8), and 2% of 100 x 150mm (4 x 6). The pieces graded had been used as different structural elements depending on their sizes. The structural uses included floor joists, wall studs, ceiling joists, and roof rafters. The predominant structural use categories of the graded lumber as indicated in Table 11 were floor joists (26 %) and roof rafters (26 %).

Table 10. lumber size distribution

Size	Pieces	Percent	Volume		Percent
			(board feet)	(m^3)	(by volume)
2 x 4	210	40	1622	3.8	31
2 x 6	186	36	2172	5.1	42
2 x 8	117	22	1285	3.0	25
4 x 6	8	2	117	0.3	2
Total	521	100	5196	12.2	100

Table 11. Distribution of prior lumber usage

Prior usage	Pieces	Percent	Volume		Percent
			(board feet)	(m^3)	(by volume)
Floor joists	137	26	2012	4.7	39
Wall studs	64	12	378	0.9	7
Ceiling joists	78	15	1041	2.5	20
Roof rafters	133	26	1406	3.3	27
Unknown	109	21	359	0.8	7
Total	521	100	5196	12.2	100

4.1 Grading Methodology

A certified SPIB Grading Supervisor visually assessed the structural grade for each piece of lumber based on the 1994 Standard Grading Rules for Southern Pine Lumber. The SPIB is one of six rules-writing agencies recognized by the American Lumber Standards Committee. The lumber was graded twice in this study:

1. The full length of each piece was graded according to the aforementioned grading rules and notes were taken as to what type of defect or lumber characteristic determined the grade (e.g., knots, slope-of -grain, wane, warp, damage; see appendix A for definition of lumber defects). The 50 x 100mm (2 x 4 inches) pieces were graded under the SPIB grading rules as “structural light framing”. This designation applies to lumber 50 – 100 mm (2 - 4 inches) thick and 50 – 100 mm (2 - 4 inches) wide. The grades under this designation (listed from highest to lowest quality) are: Dense Select Structural (DSS), Select Structural (SS), No. 1, No. 2 and No. 3. The 50

x 150, 50 x 200 and 100 x 150mm (2 x 6, 2 x 8 and 4 x 6 inches, respectively) were graded under the SPIB rules as "structural joists and planks". The grades under this designation are the same as those listed above for the structural light framing.

2. The second grading considered the effect of end trimming on grade yield [10]. For each piece with a localized grade-determining effect, an evaluation was made to determine if trimming the lumber would increase grade or if multiple pieces of higher grade could be cut from the graded piece. The grade designation was the same as used for the first grading. A grade of No. 4 was assigned to pieces which did not meet the lowest No. 3 grade for structural joists and planks and structural light framing. The No.4 grade is not an official SPIB grade but is used for comparative purposes. Where the length after trimming was shorter than 2.1m (7 feet), trimming was not done since such short pieces were considered to be of limited market value.

4.2 Lumber Grades Accounting for Damage

Overall, 243 pieces, almost half of the total number graded (46.7%) were assigned a No. 4 grade, and 17.4% were graded as Select Structural or Dense Select Structural (Table 12). Thirty percent of the 50 x 100's were graded as No.2 and 24.3% were graded as No. 4. Over half of the 50 x 150 and 50 x 200 sizes (59.1% and 70.1%, respectively) fell into the No. 4 grade. Almost all the 100 x 150 pieces (87.5%) met none of the grade designations.

Table 12. Grade distributions, accounting for damage, 521 pieces

Grade	**All sizes**		**Structural light framing**		**Structural joists and planks**					
			50 x 100 mm (2 X 4in)		**50 x 150 (2 X 6)**		**50 x 200 (2 X 8)**		**100 x 150 (4 X 6)**	
	(No)	(%)	(No)	(%)	(No)	(%)	(No)	(%)	(No)	(%)
DSS	44	8.4	33	15.7	10	5.4	-	-	1	12.5
SS	47	9.0	20	9.5	23	12.4	4	3.4	-	-
No. 1	17	3.3	6	2.9	2	1.1	9	7.7	-	-
No. 2	103	19.8	64	30.5	25	13.4	14	12.0	-	-
No. 3	45	8.6	33	15.7	6	3.2	6	5.1	-	-
No. 4	243	46.7	51	24.3	110	59.1	82	70.1	-	-
No grade	22	4.2	3	1.4	10	5.4	2	1.7	7	87.5
Total	**521**	**100.0**	**210**	**100.0**	**186**	**100.0**	**117**	**100.0**	**8**	**100.0**

