DISASSEMBLY AND RE-USE OF BUILDING MATERIALS: A CASE STUDY ON SALVAGED TIMBER COMPONENTS

A THESIS SUBMITTED TO
THE GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES
OF
THE MIDDLE EAST TECHNICAL UNIVERSITY

BY

AYDIN IŞIK

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE
OF
MASTER OF SCIENCE
IN
THE DEPARTMENT OF ARCHITECTURE

DECEMBER 2003

Approval of the Graduate School of Natural and Applied Sciences

Prof. Dr. Canan Özgen
Director

I certify that this thesis satisfies all the requirements as a thesis for the degree of Master of Science in Building Science, Architecture.

Assoc. Prof. Dr. Selahattin Önür
Head of Department

This is to certify that we have read this thesis and that in our opinion it is fully adequate, in scope and quality, as a thesis for the degree of Master of Science in Building Science, Architecture.

Asst. Prof. Dr. Soofia Tahira Elias-Özkan
Supervisor

Examining Committee Members:

Assoc. Prof. Dr. Arda Düzgüneş

Assoc. Prof. Dr. Gülser Çelebi

Assoc. Prof. Dr. Neriman Güvenç Şahin

Asst. Prof. Dr. Soofia Tahira Elias-Özkan

Françoise Summers

ABSTRACT

DISASSEMBLY AND RE-USE OF BUILDING MATERIALS: A CASE STUDY ON SALVAGED TIMBER COMPONENTS

Aydın Işık
M.Sc. in Building Science, Department of Architecture
Supervisor: Asst. Prof. Dr. Soofia Tahira Elias Özkan

December 2003, 99 pages

The objective of this study was to investigate the feasibility of using salvaged timber from deconstructed buildings in Turkey. The intention was to show that the re-use of 'waste' materials, while decreasing the cost of construction also preserves the environment from wasteful and extensive use of natural resources. It is hoped that the findings of such a study will encourage professionals to use second hand timber components in Turkey. In order to deal with the waste problem and to save our planet the re-use of construction materials from economic, environmental, social, and historic points of views should be pursued.

This research incorporated information about the re-use of timber, including ongoing projects around the world, as reported by the International Council for Research and Innovation in Building Construction (CIB) Task Group on Deconstruction (TG39), a local survey of individuals, organizations, and businesses that are related to the recycling and reuse of building materials. Local deconstruction works, recovery and re-use of timber elements and components were investigated on the basis of information obtained from the demolition contractors in Bentderesi locality in Ankara, a salvaged materials market.

Moreover the study aimed to observe how used timber components are recovered from a demolition project. By observing the demolition of a building the author was able to determine the problems in recovering timber with the least damage.

The findings of the investigation indicated that the architects and the building industry can play an important role to increase recovery rates and conditions of used timber components in construction, considerably. Instead of using nails for timber joints bolted connections should be preferred since they allow demounting and re-use with minimum damage during the deconstruction process. At the same time defects in timber due to extensive and unnecessary nailing can also be avoided. The decision on type of deconstruction, time and cost estimation, worker ability and sensitivity during disassembly influence the success of deconstruction. Tools and machinery used both on the work site and in the UBMs selling area have direct effects on the condition of recovered materials.

Keywords:
Re-use of Timber Components; Recovery; Deconstruction; Feasibility of Used Construction Materials.

ÖZ

İNŞAAT MALZEMELERİNİN AYRIŞTIRILMASI VE TEKRAR KULLANILMASI: AHŞAP BİLEŞİKLERİNİN KURTARILMASI

Aydın Işık
Yüksek Lisans, Yapı Bilimleri Anabilim Dalı, Mimarlık Bölümü
Danışman: Y. Doç. Dr. Soofia Tahira Elias Özkan

Aralık 2003, 99 sayfa

Bu çalışmanın amacı Türkiye'deki yıkılan binalardan geri alınan ahşabın uygunlugunu araştırmaktır. Bundaki eğilim 'atık' malxemelerin tekrar kullanılmasıö inşaat maliyetlerini düşürürken çevreyi doğal malzemelerin savutgan ve aşırı kullanılmasından korudugunu göstermekti. Bu çalışmadaki bulguların Türkiye'deki profesyonellerin ikinci el ahşap bileşiklerinin kullanılmasını cesaretlendirmekti. Atık sorununu çözmek ve gezegenimizi kurtarmak için inşaat malzemelerinin economik, çevresel, sosyal ve tarihi açıdan sürdürülmelidir.

Bu çalışma Uluslararası Bina İnşaatındaki Araştırma ve Yenilik Konseyi (CIB) Yıkım Grubunun (TG39) rapor ettiği halen dünyada devam eden projelerini de kapsayan ahşabın tekrar kullanımını ve inşaat malzemelerinin geri dönüşümü ve tekrar kullanımı ilgili bireysel, kuruluş ve iş dünyası incelemeleri birleştirildi. Ankara'daki geri kazanılmış malzeme satış alanı olan Bentderesi Bölgesindeki yıkım müteahhitlerinden elde edilen bilgiler ışığında yerel yıkım çalışmaları, ahşap elemanleri ve bileşiklerinin geri kazanımı ve tekrar kullanımı incelendi.

Çalışmanın bir diğer amacı ahşap elemanlarının yılım projelerinde nasıl geri kazanıldığınını gözlemlemekti; yıkılan bir binanın gözlemlenmesiyle yazar ahşabın en az hasarla geri kazanılmasındaki problemleri belirlemesi mümkün oldu.

Araştırmanın bulguları mimarların ve inşaat endüstrisinin yapımda kullanılmış ahşap bileşiklerinin geri kazanım oranlarını ve durumlarını oldukça arttırabileceğini göstermektedir. Ahşap bağlantı noktalarında çivi yerine cıvata kullanılmalıdır, çünkü cıvata yıkım esnasında malzemelerin ayrıştırma işlemi sırasında ve tekrar kullanımına en az hasara neden olarak buna izin vermektedir. Aynı zamanda fazla ve gereksiz çivi kullanımından doğan ahşap hasarları engellenmiş olur. Yıkımın başarısı yıkım tipine, zaman ve maliyet hesabına, işçilerin ayrıştırma yeteneklerine ve hassasiyetlerine bağlıdır. Geri kazanılan malzemelerin durumu, yıkım sahasında ve işlem alanında kullanılan ekipman ve makineler ile birebir ilintilidir.

Anahtar Kelimeler:
Ahşap Bileşiklerinin Tekrar Kullanımı; Geri Kazanım; Yıkım ve Ayrıştırma; Kullanılmış İnşaat Malzemelerinin Uygunluğu.

To My Parents and My Brother

ACKNOWLEDGEMENT

First of all, I am thankful to my supervisor Asst. Prof. Dr. Soofia Tahira Elias-Özkan for her extraordinary motivations, contributions and meticulous editing of my thesis, and to all my jury members for their invaluable advices.

I would like to thank Nevzat Öngün, Nabi Öngün, Murat Aktepe and other yard-owners at Bentderesi Avenue for readily providing me with information regarding their deconstruction and re-use businesses. Special thanks to Nurat Ayter for supplying me with data and itemized pricing for the cost analysis related to the feasibility report.

Finally, I am gratful to my parents Beride and Halil, and my brother Aşkın for their continous belief in me and for supporting me whole heantedly; and of course to all my friends, especially Ahmet Ugursal and Yeliz Norman for their encouragments.

TABLE OF CONTENTS

LIST OF TABLES

TABLES

LIST OF FIGURES

FIGURES

LIST OF ABBREVIATIONS

ACM	Asbestos Containing Material
C&D	Construction and Demolition
CDW	Construction and Demolition Waste
CIB	International Council for Research and Innovation in Building Construction
CO	Carbon Monoxide
DFD	Design For Dismantling
DFR	Design For Recycling
LBP	Lead Based Paint
SO2	Sulfur Dioxide
TG39	Task Group on Deconstruction
TL	Turkish Liras
USB	Used Building Materials

CHAPTER 1

INTRODUCTION

1.1 Argument

The problem of non-biodegradable and hazardous waste started with human beings. Continuous growth of population in the world will not be able to suffice with the limited natural resources in the near future. Even today this population and resource relation has reached a critical point in most EU countries and Japan. Towards the end of the century with rapid developments in technology an equally rapid change in construction techniques has lead to the accumulation of solid waste from used materials. These wastes are deposited in *landfill* areas, which have become a problem for local municipalities. Being aware that one of the solutions that evolved with the problem of solid waste collection and disposal is recovery of re-usable materials, governments and municipalities try to encourage of reduction of waste and use of salvaged materials by implementing regulatory policies, taxes and legislation arrangements. Re-use of material will diminish waste and give the opportunity to use natural resources more efficiently by returning them into their life cycle.

Recycling and re-use of building materials can considerably reduce the use of energy and natural resources and reduce the use of landfill and extraction of resources. This not only saves money and time, but also protects the environment, and material from dumping. In order not to lose the main part of the total embodied energy and used natural resources, special care must be taken in the dismantling without decreasing the quality of building materials. Furthermore, from the social point of view, local enterprises can benefit from used building materials both by selling them and opening up new opportunities for the local workforce. Especially in the Ankara region, carpenters will benefit most by this increased work opportunity, since the buildings deconstructed today were built until the 1960's timber was the main construction element even in concrete framed residences timber components like fenestration, and floor, wall and ceiling finishing took important place among construction materials.

Wood, the only renewable construction material in use today, remains the principal building material of the construction industry. Since timber is produced from trees and forests; consequently the main effect will be on the natural environment during production and supply of virgin lumber. Meanwhile, being a natural material, timber gains its exact shape and properties by loosing the free water in its composition in time, which means if it does not subject to decay during its first use life (i.e. like fire damage, dampness causing biological decay, cracks from weathering and/or overloading) it has considerably better physical properties than most of the new materials. Its carrying capacity and shearing properties are better and since load applied on it does not cause any deformation on the original shape of structural elements it is better to use salvaged lumber.

Therefore, together with the advantages and obtained profits from re-use of timber, use of natural material will be further explained. From the economic point of view timber cost will decrease and total budget in construction will decrease. Salvaged material from the building gives opportunity to re-use timber effectively and cheaply. From the environmental point of view, re-using and recycling resources can save our planet.

1.2 Objectives

The aim of this study was not only to find out cost of virgin timber elements and salvaged ones in order to compare them from the economic point of view but also to investigate the feasibility of using salvaged timber from deconstructed buildings in the Ankara region. It’s hoped that the findings of such study will encourage professionals to use second hand timber components in new buildings/constructions.

Another objective of this study was to observe how used timber components are recovered from a demolition project. By observing the demolition of a building in Ankara, the author was able to determine the problems in recovering timber with the least damage.