Table 13. Grade determining factors (521 pieces)

Reason	Pieces	Percent (%)
Shake	20	3.8
Split	5	1.0
Knots	25	4.7
Damage	296	56.8
Wane	30	5.8
Slope of grain	3	0.5
Warp	6	1.2
Twist / other	29	5.6
Unknown	16	3.1
Meets highest grade	91	17.5
Total	**521**	**100**

Damagewas the grade-determining factor of 296 pieces, more than half of the lumber graded (Table 13). Damage in the pieces was classified as defects from the construction process (nail holes, bolt holes, etc), those occurring during the service life of the structure (decay, insect attack, etc) and those from the deconstruction process (edge splitting, gouges, etc). Damages resulting from the construction process or during the life of the building are pre-existing. However, adopting appropriate process and methods in deconstruction can minimize damage from deconstruction.

4.3 Effect of Trimming on Lumber Grades

Of the 296 damaged pieces, 170 pieces (57.4%) were trimmed to eliminate grade-determining defects and increase grade. The distribution of the pieces selected for trimming is shown in Table 14. 126 damaged pieces were not trimmed since trimming would have resulted in a length shorter than 2.1m (7 feet), which had very low market value. The predominant size trimmed was 50x 150mm (2 x 6), which accounted for 77 pieces (45 %). Fifty one pieces (30%) of 50 x 100 mm (2x4) were trimmed, and 42 pieces (25%) of 50 x 200mm (2 x 8in) were trimmed. Approximately 82% (139) of the pieces trimmed had a previous grade designation of No. 4. As can be seen in Table 15, trimming resulted in a higher grade for the pieces and less than 2% of the trimmed pieces were graded as No. 3 or below. More than half of the trimmed pieces (54.7%) were graded as select structural or better having no grade reducing defects after trimming. The effect of trimming on the grade yield can be seen from Table 16. On average, there was an increase of 3 grade levels in the trimmed pieces and an average reduction in length of 720mm (2.4 feet). The effect of trimming on the grade distribution for all sizes is shown in Table 17. Overall the effect of trimming on the grade is very marked in grade No. 4 designation, which was reduced from 47% before trimming to 20% after grading (Figure 6). The percent of pieces with a grade designation of select structural and better increased from 17% to 36% by trimming. Figure 7 compares the grade distribution for the 50 x 100 mm (2 x 4) before and after trimming. The greatest change in the grade distribution of the 50 x 100 mm (2 x 4) is in the number of grade No. 4 designation, which was reduced from 24% to 10% after trimming.

Table 14. Original distribution of pieces to be trimmed and regraded

Grade		**All sizes**		**50 x100mm (2 X 4)**		**50 x 150 (2 X 6)**		**50 x 200 (2 X 8)**		**100 x 150 (4 X 6)**	
		Total	Trimmed	Total	Trimmed	Total	Trimmed	Total	Trimmed	Total	Trimmed
DSS		44	-	33	-	10	-	-	-	1	-
SS		47	-	20	-	23	-	4	-	-	-
No. 1		17	1	6	1	2	-	9	-	-	-
No. 2		103	13	64	9	25	3	14	1	-	-
No. 3		45	15	33	10	6	4	6	1	-	-
No. 4		243	139	51	31	110	68	82	40	-	-
No grade		22	2	3	-	10	2	2		7	-
	No	**521**	**170**	**210**	**51**	**186**	**77**	**117**	**42**	**8**	**-**
Total	**%**	**100**	**32.6**	**100**	**24.3**	**100**	**41.4**	**100**	**35.9**	**100**	**0**

Table 15. Grade distribution of pieces after trimming (170 pieces)

Grade	**All sizes**		**Structural light framing**		**Structural joists and planks**					
			50 x100mm (2 X 4)		**50 x 150 (2 X 6)**		**50 x 200 (2 X 8)**		**100 x 150 (4 X 6)**	
	Pieces	Percent	Pieces	Percent	Pieces	Percent	Pieces	Percent	Pieces	Percent
DSS	11	6.5	11	21.5	-	-	-	-	-	-
SS	82	48.2	14	27.5	44	57.1	24	57.1	-	-
No. 1	7	4.1	7	13.7	-	-	-	-	-	-
No. 2	67	39.4	19	37.3	30	39.0	18	42.9	-	-
No. 3	3	1.8	-		3	3.9	-	-	-	-
No. 4	-		-		-	-	-	-	-	-
No grade	-		-		-	-	-	-	-	-
Total	**170**	**100.0**	**51**	**100.0**	**77**	**100.0**	**42**	**100.0**	**-**	**-**

Table 16. Effect of trimming defects

Size	**Pieces**	**Percent of total (521 pieces)**	**Avg. grade increase (No. of grades)**	**Avg. length reduction**	
				mm	**Ft**
All sizes	170	32.6	3	720	2.4
2 x 4	51	9.8	3	810	2.7
2 x 6	77	14.8	3	690	2.3
2 x 8	42	8.0	3	630	2.1
4 x 6	-	-	-	-	-

Table 17. Grade distributions trimmed compared with untrimmed (521 pieces)

Grade	**Untrimmed**		**Trimmed**	
	Pieces	Percent	Pieces	Percent
DSS	44	8	55	11
SS	47	9	129	25
No. 1	17	3	23	4
No. 2	103	20	157	30
No. 3	45	9	33	6
No. 4	243	47	104	20
No grade	22	4	20	4
Total	**521**	**100**	**521**	**100**

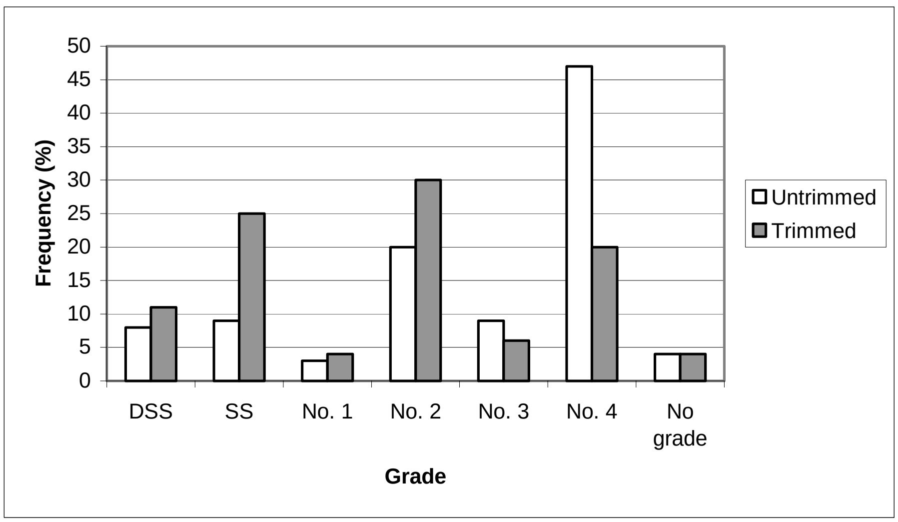

Figure 6. Grade distribution: trimmed compared with untrimmed all sizes.

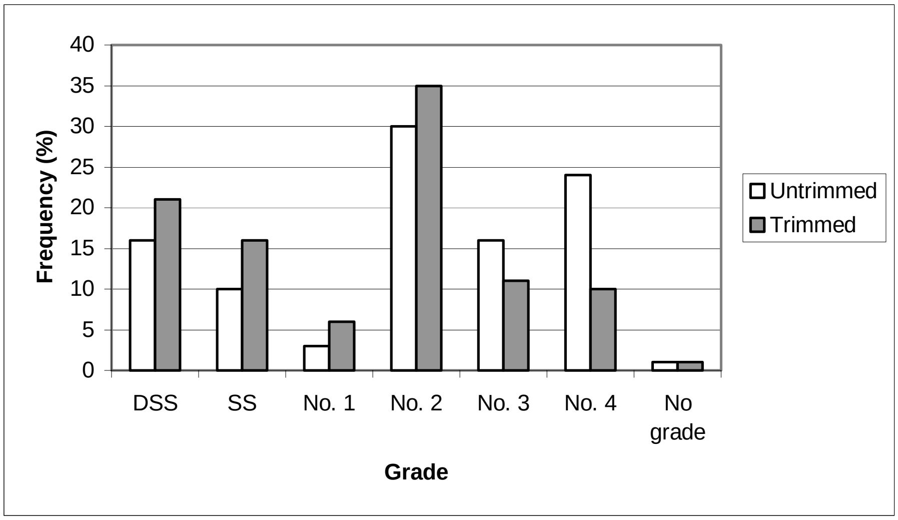

Figure 7. Grade distribution: trimmed compared with untrimmed 2 x 4's.