Resources are limited in the world, so is the space needed to dump solid wastes from demolition. It was intended to show that re-use of ‘waste’ materials while decreasing the cost of construction would also preserve the environment from the wasteful and extensive use of natural resources.

From a more general point of view it was aimed to encourage the researchers in Turkey in giving special attention to the re-use of construction materials from economic, environmental, social, and historic points of views. Furthermore, use of local material requires local know how and/or unskilled workers, which generally is cheaper and provides job opportunity to local residents.

1.3 Methodology

The methodology for this research incorporated a cross-disciplinary literature review on re-use of timber, including ongoing projects around the world reported by the International Council for Research and Innovation in Building Construction (CIB) Task Group on Deconstruction (TG39), a local survey of individuals, organizations, and businesses that are related to the recycling and reuse of building materials (Appendix A). A literature survey was conducted on publications available at the Middle East Technical University Library and Bilkent University Library for limited published documents in Turkey, and other web sites related to the timber salvaged from deconstructed buildings around the world.

Local deconstruction works, recovery and re-use of timber elements and components were investigated on the basis of information obtained from the demolition contractors in Bentderesi locality in Ankara, a salvaged materials market. Before starting the survey, the contractors were interviewed in order to gather information about recovery methods, transportation, storage and marketing of salvaged construction material in Ankara.

The survey also covered such aspects of re-used timber components as damage during deconstruction and steps adopted in repairing and recovering the components for resale. Furthermore a market survey on new timber components was conducted in order to compare the prices of new and re-used timber materials.

1.4 Disposition

After this introductory chapter, Chapter 2 consists of a literature survey regarding deconstruction and re-use of materials. Re-use of timber components obtained from demolition is also represented in this part. In Chapter 3,50
the material and methodology of the study are presented.

Material presented in the preceding chapter are discussed and analyzed in the Chapter 4. This Chapter focuses on the buildings of the research based on the market survey and observations made on a demolition site regarding the deconstruction of timber components of the conventional apartment building in Ankara. Data, regarding the market research results, was analyzed and presented as a feasibility study for using second hand building materials in new construction evaluated regarding market research results, which is gathered by the author.

Finally, Chapter 5 concludes the study by recommending questions for further research in this field.

CHAPTER 2

DECONSTRUCTION AND RE-USE OF BUILDING MATERIALS (TIMBER): A LITERATURE SURVEY

This chapter presents a literature survey on three subjects related to the re-use of building materials: deconstruction[1] of building, re-use of materials and timber re-use. The first part of the chapter deals with deconstruction of buildings with respect to demolition[2], aspects of deconstruction and criteria for efficient deconstruction and disassembly[3]. The second part consists of sustainable building design, the ideas on hierarchy of recycling - by explaining the differences among them and summarizing them into a general theory - and market demand on used building materials. In the last part, the physical and chemical properties of recovered timber material and the virgin one are compared then the treated and untreated timber components were examined.

It should be noted that it was very difficult to find researches and published materials on salvaged building materials and their re-use in new projects in Turkey. Furthermore, on-line information related to re-use of timber components in other countries of the world was also limited to some small-scale projects and few conferences reports. There is an urgency for finding systematic ways and means for re-use of timber building in order to save our history, preserve natural re-sources for the future and keep our planet inhabitable.

---

[1]"Taking apart components without damaging in order to reusing them" (Hobbs and Hurley, 2001).
[2]"A term for both the name of the industry and a process of intentional destruction" (Hobbs and Hurley).
[3] "Taking apart components without damaging, but not necessarily to reuse them" (Hobbs and Hurley).

2.1 Deconstruction of Buildings

According to Guy (2001), deconstruction is a way of unconstructing buildings for the feasible recovery of reusable and recyclable building materials. Though it is also called salvaging, it is not "cherry-picking," - a removal of only the highest value materials, leaving the remainder for disposal- it is a comprehensive whole-building strategy for dismantling.

Deconstruction can also be defined as the careful dismantling of buildings with the goal of maximizing the re-use potential of the components and minimizing the amount of materials that are landfilled. Chini and Acquaye (2001) claim that the increasing cost of landfilling, forced the construction industry to turn its focus to deconstruction or building dismantlement to salvage reusable components of the deconstructed buildings – "close the loop" of material cycle - and to decrease the amount of the waste sent to landfills. 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 presence of hazardous materials and their impact on the process and products; the available time for building removal.

2.1.1 Pre-deconstruction Process

The deconstruction of buildings has gained more and more attraction in recent years (Schultmann, Garbe, Seemann and Rentz, 2001). Deconstruction and dismantling of buildings helps to increase the amount of components to be re-used or materials to be recycled. On the other hand demolition often leads to the mixing of various materials and contamination of non-hazardous components. Hence, the share of demolition waste[4] deposited in landfills can be reduced.

2.1.1.1 Planning Deconstruction

Goal of deconstruction is to increase resource and economic efficiency and reduce pollution impacts in the adaptation and eventual removal of buildings, and to recover components and materials for re-use, re-manufacturing and recycling (Guy and Shell, 2002). In order to achieve this goal, deconstruction work should be examined carefully.

As buildings were designed and built to satisfy the requirements of customers, only their performance, such as structural performance, durability[5] or indoor air quality, was considered. The performance of the buildings after their service life was seldom discussed in the process of building design. Buildings should be designed considering every aspect of their lifecycles. The possibility of recycle and re-use of the building itself should be carefully thought about in the process of initial design. For example as the roof framing is deconstructed at high locations, connectors should be designed so that time consuming and dangerous work can be avoided, and also the lumber would not be damaged in the process of removing the connectors (Nakajima, Kawai, Hiraoka and Miyamura, 2003).

Renovation or demolition reuse/recycling begins prior to work on site with an assessment of the structure. Designers, owners and contractors work together to identify those materials and items that will be reused or recycled and determine how to most effectively manage those materials that cannot be reused in order to minimize waste. The financial feasibility of managing this waste is often then

---

[4] 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 (Hobbs and Hurley, 2001).
[5] The endurance of a material or assembly determines how often it requires maintenance or replacement (Kim and Rigdon, 1998c).

analyzed to determine how much and what items should be included in the plan. The resulting decisions should then be incorporated into the specifications to ensure compliance. Next, sources of recycling and/or disposal should be identified. Many large cities have created reference manuals to aid contractors in this area. Additionally, in some areas construction waste firms have sprouted that act as intermediaries between the contractors and the waste handlers. They have developed networks of reuse, recycling and disposal and can offer 30%-60% reductions in waste management costs. In other areas, however, few resources have been developed in this area and locating sources for reuse/recycling can be quite difficult (Tinker and Burt, 2003).

Once deconstruction begins, contractors and subcontractors first separate reusable items such as doors, woodwork, hardware and metals. There are many profitable markets for these items or they can be donated to charities as mentioned above. Next, on-site separation of building materials should occur for such materials as brick, concrete, steel and other large wastes. These are generally sorted into separate bins free from contaminants and other materials and then transported to a previously identified receiver (Tinker and Burt, 2003).

Schultmann et. al (2001) assert that significant improvements in the quality of waste arising from demolition can be achieved by the application of selective dismantling. 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 re-use, recycling or disposal of the materials, if dismantling and recycling are planned well (Appendix B).

In the plan for deconstruction process it should be pointed out that the principle of **Repeat, Rethink, Renew** is both a hierarchy of the environmental benefits of reuse options and a set of reuse methods (Willims and Guy, 2003).

(i) Repeat, Rethink, and Renew

The first thing that has to be done before deconstruction is to decide the second use life of building components after dismantling. According to Williams and Guy (2003) there are three strategies. R*epeat* involves the least expenditure of additional energy while giving a second life to the building material. When a framing member is directly re-used as a framing member, no energy needs to be expended to utilize the wood for re-use, no milling or addition of paint or other finishes. From a sustainability perspective, this is the most efficient utilization of the re-use options. When employing the method of *rethink*, an analysis of material properties or fitness for purpose takes precedence over the original function of the material. In fact, the more completely the original function can be forgotten or ignored, the easier it becomes to envision new possibilities. This may require the modification of the material and may end up using more resources. *Renew* is a reminder that re-use is not a way of designing that excludes or ignores the value of new materials in appropriate situations.

(ii) Source Separation

Careful separation of sources both job-site and in the display area take an important place in the planning of deconstruction of buildings. According to Kim and Rigdon (1998c), the recovery of construction and demolition (C&D) debris consists of collecting and sorting the material prior to delivery to a re-use or recycling facility. The success of job-site source separation depends on the ability of the workers to keep materials clean and sorted. Contaminated materials will not be accepted for recycling: in order for savings to take place, bins must be identified and workers and sub-contractors must be held responsible. On large projects, roll-off bins are strategically placed to receive the materials as they are generated.

According to Chini and Acquaye (2001), based on the material type and condition, items are immediately re-used, processed further, or disposed of. Therefore, it is important to have the storage space, processing space, and dumpsters close to the structure. The de-nailing and processing area is prepared so that de-nailing and sawing off damaged ends of salvaged lumber to get pieces of better quality and higher valuable is possible (Figure 2.1).

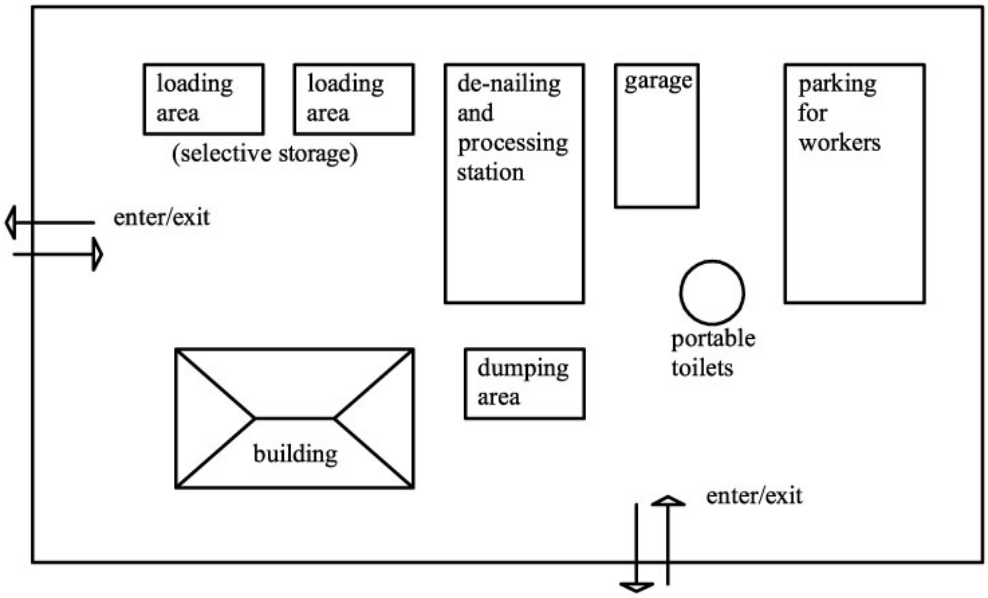


Figure 2.1 Diagram of field organization for deconstruction (Chini and Acquaye, 2001: p. 148)

Kim and Rigdon (1998c) declare that time-based removal by hauler takes advantage of the fact that on residential and smaller commercial projects, only one major type of waste is produced during each phase of construction. The waste hauler is contracted to separate and remove the materials before they become mixed with the materials from the next phase of construction. Source separation and load stratification enable haulers to deliver clean feedstock material back into the economy while saving money. For example during World War II the German economy flourished because of efficiencies in collecting, sorting, and recycling materials. Facing a natural resource crisis 50 years before any other developed country in 1939, they quickly became the most energy- and resource-efficient self-governing state in the world.