4.4 Results of visual grading

- The predominant grade designation for the 50 x 100's (2 x 4's) was No 2; the predominant grade designation for the 50 x 150's (2 x 6's) and 50 x 200's (2 x 8's) was No. 4 grade. Almost all the 100 x 150 pieces (87.5%) did not meet any of the grade designation.

- Damage was the prevailing grade-determining factor of 521 pieces of lumber graded, and accounted for a reduction in grade of more than half of the pieces (56.8 %).

- Of the 298 damaged pieces, 170 were trimmed to a marketable length greater than 2.1m (7 feet) to eliminate grade-determining defects. Trimming had a marked effect on the No. 4 grade designation, which was reduced from 47% to 20%. The lumber pieces without grade-reducing defects, which had a grade designation of, Select Structural or better increased from 17% to 36% with trimming.

- Trimming increased the grade of about 33% of the lumber. On average trimming increased the grade of the pieces by three grades levels although there was an average reduction in length of 720mm (2.4ft).

5. CONCLUSION

One of the main barriers to the widespread reuse of smaller dimensional salvaged lumber is the lack of up-to- ate grading or certification stamp. Often consumers are hesitant in purchasing wood for structural applications that lacks certification. Evaluating salvaged lumber with existing grading rules may not result in the most efficient use of this resource. Research studies including mechanical testing of salvaged lumber are needed to determine if the properties of wood have statically changed during the loading period. New, more appropriate and performance-based , grading rules are needed for salvaged lumber.

The results of the bending and shear tests on the salvaged lumber tested in this study compared very well with the results of virgin lumber tested under similar conditions. The salvaged lumber was denser than the new lumber. On average, the salvaged lumber was 50% higher in density than the virgin lumber.

- The allowable bending stress of the samples tested was highest in the studs from building 2 which had a value of approximately 117% that of the virgin lumber tested. The least allowable bending stress was obtained from rafters in building 1, with a value of approximately 67% that of the virgin lumber.

- The allowable modulus of elasticity (E) was least in the virgin lumber. The salvaged lumber had an allowable Modulus of Elasticity ranging in value from 109% to 137% that of the virgin lumber tested.

- The allowable shear stresses parallel to the grain were highest in the virgin lumber which was markedly without much of the checks and splits found in the salvaged lumber. The salvaged lumber compared to the virgin lumber as follows:

    - The allowable shear stresses parallel to the grain for studs salvaged from building 1 was 50% that of the virgin lumber.

    - The allowable shear stresses parallel to the grain for studs salvaged from building 2 was 95% that of the virgin lumber.

The results of visual grading of salvaged lumber conducted by the SPIB found the predominate grade reducing factor to be the presence of damage. Of the damaged pieces, 170 were trimmed to a marketable length greater than 2.1m (7 feet), to yield a higher grade. On average trimming the damage caused by construction, usage and deconstruction increased the grade of 32.6% of the pieces by 3 grade levels with an average reduction in length of 2.4 feet. Trimming produced pieces of very high grade and increased the number of pieces graded as Select Structural or better by approximately 20%.

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7. APPENDIX A

Defects and characteristics that affect the structural properties of wood:

Knots: that portion of branch or limb that has been incorporated into the main body of the tree.

Slope of grain: the deviation of wood fibers from a line that is parallel to the edge of a piece of lumber. It is expressed as a ratio (1 in 8, 1 in 12, etc.)

Wane: wood missing, usually on the edge, because of bark coverage or peel off.

Warp: a distortion caused by the wood twisting or bending out of shape.

Checks, shakes, and splits: separations of wood fibers. Checks are radial cracks caused by nonuniform volume changes as the moisture content of wood decreases. Shakes are cracks, which are usually parallel to the annual ring and develop in the standing tree. Splits represent complete separation of wood fibers throughout the thickness of a member.