2.1.1.2 Design for Disassembly

> “Regarding discarded materials as ‘already refined ores that are most concentrated in urban areas,’ Urban Ore is a successful model for an industry that exists between the demolition of buildings and the recycling, landfilling, or incineration of materials.” (Kim and Rigdon, 1998: p. 72)

Buildings, being an accumulation of materials, provide a means of storing resources for future use. For these resources to be reusable or recyclable, Kim and Rigdon (1998) suggest that the construction systems should be designed in such a way that allows for conservative disassembly. Conventional site-built approaches to design for disassembly are usually based on post-and-beam construction types, which most effectively separate structure from enclosure.

Deconstruction serves as a means to an end, its purpose is the recovery of building elements, components, sub-components, and materials for either re-use or recycling. Guy and Shell (2002) declare that within the idea of design for deconstruction there is a distinction between designing for re-use and designing for recycling based upon components and types of materials used in a building. Deconstruction per se implies a high degree of refinement in the separation of building components. If a building were deconstructed to some hypothetical maximum it would result in materials and components down to the level of their original form before construction. It is not practical to approach design for deconstruction at the whole-building level in this manner as some components, such as a window for instance, may be obsolete by the time the building is deconstructed and undesirable for re-use as exterior windows.

Crowther (2001) claims that a notable impediment for deconstruction of timber buildings was often damage to components by water leakage and wood-boring organisms over time. This damage weakens the building structure and reduces the value of the recoverable materials. If nothing else design for deconstruction would also add impetus to design for durability and solve the problem that it is of little utility to efficiently disassemble a building if the materials themselves have not been protected from decay. Although chemical sealants, coatings and adhesives add water protection and strength to building materials, they are significant prohibitions to hand deconstruction. From an environmental perspective, these types of additives should be eliminated with the recognition that mechanical methods of water protection and connections will require additional design and construction effort. The resulting reduction in performance, if one occurs, can be overcome by the ease of disassembly (by using screws and bolts for instance) for replacement and repair of components and sub-components. On a fundamental level timber is a highly preferable material in design for deconstruction since it is flexible for both re-use and recycling, a “natural” material, and can be readily connected using interstitial connecting devices such as bolts.

According to Crowther (2001: p.1), “one of the major hindrances to successful deconstruction, for the re-use 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 re-use. This would have significant advantages both economically and environmentally.”

Guy and Shell (2002) suggest that if the structure is made of timber the focus is primarily on the roof structure. The first consideration might be to design the roof structure that is composed of a series of trusses. If designed with the intent of addressing deconstruction safety, the trusses could be lowered to the ground as single units and possibly re-used as trusses or dismantled further. Another consideration will be the type of connections to be incorporated in the design. For timber structures, the basic choices are to use either bolted or nailed connections. From a deconstruction point of view, bolted connections would generally be preferred as these do less damage to timber members than do nails. From a safety perspective, bolted connections are also preferred because it is easier to assess when a connection is no longer attached and when it is ready for removal. With a nailed connection that contains four nails, it will be difficult to assess when the connection is no longer intact. The connection might hold reasonably well when one nail is withdrawn, but the connection might fail once the second or third nail is withdrawn. Of course, with nailed connections, it may be difficult to withdraw nails one at a time. Instead, the wood members might be forced apart by means of an impact blow, as from a sledgehammer. This will generally do additional damage to the wood.

High-slope roofs are problematic for deconstruction working platforms, therefore the use of ridge caps that are easily removable and allow access to the roof structure for tie off, or are designed to support the requisite load for a worker lifeline for roof finish and sheathing removal, would facilitate both roof repair and ultimate deconstruction. Panelized roofs that allow the mechanical removal of large sections of roofs for processing on the ground would preclude the need for fall protection and risks and added time involved from working at heights (Guy et. al, 2002).

Roof structure becomes unstable when deconstruction proceeds and it is difficult to pull out nails in a high place. The members composing the attic have the possibility to be damaged in the process of deconstruction (Nakajima et. al, 2003). Therefore, it is important to review the joints that connecting the members that compose the roof structure and to develop new connecting methods for easy removal in high places. For example, the usage of dual head nails or wood screws for as connecting device may minimize the damage of the members in the process of deconstruction.

According to Dorsthorst and Kowalczyk (2001), 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’ (Figure 2.2). 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 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.

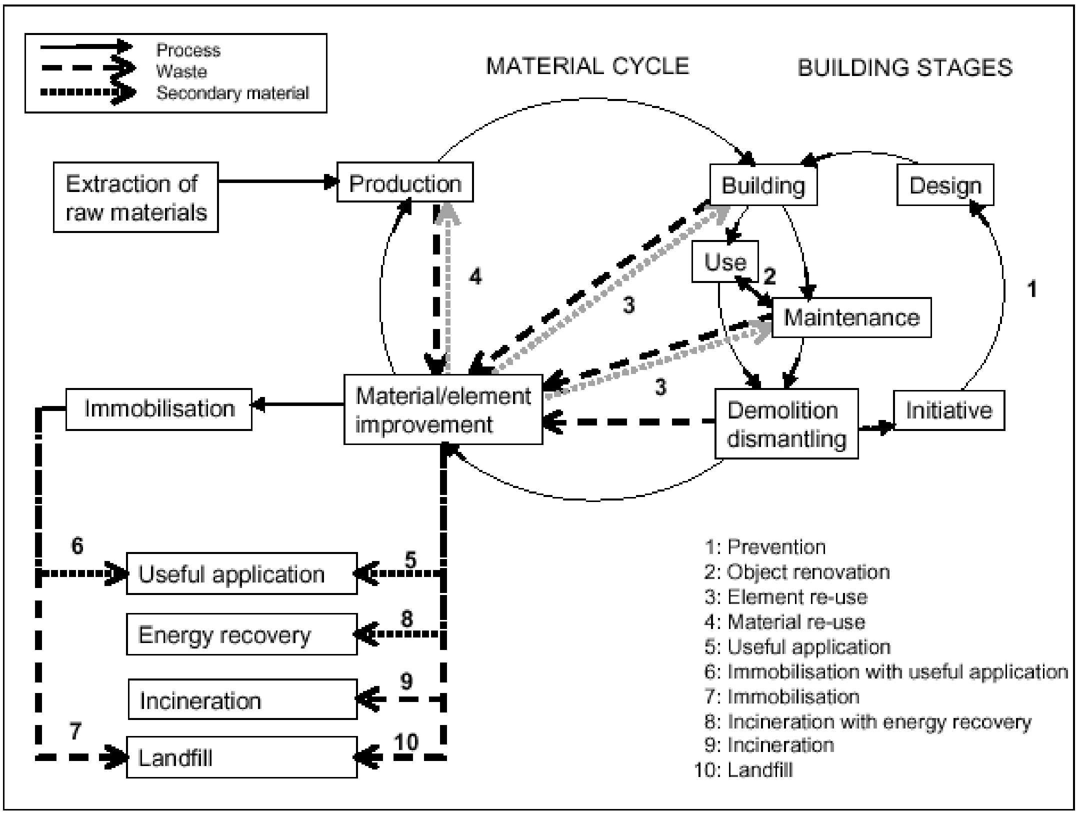


Figure 2.2 Integral Chain Management (Dorsthorst and Kowalczyk, 2001: p. 56)

Efficient use of materials and waste minimization are integral constraints that need to be addressed in any building project. Through Design for Reuse, building designers can not only reduce waste, but also discover additional potential for creativity and excitement in design (Willims and Guy, 2003).

Timber-framed architecture is a good manifestation of design for disassembly, as are most post-and-beam type structures if their connections are either exposed or accessible. Obviously, bolts, self-tapping screws, and gaskets make disassembly easier than nails and glue; however, these types of connections increase materials costs and slow construction time.

2.1.2 Aspects of Deconstruction

> "Architecture is one of the most conspicuous forms of economic activity" (Kim and Rigdon, 1998: p. 6).

While limited salvage has long been a part of demolition practices, deconstruction aims to increase re-use options by pushing materials salvage beyond such items as windows, doors and light fixtures to include such elements as flooring, siding, roofing and framing where these materials have retained their value. In some cases, deconstruction can generate items that are no longer available anywhere like works of craftsmanship and art in old buildings (Williams and Guy, 2003). More advantages and problems of deconstruction are explained further in the following sections:

(i) Advantages of Deconstruction

According to Chini and Nguyen (2001), the main benefit from deconstruction of buildings is that materials are being diverted from landfill and so natural resources are preserved. Other benefits include *social benefits*, which provide employment opportunities, low-cost building materials, and generates other businesses to support deconstruction infrastructure, *economic benefits* that get profit of salvaged materials, return older buildings' craftsmanship quality materials to construction industry, give opportunity for demolition contractor to expand, and *environmental benefits*, which decrease site disturbance, preserve space at landfills and energy by re-using materials.

As well successful strategies for implementing deconstruction can reduce the energy use, land consumption, groundwater degradation, deforestation and greenhouse gas production associated with wasted wood resources. The benefits over conventional demolition will vary from project to project. Besides, deconstruction projects have demonstrated that the intensive but relatively low-skilled hand deconstruction work can provide new jobs for unskilled workers and can act as a practical entrance point for labor force development throughout the construction trades (Guy, 2001). In addition, it provides feedback for the architect to design structures to extend their longevity through cost-effective maintenance, repair and adaptation.

(ii) Problems in Deconstruction

The deconstruction process may run into obstacles even after addressing all required items. These are project specific constraints of which some are outside the control of participating parties that will limit recovery rate. Chini and Nguyen (2003) state them as labor constraints, site constraints, project funds, hazardous material constraints, and weather constraints. As insufficient number of workers will reduce productivity or the amount of material recovered in a given time and increase labor cost. Small site hinders maneuverability and proximity of other structures lower productivity, limit amount of on site storage and processing (sorting and de-nailing) spaces. Small deconstruction budget will limit number of workers, equipment and tools, so trim profit margin, since most salvaged materials are not resold right away. Any hazardous material must be removed, leaving less material to be recovered. Lastly adverse weather conditions (rain or heat) can lower productivity and also damage exposed materials (Chini and Nguyen, 2003).

2.1.2.1 Social Benefits

Deconstruction and proper disassembly of building materials can support the economic development of communities by providing jobs and job-skills training (employment opportunities), and affordable building materials (good quality, energy efficient, low-cost building materials), and generates other businesses to support deconstruction infrastructure. At the same time, not removing a community's irreplaceable historic fabric should be rewarded (Guy, 2003).

2.1.2.2 Environmental Aspect

According to Kim and Rigdon (1998b), while cost efficiency used to be the major goal when buildings had to be removed, nowadays-environmental compliance has also to be respected. Architects are in a position to encourage the production of a wider variety of sustainable materials by contacting manufacturers for more specific information and refusing to specify materials made through highly polluting processes.

The definition of environmental balance can be based on the indicators connected with the following issues: load of the construction and demolition waste (CDW) on the environment; consumption/ safeguard of the natural resources; availability of raw materials; availability of secondary raw materials; impacts connected with the transport of CDW materials, in terms of consumption and harmful emissions; acoustic impacts and pollution from dusts connected to the different solutions of demolition (Lassandro, 2003).

Today most building materials from demolitions are either recycled with a considerable quality decrease or not recycled at all. Recycling (and re-use) building materials can considerably reduce the use of energy and natural resources and reduce the use of land for landfill and extraction of resources. The main part of the total embodied energy[6] and used natural resources are then lost. Recycling can bring a considerable part of this back into use again (Thormark, 2001). From an environmental standpoint, re-use conserves all of the embodied energy required to extract, transport, and process the raw materials, whereas recycling requires

---

[6] The embodied energy of a material, product, or assembly includes the energy required to extract and process the raw materials, manufacture the product, and transport the material and product from source to end use (Kim and Rigdon, 1998a).

additional energy inputs for recovery, transportation, and re-manufacturing. Building products with *lower* embodied energy include wood, wood fiber, agricultural fiber, re-used materials, and many recycled-content and byproduct-based products.

Natural materials are generally lower in embodied energy and toxicity than man-made materials. They require less processing and are less damaging to the environment. Many, like wood, are theoretically renewable. When natural materials are incorporated into building products, the products become more sustainable. The circulation of materials is considered one of the principle laws of general ecology. Kim and Rigdon (1998b) describe the principle as the rate of cycling of materials is a more important indicator in determining productivity than the amount present at any one place at any one time; material cycles become more closed as a system matures; and the role of waste products in the overall health of the system increases.

(i) Resource and Energy efficiency

Resource efficiency as stated by Kim and Rigdon (1998a) is the proactive process of preventing spent materials from entering air, land, or water. With this “up-stream” (instead of “end-of-pipe”) approach, we can reduce or eliminate waste at the source and reduce the demand on natural or virgin resources. By designing toxic and hazardous waste out of the manufacturing process, compliance and paperwork costs associated with environmental regulations are also eliminated. Waste prevention and source reduction also improve resource efficiency, allowing businesses to be more competitive with enhanced public image.

In addition to specifying materials that are inherently less wasteful, the architect can optimize resource efficiency by maximizing the building’s use and function while minimizing its size. Strategies that simplify the building's shape, use standard material modules, reduce excess circulation space, and provide for growth and change increase material efficiency by design (Kim and Rigdon, 1998c).

Kim and Rigdon (1998c) further claim that e*nergy efficiency* is an important feature in making a building material environmentally sustainable. Depending on type, the energy efficiency of building materials can be measured with factors such as R-value, shading coefficient, luminous efficiency, or fuel efficiency. The ultimate goal in using energy-efficient materials is to reduce the amount of artificially generated power that must be brought to a building site.

(ii) Natural Environment - Habitat

According to Kim and Rigdon (1998b), habitat refers to the natural environment in which a species is found; usually, these areas are undeveloped. Cutting forests for lumber or removing vegetation for mining destroys the habitats of animal and plant species. A microclimate may be immediately and severely altered by the removal of a single tree that protectively shaded the plants below.

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 sulfur dioxide (SO2). Environmental and health hazards associated with these gases include global warming, decreased visibility, smog, eye irritation, and lung damage (Chini and Acquaye, 2001).

Tinker and Burt (2003), state that one of the greatest environmental benefits of waste management is the increased life of landfills that reduces the need to designate more land to this process. By reducing the amount of waste going to the landfill, the effects of global warming as a result of greenhouse gas emissions produced in landfills can be reduced as well. Moreover, resources are conserved as previously used materials and products are reused instead of fabricating new products.

(iii) Solid Waste

Ten percent of the materials used in building and construction end up as waste. But waste does not end there; it actually increases several-fold during the lifetime of a building due to maintenance, renovation, and finally, demolition. Also, in other parts of the world this building and construction waste is a matter of concern. Erkelens (2003: p. 125) claim that "the enormous amount of waste produced during building and renovation is a serious environmental problem, which is worsening as building activities increase over the years. Reduction of demolition to a minimum will not only result in less waste, but also in less need for new materials." Referring to Smith, Erkelens (2003) noted that in the USA, 20% of the total materials were wasted.

Waste takes the form of spent or useless materials generated from households and businesses, construction and demolition processes, and manufacturing and agricultural industries. The shorter the useful life of consumer goods, the greater the volume of useless goods will result (Kim and Rigdon, 1998c). Materials resulting from the construction and demolition of buildings and infrastructure constitute a major share (10–15%) of the total municipal solid waste stream; natural disasters such as floods, earthquakes, and hurricanes greatly increase these percentages. Kim and Rigdon (1998b) designate that:

> The "law of supply and demand" also works in reverse: reduced demand for a product results in lower production. Lowered production means less waste discharged and less energy consumed during manufacturing, as well as a lower volume of raw materials that must be gathered. Reducing waste in the manufacturing process increases the resource efficiency of building materials. Oriented strand board and other wood composite materials are made almost entirely from the waste produced during the process of milling trees into dimensional lumber. Kilns used to dry wood can be powered by burning sawdust generated on-site; reducing both the waste that leaves the mill (to be disposed of in landfills) and the need for refined fossil fuels.

Tinker and Burt (2003: p. 386) claim, "Construction waste management involves planning and implementing waste reducing strategies to minimize the amount of jobsite materials that end up in a landfill." Waste management includes reducing the amount of waste produced on a jobsite, reusing as many materials and fixtures as possible and recycling those items that can not be reused in their present form.

Architects are encouraged to design around standardized building material sizes as much as possible. Kim and Rigdon (1998a) reported that in the U. S., this standard is based on a 4'x8' sheet of plywood. Excess trimming of materials to fit non-modular spaces generates more waste. Designing a building with these standard sizes in mind can greatly reduce the waste material created during the installation process. Efficient use of materials is a fundamental principle of sustainability. Materials that are easily installed with common tools also reduce overall waste from trimming and fitting.

2.1.2.3 Feasibility of Disassembly of Building Materials

Lassandro (2003) state that the economic definition of an intervention aimed to recycle and re-use materials/components can be based on the following evaluations:

- Costs of different possible demolitions (controlled or selective demolition, deconstruction, cherry-picking of materials);
- Costs for transport of CDW;
- Waste disposal fees and waste treatment center’s’ fees;
- Eco-taxes, e.g. in Italy there is a different eco-tax in each region;
- Costs for treatment of CDW in the construction site;
- Incomes from the re-use of materials/components (salvage value).

Lassandro (2003: p. 116) also states that “all these costs depend on the context characteristics, such as the presence of local qualified companies specialized in controlled and selective demolition and appropriately equipped (laser systems, special diamond blades, and water-demolition techniques, etc.).” In fact, a fixed treatment installation asks fees comparable to the necessary costs for the use of mobile plants. Moreover, the fee can also be reduced if the quality of CDW is good. Architectural ornament, metals, doors, windows, plumbing, good lumber, hardware, pipe, clean brick, and wire can all be removed prior to the arrival of the demolition team. The remaining materials are wasted because their separation is not considered cost-effective.

A particular subject is the eco-tax. In Italy (Lassandro, 2003), a special tax - called “eco-tax” - was introduced for the disposal into landfills according to the national law n.549/95 art.3, to promote the decrease of CDW production and their recycling and recovery of energy and raw materials. In particular, every region has to fix the amount of the tax between 1,03 Euro and 10,30 Euro per ton of CDW. As a consequence, the eco-tax that can be saved with CDW recovery is different in each region, according to the regional political aims and the awareness of environmental issues (e.g. it is 4 Euro per ton in the region of Apulia in Southern Italy, 7,75 Euro per ton in Emilia Romagna and 1,33 Euro in Tuscany).

A salvage rate or percentage described by Guy (2001) 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, illustrated in Figure 2.3, combines these estimates and variables to determine the cost-effectiveness of a deconstruction project. The equations of net income of a deconstruction and demolition from the Contractor’s perspective are the expressions:

The Net Income for Deconstruction Is:
(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 2.3 Economic Equations for Demolition and Deconstruction (Guy, 2001: p. 126)

Guy (2001) asserts, as 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.

Kim and Rigdon (1998a) describe **economy of resources** as the reduction, re-use, and recycling of the natural resources that are input to a building. Conserving energy, water, and materials can yield specific design methods that will improve the sustainability of architecture (Figure 2.4). These methods can be classified as two types, input-reduction methods, which reduce the flow of nonrenewable resources input to buildings, and output-management methods, which reduce environmental pollution by requiring a low level of waste and proper waste management.

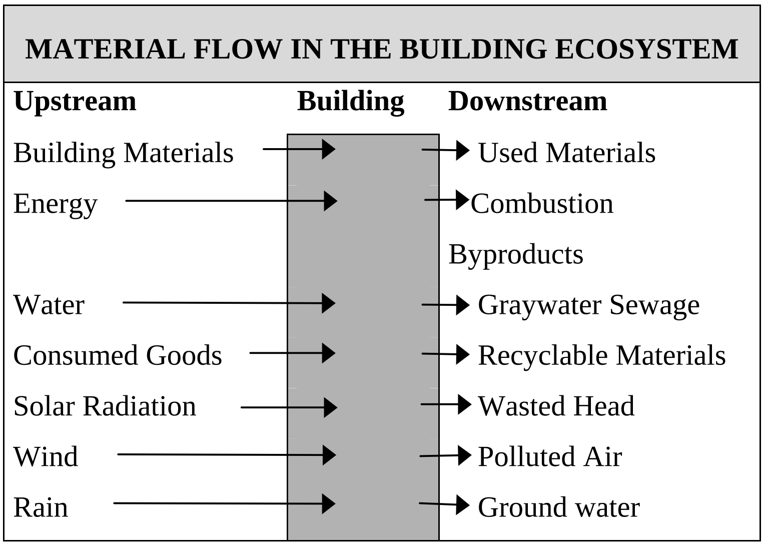


Figure 2.4 The input and output streams of resource flow (Kim and Rigdon, 1998a: p. 9).

By economizing resources, the architect reduces the use of nonrenewable resources in the construction and operation of buildings. There is a continuous flow of resources, natural and manufactured, in and out of a building. This flow begins with the production of building materials and continues throughout the building's life span to create an environment for sustaining human well-being and activities. After a building's useful life, it should turn into components for other buildings.

2.1.3 Criteria of Efficient Deconstruction

According to Abdullah and Anumba (2003), there are six main criteria and several sub-criteria that affect the choice of demolition techniques. The main criteria are: structural characteristics, site conditions, demolition cost, past experience, time, and reuse and recycling. In addition, research done by Kasai (1988) suggested that there are eight criteria: structural form of the building, location of the building, permitted level of nuisance, scope of demolition, use of building, safety and demolition period. Both researchers agreed that the decision makers have to keep in mind that health and safety is the main concern in the selection process.

Chini and Nguyen (2003) recommended some principals for optimum deconstruction both for the industry and regulatory agencies and for building selections. First one is to promote the use of salvaged materials in the design and construction of new buildings. Design new buildings that specify use of a percentage of salvaged or recycled materials. Construction process can utilize salvaged lumber for support structures and formworks. Industry and regulatory agencies can create a market (demand) for salvaged building materials in the local community. This would in turn help keep salvaged material value up and offset deconstruction costs. In addition, it helps to create more jobs and entrepreneurial opportunities.

Second is the cooperation between land use jurisdictions and regulatory agencies to ensure efficient building removal process. Actively involving local enforcement agencies will provide guidance before the removal begins, discuss respective needs, and prevent regulatory gaps. The next one, giving a reference to Cook (1997), is deconstruction permit. Typical demolition permit contains a waiting period before new construction. Deconstruction permit would extend that period to accommodate manual labor. Permit fees should be based on the projected volume of wastes. The permit should be a one-stop for deconstruction, which can save contractors time and the land use jurisdictions indirect costs.

The operations of building demolition should be scheduled to increase the possibility of re-use of structures, components and materials. This is only possible by changing the demolition phase into deconstruction. The technical and functional building life can been extended by improving its quality and sustainability through the choice of materials, components, constructive systems, and flexible building structure (Giglio and Capua, 2003). Disassembly potential indicates the transformation capacity of structures and informs us as to whether specified material systematization, structuring, and detailing (of building or system configuration) are suitable for expected use scenarios (Dumisevic, Cifcioglu and Anumba, 2003).

The deconstruction process will run into further obstacles even after addressing all required items. All the constraints or a combination of them can drastically reduce the diversion rate (Chini and Nguyen, 2003). These are project specific constraints, which some are outside the control of participating parties, that will limit recovery rate. They include labor constraints, site constraints, project funds, and weather constraints that are briefly explained in the subsequent sentences. Insufficient number of workers will reduce productivity or the amount of material recovered in a given time. High labor cost is one reason for lower number of workers. Lack of experience will also lower productivity, but will improve over time. This can also increase damage while removing components.

Small site hinders maneuverability, thus lowering productivity, limit amount of on site storage and processing (sorting and de-nailing) spaces. Proximity of other structures will also restrict workspace and maneuverability. Site conditions decreased productivity and diversion rate at some buildings. Adverse conditions included small size of the lot, vegetation, and proximity of other structures. A large obstacle-free site improved maneuverability, thus increasing recovery rate. Larger site allowed workers to position processing areas closer to their immediate work area. This freed up time it would take to transport the removed components to a single or off-site processing area (Chini and Nguyen, 2003). Small deconstruction budget, unless publicly funded, will limit number of workers, equipment and tools. The budget can also trim profit margin, since most salvaged materials are not resold right away. Most deconstruction projects will lose money before gaining back from resale. Adverse weather conditions (rain or heat) can lower productivity and also damage exposed materials.

The recovered materials have to be reused or recycled. The cost-effectiveness of deconstruction versus demolition depends on the value of recovered or salvaged materials. More diverted materials mean more value and income to offset costs associated with deconstruction (Chini and Nguyen, 2003). In the following parts different phases for increasing the value of disassembled materials are explained:

2.1.3.1 The Industry and Regulatory Agencies

Chini and Nguyen (2003) claim that industry and regulatory agencies can create a market (demand) for salvaged building materials in the local community. This would in turn help keep salvaged material value up and offset deconstruction costs. In addition, it helps create more jobs and entrepreneurial opportunities. Design new buildings that specify use of a percentage of salvaged or recycled materials. Finally, construction process can utilize salvaged lumber for support structures and formworks. Actively involving local enforcement agencies will provide guidance before the removal begins, discuss respective needs, and prevent regulatory gaps. (Cook 1997)

Typical demolition permit contains a waiting period before new construction. Deconstruction permit would extend that period to accommodate manual labor. Permit fees should be based on the projected volume of wastes (Guy and McLendon, 2001). The permit should be a one-stop for deconstruction, which can save contractors time and the land use jurisdictions indirect costs (Cook 1997). Licensed contractors who specialize in demolition are encouraged to incorporate deconstruction into their services. The combined experiences of their crew(s) will provide necessary skills to disassemble buildings efficiently and cost effectively. Training programs will aid in effective recovering of materials. Any contractors licensed for demolition (deconstruction is considered demolition for permit purposes) should provide general liability insurance, workers compensation insurance, bonds and other forms of surety. Contractors would also file Liens and Liens releases.

2.1.3.2 Building Selection Phase

The site's location must be considered to assess proximity to public view. Market demand is the biggest motivator for deconstruction because it provides opportunities for contractors to participate. Marketability also increases the salvage value of materials in order to offset the costs of deconstruction and make it profitable. If the site is near a main vehicular route or a dense center, the chances for public interest are greater than a rural site. This does not mean that deconstruction of a building on a rural site will divert less materials than an urban site. However, the redistribution of salvaged materials increases, as well as the resale rate.

The area around the building can facilitate the pace of operation. Like construction projects, deconstruction operation requires careful planning of the area for logistical reasons. A typical operation requires space for processing of materials, which include a de-nailing station and disassembly area for large sections of the building. Other required spaces include storage areas for processed materials and container areas for recyclable materials. An ideal site consists of few trees with moderate brushes, slight to no slope, adjacent structure, if any, not closer than 15 feet on both sides, a minimum of 30 feet clearance on any two adjacent sides. If a site does not meet all criteria, adequate measure must be taken to provide necessary spaces. Meaning, additional time have to be taken into account for site preparation. In contrast, a confined site will hinder the pace of operation and reduce the waiting period before new construction. Contractors have to provide off site warehouse if there are no room on site for storage. In addition, time is also wasted for transporting materials off site.

The condition of the building's structure is a strong indication to the amount of materials that can be recovered, but not necessarily the rate of diversion. If the building is relatively in good condition, the crew will feel safer to remove components faster without worrying about structural failures. Good condition also includes little to no physical defects on structural components. Careful investigation of the structure is required to assess the condition before deciding whether to deconstruct or demolish. The investigation might involve studying the latest available construction documents, hiring a building inspector or a licensed structural engineer, hazardous material specialist, and any other demolition experts. However, when the conditions are poor or that the structure is run down, demolition might be the best solution to building removal. Demolition can be cost effective if heavy equipment is used in to clean up after selective deconstruction.

This recommendation for selecting building is at a smaller scale than investigating the building's integrity. A contractor can utilize the same investigative methods as mentioned above. Investigating components' condition can occur simultaneously with building inventory assessment. The ideal condition of individual components include little to no defects or damages that can be remedied with little efforts. In addition, components such as wood framing must not have any signs of termite and water damage. Coring samples of walls, floors and roofs can determine the feasibility of deconstruction. Similarly, when the conditions are poor demolition might be the best solution to building removal.

An important issue for contractor to consider before signing a contract is scale of the project. Meaning, the project must involve more than one building of similar construction type (for example, older residential development). To promote and make deconstruction more feasible, a contractor must select a project that includes removing more than one building. The more buildings deconstructed at one time equate to more potential materials for reuse in larger new projects. In addition, increased supply of similar components with a market can reduce cost of salvaged materials.

2.1.3.3 Operation Phase

This process occurs after a building has been selected for deconstruction and/or a contract was signed. Conducting a building inventory assessment allows the contractor to account for existing materials that can be salvaged. It also becomes an investigative tool for determining the condition of components and subsequently the structural integrity of the building. The value of material can be determined at this state. The assessment finds, quantifies and qualifies the materials in a structure before deconstruction begins (Cook, 1997). In addition, future research on deconstruction could use the inventory to compare the diversion rate and analyze which materials were more feasible to salvage.

Recovered materials should be immediately sorted and segregated right after cleaning or de-nailing. Processing materials requires the most time in deconstruction operation. Controlling the flow of materials on the job site is critical to productivity. Moving de-nailing station(s) near the immediate area of work can reduce travel time. Locating containers and dumpster in a strategic areas, will not only create a safe job site, but also minimize walking time. The efficient handling of material will free up workers to disassemble more material in a given day or can increase the amount of reusable materials by carefully removing them.

The best way to disassemble components from greater height like roof is to transfer large sections to the ground. This method will require light crane or a pick-up truck. Disassembly labor is more efficient on the ground than at heights. It is also safer since workers will be pulling and knocking components free from each other on a flat surface. Using a light mobile crane to lower whole roof section to the ground may reduce labor costs as well as worker compensation insurance.

Combine manual and mechanical deconstruction - Not all buildings are constructed entirely of wood frames. A lot of buildings have masonry components that require more than manual labor to remove. A combination of manual and mechanical approach is ideal for larger deconstruction projects, especially buildings containing brick veneer, concrete masonry units, and concrete foundation. Mechanical deconstruction can save time and money when there are not enough workers.
(Chini and Nguyen, 2003).

2.2 Re-use of Building Materials

> "Finding uses for the useless." (Kim and Rigdon, 1998c: p. 27)

Answering to the question whether re-use of materials is a reality or utopia isn't quite simple; it is a combination of four different aspects: technical, environmental, economical and regulations. Though almost everything is dismantable with the current techniques, there are important points which define the disassembly i.e. feasibility, reduction of an environment impact etc. Recycling effectively reduces the level of materials released to the environment, decreases our dependency on virgin material sources, and develops sustainable economies. The success of recycling relies not only on effective recovery strategies and markets for recovered materials, but also on the availability of materials that are easily recyclable. Chini and Nguyen (2003) state that the cost-effectiveness of deconstruction versus demolition depends on the value of recovered or salvaged materials and their rate of recovery vary with the methods of deconstruction.

According to Erkelens, re-usable materials are materials that do not require any treatment apart from cleaning. Recyclable materials are materials that may be used as raw material for the production of new materials. Similar to Erkelens, Kim and Rigdon (1998a) divide building components derived from resources three major categories *re-used materials* that are re-used after minimal reprocessing, r*ecycled-content material*s that are highly processed composites usually containing a post-consumer-recycled feedstock held together by some form of binder, *byproduct-based material*s these employ minimally processed agricultural or industrial byproducts.

2.2.1 Sustainable Building Design

A definition of *sustainability* is "meeting the needs of the present without compromising the ability of future generations to meet their own needs." (Kim and Rigdon, 1998a: p. 6)

In industrialized, capitalistic societies, consumption is regarded as a virtue. Kim and Rigdon (1998a), imply that it is plausible for a society to establish resource-efficient social and economic infrastructures while raising its economic status. This in turn increases the combined impact of architecture on the global ecosystem, which is made up of inorganic elements, living organisms, and humans. The goal of *sustainable design* is to find architectural solutions that guarantee the well-being and coexistence of these three constituent groups.

Parallel to that the ultimate goal and challenge of sustainable design could be defined as to find "win-win solutions" that provide quantitative, qualitative, physical, and psychological benefits to building users.

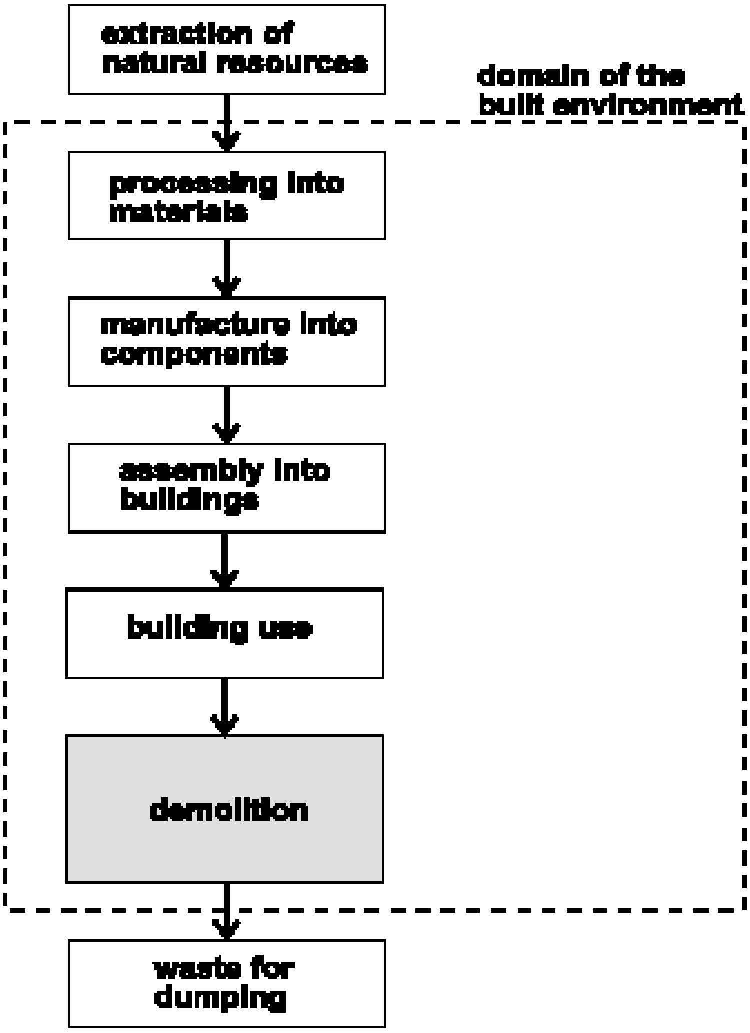
Crowther (2001) states some basic principles for sustainable activity:

- Conserving energy, a building should be constructed so as to minimize the need for fossil fuels to run it;
- Working with climate, buildings should be designed to work with climate and natural energy sources;
- Minimize new resources, a building should be designed so as to minimize 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 recognizes 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.

In order to achieve environmentally responsible construction it's very crucial to minimize resource consumption, maximize their re-use and use renewable or recyclable resources. In addition protecting the natural environment, creating a healthy, non-toxic environment and pursue quality in creating the built environment is not less important.

2.2.1 Theories for Hierarchy of End-of-life Scenarios

In the hierarchy of actions required for closing the materials loop, protecting the environment, and conserving resources, deconstruction and materials re-use ranks above recycling and just below minimizing the mass of materials used in the built environment (Figure 2.5). Crowther (2001) presents seven theories for hierarchy recycling scenarios, each concerning with different stage of built environment, in order to explain concept of recycling. The first four theories are related to industrial design concept, the notion of reduced environmental impact through improved rates of material and component reuse to minimize waste.



.

Figure 2.5 Dominant Life Cycle of the Built Environment ,cradle to grave (Crowther, 2001: p. 13)

(i) Young (1995) in the writing on industrial design and product manufacture for reduced life cycle energy consumption, discusses 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.

From the point of view of conserving energy during manufacturing, Young (1995) 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 process, the least energy use and the least environmental burden.

(ii) Ayres and Ayers' (1996) 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.

(iii) Also writing on the topic of Industrial Ecology, Graedel and Allenby (1995) propose the end-of-life scenarios of maintenance, recycle subassemblies, recycle components, and recycle materials. Within the context of Young 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 recognize the environmental hierarchy of the scenarios, in which maintenance is preferable to remanufacturing, which is in turn preferable to recycling.

(iv) Yet another group of end-of-life scenarios is intended by Magrab (1997) who explicitly refers to the scenarios as a hierarchy. He uses the terms re-use, 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 (1997) notes that the higher one in the hierarchy the more the investment of raw materials, labor and energy is conserved.

Most writers in the field of environmentally sustainable architecture have noted the environmental advantages of re-use and recycling, and there are many excellent examples of built work where materials and components have been re-used. Despite this there has been until recently a lack of critical analysis of the possible effects that re-use 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.

(v) Fletcher, Popovic and Plank (2000), 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; re-use, repair, reconditioning, and recycling of materials. Grouping the scenarios into two levels, the product level, and the material level then simplify the model. The scenarios of re-use, 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. Firstly *Systems level*: Adaptable building, which can change to suit changing requirement. Then *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. And lastly *Material level*: When a product has been stripped back its constituent materials these can undergo recycling.

(vi) Guequierre and Kristinsson (1999) 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, they 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-re-use scenarios of landfill, and incineration.

Guequierre and Krstinsson's (1999) 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 re-use as a system.

(vii) Kibert and Chini (2000) 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, re-use, 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 re-use is similarly broken into the re-use of materials and the more advantageous re-use of components or products. Table 2.1, not only displays the hierarchy of the parts of the theories, including Crowther's own scenario at the end but also distinguishes the relation among all groups of recycling.

Crowther (2000) summarize end-of-life scenarios mentioned above in four (differently scaled) possible technical results, which have been previously proposed by the author; the re-use 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 re-use or relocation;

-Component re-use or relocation in a new building;

-Material re-use in the manufacture of new component; and

-Material recycling into new materials.

Table 2.1 Levels of Hierarchy of End-of-life Scenarios , Recycling (Crowther, 2001: p. 17)

Reference	**Young** (1995)	**Ayres** (1996)	**Graedel** (1995)	**Magrab** (1997)	**Fletcher** (2000)	**Guequierre** (1999)	**Kibert &Chini** (2000)	**Crowther** (2000)
Most desirable					System Level			Re-use building
↑	Re-use	Re-use		Re-use	Product level	Repair product	Re-use of product	Re-use product
	Maintain	Repair	Maintain		Product level	Repair product	Re-use 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	
				Burning		Burning	Burning	
Least desirable				Landfill		Landfill	Landfill	

The first scenario, *building re-use* is that of relocation or re-use of an entire building. This may occur where a building is needed for a limited time period but can later be re-used elsewhere for the same or similar purpose. A good example of this is the Crystal Palace of 1851. The second scenario *component re-use* is the re-use of components in a new building or elsewhere on the same building. This may include components such as cladding element or internal fit out 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. The third scenario *material re-use*, 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 re-used or re-processed into smaller members. Even today we still see the re-use 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. The final scenario *material recycling*, 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. Lastly, end-of-life scenarios proposed Crowther are depicted as 'domain life cycle of built environment' in Figure 2.6.

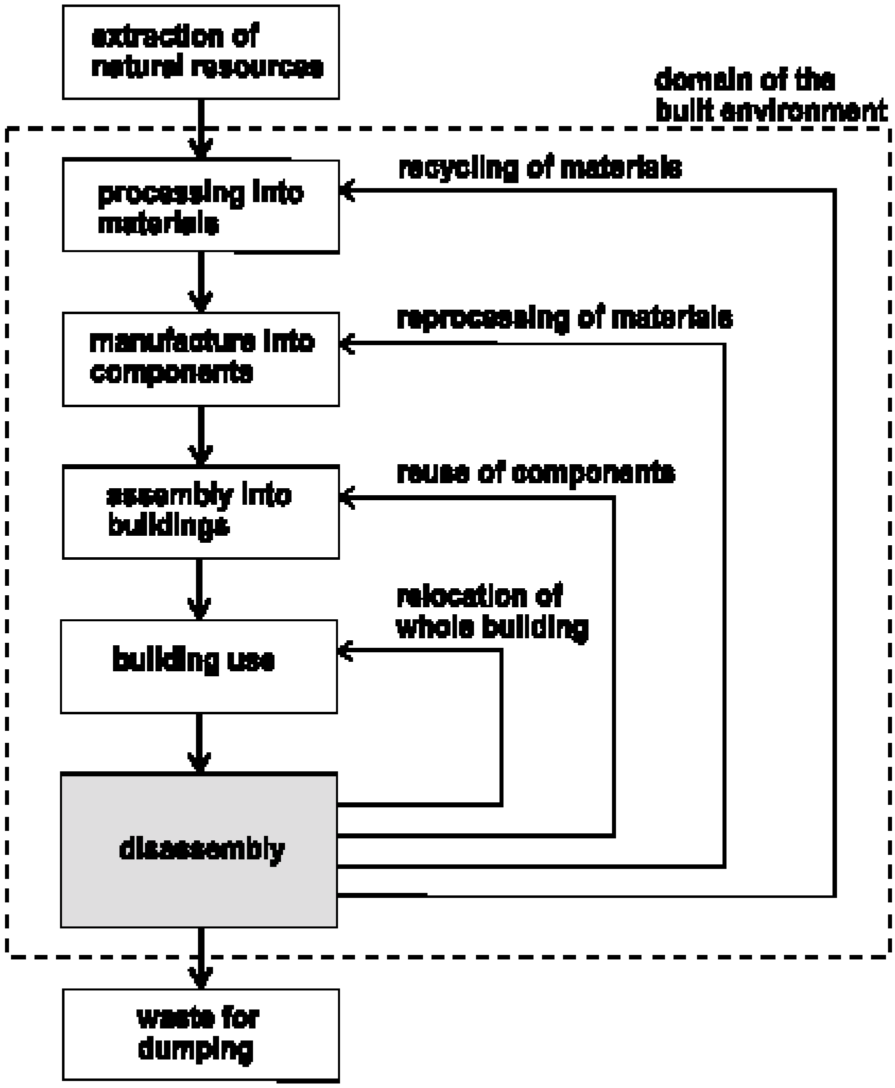


Figure 2.6 Possible End-of-life Scenarios for the Built Environment (Crowther, 2001: p. 18).

2.2.3 Market Demand

To make a choice between different materials, which can be used for the manufacturing of products or constructions, the main issue is to define how do they perform with respect to their material properties such as: strength, corrosion, durability, etc. The level of the performance will then be compared with the price paid for used material with respect to new materials. With time the choice becomes more complex as expectations are increased concerning safety, utility, fire resistance and low energy use.

Market demand is the biggest motivator for deconstruction because it provides opportunities for contractors to participate. Marketability also increases the salvage value of materials in order to offset the costs of deconstruction and make it profitable. As mentioned earlier, the chances for public interest are greater than a rural site when the site is near a main vehicular route or a dense center. This does not mean that deconstruction of a building on a rural site will divert less materials than an urban site. However, the redistribution of salvaged materials increases, as well as the resale rate and the construction type. The market demand will motivate deconstruction to supply salvaged wood products. Since both salvaged dimensional lumber and wood finishes are attractive to post market consumers, wood is still a commodity for most construction types. Wood framing had the highest recovery rate than most of the other material in the buildings. In addition, individual wood components are lighter to manually handle and easier to separate (Chini and Nguyen, 2003).

There are two distinct market sectors related to resource recovery, each with their own characteristics and issues. Markets for low volume, high value, rare, unique or antique architectural components appear to be well established or developing, and are largely self-supporting economically. This sort of recycling occurs nationally almost irrespective of the size and financial circumstances of the locality. Many of these recyclers are small, essentially connected to the domestic market and will pass customers on to other similar organizations if they do not have the items the client require. Native timber and bricks are also often held in the salvage yards of demolition contractors. The market for such items is flourishing and it is often difficult to meet demand. Specialist equipment and machinery is sometimes recovered from buildings and often pre-sold before removal (Storey and Pedersen, 2003).

Some other recovered materials are high volume, low value, such as concrete. The market for such materials in New Zealand is currently restricted and is mainly in Auckland where there is a shortage of readily accessible, local aggregate (Appendix C). For more geographically isolated areas with low or dispersed populations it is more difficult for the salvaged goods market to grow due to the scale of economy and the inherent physical and economic feasibility of creating usable products and finding local markets or transporting heavy and bulky items to larger centers. Growth in these areas would require subsidies, which would have the effect of distorting the market and would be unlikely to find favor in the current political climate (Storey and Pedersen, 2003).

Direct sales of the processed material from the site of processing will mean transportation is minimized and this practice should be encouraged. As might also provide free or very low cost dumping of separated clean C&D waste, which would facilitate future recovery once, volumes or market conditions permitted this (Storey and Pedersen, 2003).

Elias-Özkan (2002) suggest that demolition contractors and used building material sellers should get together to form a such a cooperative that it could easily help the members maintain a catalogue of material available at each yard. Better still, these yards could specialize in certain components or fixtures only and the cooperative could step in to collect and distribute building material from the demolished structures. Establishing a web-site through the cooperative and putting the itinerary on-line will make the purchase of second hand material less of a hassle and also more accessible by advertising the available stock.

(I) Storage

The store can range from 8,000 square feet to 25,000 square feet and larger plus yard storage. Several stores in larger cities hover in the 20,000 square foot range. A store is viable somewhere from 8,000 to 10,000 square feet (same is in Bentderesi in Ankara). Going beyond that in size depends on three things: handling framing lumber in an efficient manner, how quickly good material comes along, which is generally related to size of town, and how disciplined management is about discounting, giving away and/or throwing away stale inventory (Odom, 2003).

The most important selling aspect in any retail facility is the organization and display of goods. 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 resulting from the demolition of buildings. Kim and Rigdon (1998c) insist that to many people, a re-use business looks like a junkyard; however, if the yard is designed as an enjoyable shopping environment, the merchandise will sell. Keeping the yard safe, clean, and organized is a routine problem for re-use businesses (Figure 2.7). Tidiness is imperative in this business. As retailers, these businesses need to remember to keep the merchandise accessible (Odom, 2003).

Figure 2.7 Salvaged wood materials at Second Use in Woodinville, WA (Kim and Rigdon, 1998c: pp. 72-73).

One of the first improvements needed in a used building materials store is removable door and window storage rack. These can be constructed out of salvaged materials if any is available yet. Eventual storage of over 500 doors is not uncommon for a store, and this is made easier by removal of at least the knobs from the doors, if not the hinges also. It also protects the doors from damaging each other. The heaviest and most often sold things, like solid core doors, should be close to the loading door. Lighter or less frequently sold items can be in either areas of low ceiling height, on a second floor if there is one, or toward the back of the store. Although toilets sell well, they are best kept hidden away for aesthetics, while the occasional porch column or Victorian spindle is worthy of placement near the cashier.

An item well displayed is already half sold. An average of four or five weeks display time for most materials (with the exception of doors and windows) is a good target. Doors and windows require a larger stockpile to meet the wide demand in size, finish and style the public is looking for, and therefore longer storage time to accommodate the odd style or size. Recovered materials should be immediately sorted and segregated right after cleaning or de-nailing. Processing materials requires the most time in deconstruction operation. Controlling the flow of materials on the job site is critical to productivity (Elias-Özkan, 2003).

(ii) Consumers

Used building material customers are primarily homeowners, often do it yourselfers. Landlords, arts and crafts folk, and small business owner/operators are also regulars. Some stores that advertise use the classifieds in the daily paper as well as the weekly advertiser type paper for reaching these customers. Classified advertising is essential to a small size store not only to keep your business name in the public eye but also to help manage limited space (Odom, 2003).

2.3 Timber Re-use

The need to focus on wood construction is due to the fact that there are tens of thousands aging residential and other similar buildings that require demolition in the world. A very high percentage of them were constructed using wood as structural and non-structural components. The salvaged lumber held the most value and had the greatest potential for re-use.

According to Kim and Rigdon (1998c), *wood* is the harvested material most commonly used in buildings and building products in residential buildings and many commercial structures in US. Wood products such as plywood, particleboard, and paper are used extensively throughout the construction industry. Until recent years, the most common method of harvesting wood was clear-cutting, a process wherein all vegetation within a given area is removed for processing. Now, where clear-cutting takes place, lumber companies are required to replant the area. Some lumber is now being produced on tree farms ("plantations"). However, replanting alone does not replace the natural biological diversity that existed before harvesting. Monoculture (same-species) plantings are particularly vulnerable to disease and insects. More companies now practice "selective cutting": choosing only those trees large enough or valuable enough to remove and leaving the surrounding vegetation intact. Sustainable forestry practices include a professionally administered forestry management plan in which timber growth equals or exceeds harvesting rates in both quantity and quality. In addition, rivers and streams are protected from degradation, damage to the forest during harvesting is minimized, and biodiversity and fair compensation to local populations is emphasized.

Kim and Rigdon (1998c) further declare some environmental problems during harvesting of wood such as loss of biodiversity, plant and animals habitat, species extinction, solid erosion, deforestation, and increase carbon dioxide in atmosphere with the result of increase of global warming. Also during the production of lumber, fuels used in mills pollute the air through the emission of toxic gases such as carbon monoxide (CO) and sulfur dioxide (SO2). Environmental and health hazards associated with these gases include global warming, decrease visibility, smoke, eye irritation, and lung damage.

Kim and Rigdon (1998c) declare that job-sites generate wood in the form of construction, demolition, and land clearing debris. Construction debris includes off-cuts of engineered wood products, solid sawn lumber, and pallets from material deliveries. Demolition generates timbers, trusses, framing lumber, flooring, decking, and millwork, doors, and window frames suitable for re-use or recycling depending on their condition. Wood that is recycled must be free of chemicals, including paint, stain, waterproofing, creosote, pentachlorophenol, petroleum distillates, and pressurizing treatments. The stumps and branches from land clearing can be chipped and composted, recycled as boiler fuel, or re-used on-site as landscaping mulch. Timber joists and planks are mostly bought by building contractors for formwork or scaffolding.

Hobbs and Hurley (2001) state that timber recycling is now a common route for large amounts of untreated timber waste generated in built up areas, in UK. The main market is wood panel product manufacture with virgin feedstock being replaced with up to 30% recycled wood fiber 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 re-used or recycled; formwork presents problems in the concrete and oil contamination. One of its main findings was that “optimal separation of C+DW must take place to maximize recovery of material for re-use and recycling”.

Kim and Rigdon (1998c) classify end-use of wooden materials into three groups. *High-value end-uses of solid wood material*- salvaged wood components and finger-jointed lumber; *high-value end-uses for wood fiber material*- paper, particle-board, fiberboard, oriented strand board, parallel strand lumber, and many fiber-cement and wood-plastic composites, and *low-value end-uses for wood fiber*- biofuel, mulch, animal bedding, and compost bulking agents. Although each end-use has its own specifications, clean, uniform wood debris will achieve the highest possible value. For example, relatively clean lumber off-cuts should be recycled into high-value particleboard or finger-jointed studs, not down-cycled into hog fuel or landscaping mulch.

(i) Environmental Benefits

Timber is a natural renewable resource and as such can have a very low environmental impact, though a greater amount of recycling and re-use will obviously benefit the overall environmental audit for building components. There is however current re-use of high value items such as large section beams and timber flooring, although a potential to greatly increase the amount of timber suitable for re-use in construction still remains. Nailed connections used frequently in timber construction offer potential for accidents. Such risks are reduced by the help of safety clothing, such as steel mid-sole boots and protective gloves for handling.

The most common and most reusable material that results from deconstruction is timber. Guy (2001) asserts that recovered timber components and elements for direct re-use 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. 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.

(ii) 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 re-use or recycling. According to Hobbs and Hurley (2001), 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 structural re-use. Either option would require research to establish basic rules for re-use 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 re-used or recycled.

The salvaged lumber held the most value and had the greatest potential for reuse. Each piece of recovered lumber went through some kind of visual grading by certified inspectors to determine their reuse potential (Chini and Nguyen, 2003).

2.3.1 Treated Timber Components

Asbestos containing material (ACM) and lead based paint (LBP) were the two culprits that plagued deconstruction. Most of the buildings had some form of ACM and/or LBP, which required professional abatement before deconstruction could began. Hazardous material abatement applied to demolition as well when jurisdiction called for. As a result, diversion rates were affected by discovery of ACM and/or LBP (Chini and Nguyen, 2003).

A note on the careful consideration of finishes and adhesives; the use of lead-based paint, asbestos containing materials, and messy, difficult-to-remove adhesives has been a barrier to the successful deconstruction and reuse of materials. The required investment in time and money to remove and dispose of these contaminants has made many prospective deconstruction projects unfeasible. Learning from these past mistakes when designing for reuse will help preserve the materials on into the future (Willims and Guy, 2003).

Giving preference to recycled materials, to simple materials, not composite, reusable, limiting the use of hills, varnishes, can be avoided that the separation of these materials becomes problematic. It's important, besides, the components' econstruction modality, so these are not damaged, and this depends on connections' types of the structures: chemistry (hill, adhesive), physics (welding) or mechanics (Giglio and Capua, 2003).

If hazardous materials are present, an aggressive approach to removing these materials for safe disposal is preferable to allowing them to leach into soils and groundwater over time from the decay of the building(s) (Guy, 2003).

The hazardous materials management plan includes proper recycling and disposal of all other hazardous materials besides asbestos and lead-based paint, including refrigerants, chemicals and paints, mercury, PCBs, etc. Reward the site separation of all hazardous materials including those that may be left where only a partial removal of salvageable materials takes place (Guy, 2003).

The applicability of lead and asbestos regulations are dependent on type of structure, size of the structure, previous use of the structure, end-use of a structure or its component materials, owner of the structure, location/ relocation of the structure. (Houlemard and Cook, 2003)

Types to deal with LBP

The existing buildings contain high quality, low value materials whose reuse is complicated by LBP. To make matters worse, lead based paint was originally thinned with leaded gasoline resulting in the lead contamination substantially penetrating the substrate material. The buildings each have unique histories of maintenance and repairs, which complicates hazardous material abatement projections. The presence of LBP restricts the potential for reuse or relocation of buildings where there is a potential for contact with children. Up to 50% of building removal cost is attributable to hazardous material abatement. An upfront program for systematically evaluating the unknown hazardous materials is required. Post-deconstruction soil sampling showed that the activities of deconstruction did not create any LBP soil contamination (Houlemard and Cook, 2003).

A different solution, for industry and regulatory agencies, may be to use demolition standards for handling LBP and ACM. Deconstruction is a form of building removal. Many regulatory agencies require hazardous material assessment and abatement for any building that require removal. Demolition standards could address many common issues concerning proper procedures and practices, such as the safest way to manually disassemble components that contain low levels of hazardous material (beneath the threshold level that classifies the material as hazardous), or how much air exchange per hour is required. Asbestos surveying and handling, as well as lead surveying and handling are required for both demolition and deconstruction. This enforcement creates an equal starting point for both forms of building removal (Chini and Nguyen, 2003).

In the operation process, provide wall and floor coring as part of investigating the content of materials and building material inventory. Discovery of hidden asbestos layer after work has begun can hinder progress dramatically (Chini and Nguyen, 2003).

Any hazardous material must be removed, leaving less material to be recovered. Some hazardous materials are disposed of when the cost of abatement does not justify cleaning or that the components that contained it does not have a reuse potential. For the health of workers and the environment, the correct and safe handling and disposal of all hazardous materials should be followed (Guy, 2003).

One of the most onerous aspects of modern architecture and construction readily found in most US buildings built before 1970 or so is the presence of LBP and ACM.

At a secondary level, PCBs, mercury, and ozone depleting chemicals are also hazardous materials that greatly complicate the recovery of building materials for re-use and recycling while not endangering workers and/or expending large sums to separate these materials from potentially reusable or recyclable base materials or sub-components. The regulatory requirements for worker protection and disposal of hazardous materials were a large cost for the deconstruction of older wood-framed residential structures, and the presence of lead-based paint is an impediment to wood re-use.

2.3.2 Untreated Timber Components

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: damage during the construction process, which includes nail holes, bolt holes 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.

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 major barrier to the structural re-use of salvaged dimensional lumber is the lack of up-to-date grading or certification stamps. 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 (about 30%) or disallowed and is not used for its highest value use (Chini. and Acquaye, 2001). 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.

Chini and Acquaye (2001), report the results form 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 - 1997. The measures showed that the stiffness of the recycled lumber measured by its Modulus of Elasticity, was found to be approximately equal to that of current production. Bending strength of the lumber salvaged measured by its Modulus of Rigidity was somewhat less than the bending strength of lumber produced today.

Factors, affected the salvage value and marketability of the materials, are categorized by Chini and Acquaye (2001). The affect of the first factor, type of materials, is stated as the framing lumber, which had wide application and used in large quantities was relatively easier to sell while finished materials such as windows and hardwood flooring which have specific dimensions, specific uses and require more targeted marketing. The second factor, time of year, the interest of construction firms and do-it-yourselfers in building materials in the summer or spring is much more than in the winter, depending on the geographic location. The next factor, condition of the local economy means demand for building materials goes parallel to construction and remodeling activity. And the last factor is retail-building material where 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.

Furthermore, lumber recovered from demolition is being used in renovations and new construction, for both environmental and aesthetic reasons. Timber-framed structures are often dependent upon recycled wood due to the difficulty in obtaining large logs. Timbers, flooring, trim, and paneling are salvaged from the demolition of old houses and barns, then cleaned up and re-sawn if necessary.

According to Guy, Shell, Esherick, Homsey, Dodge & Davis Architecture (2002) more than nine residential structures have been deconstructed by the Center for Construction and Environment between 1998 and 2002. These structures were light wood construction on wood floor structures raised on piers. Walls were lightwood framing with drywall, wood lath and plaster, wood interior finish, wood exterior finish and combinations of asphalt shingle and metal roofing. Light wood framing is also known as “stick-framing” which indicates the method of construction and hence most appropriate method of deconstruction, i.e. stick by stick. As wood has considerably more value in re-use than in recycling and mechanical equipment is difficult to use at a “stick-by-stick” level of disassembly, this type of structure lends itself to hand deconstruction.

These structures were typically deconstructed by removing all interior non-structural elements, layer by layer, removing the structural elements starting with the roofs, then the load bearing walls, then the floor structure and foundation. Because workers are within the building at every step of the process, the building must be structurally sound at every stage of the deconstruction. Structure versus non-structure, sizes and weights of components and materials, and the height of exterior and interior elements relative to human scale, are key elements that control the deconstruction effort.

Japanese wooden architecture is a complete architectural system in which the expansion, remodeling, removal and reconstruction of buildings are possible according to life styles (Crowther, 2001). 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 remodeled to suit changes in the occupants' requirements without affecting the primary structure and without the wastage of building materials that other techniques produce.

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).

According to Kim and Rigdon (1998c), wood building materials have evolved to make use of formerly undesirable small-diameter and faster growing trees as well as the off-cuts from mills. The new generation of engineered lumber products that are manufactured using resins, heat, and pressure include I-joists, laminated lumber from veneers or strands, and finger-jointed lumber. The consistently high quality of manufactured framing material over solid-sawn lumber results in less waste at the job-site and an immediate 10–15 percent cost savings, because builders can use everything sent to them.4 Factory-made panel systems, such as the stressed-skin foam-core and paper honeycomb-core structural panels are also inherently less wasteful due to highly efficient material-to-strength ratios. Because engineered and panelized products are manufactured according to the designer's specifications, the wastes can be "swept up" in the factory, thereby avoiding more costly recycling or disposal efforts at the job-site.

CHAPTER 3

MATERIALS AND METHOD

In this chapter are presented materials and methodology of different surveys performed by the author to research local practice of deconstruction on site and re-use of timber components in Turkey. The feasibility works of UBM were done in the context of Ankara. The prices are compared with virgin material costs and a case of residential unit building is examined. Materials and methods used in this study are explained in sections 3.1 and 3.2, respectively.

3.1 Materials

It should be noted that it was very difficult to find any published materials on salvaged building materials and their re-use in new projects in Turkey. Furthermore, on-line information related to re-use of timber components in other countries of the world was also limited to some small-scale projects and few conferences reports.

Four separate two-storied buildings were observed and photographed during the deconstruction process, in Sögütözü locality. The area is situated between the Sözütözü road and the military field at the rear of the Ankara Intercity Bus station (AŞTI). The purpose of deconstructing and demolishing of the old single and two story concrete framed squatters, probably built in 1960's, is to clean away the 5.000m2 area for huge construction of a big shopping mall, office units and residences. All components were taken away separately (selective deconstruction) and transported according to their classification, like windows and doors first, timber components and roofing tiles next, interior finishing and other useful materials last.

Timber components from two of the structures were deconstructed in the presence of the author, and the next two were disassembled in a two days period and concrete framework demolished. Informal interviews were taken both with the demolition contractors and unskilled workers from work site and warehouse. The findings are presented in the following chapter.

Deconstruction yards located on the main road to Aktaş were visited several times to observe UBMs yards and data were collected from the demolition contractors. The contractors yards occupying about 600m² total area, 400m² of which is covered, are used as warehouse and re-processing workshop for denailing, re-sizing etc., storage when the recovered materials are waiting to be sold, and display area of used building materials (UBM). In the yards different building materials are stored and sold, such as roofing tile, brick, door-set, fenestration, kitchen sink, wash-basin, iron grill, steel elements/components etc. Not all are supplied from the same yard, however there is distinction between the owners, while some are concentrating on steel products, others sell brick and roofing tile or timber components.

Lastly a price list of UBMs was collected from the market in Ankara, from yard owners in Bentderesi locality. The prices of virgin materials, on the other hand, were collected from new timber materials sellers in Siteler area. The data were summarized in a table in order to make comparison between them.

The data for the five-story building (consisting of an area of 2.650m²) were supplied by theNurat Ayter, quantity surveyor. The concrete framed structure consists of hollow brick walls, plastered and painted. Timber skeleton of pitched roof is covered with standard guttered roofing tiles and rain gutters are made of zinc. The fenestrations are double glazed timber framed, while door-sets are made of hard white wood. The white marble is used in staircase whereas ceramic tiles in varying sizes are applied in kitchens and wet spaces. The architectural drawings were not available from the architect.

3.2 Method

In the light of the materials obtained from the literature survey on the timber re-use from the libraries of METU and Bilkent Universities and web research the previous works being done in other countries, strategies were decided. After a brief research in Ankara, it is been revealed that UBM are being sold in Bentderesi Avenue on the way of Aktaş. The first trip was made in November 2001, which was pursued by several surveys in three-year period. Informal interviews with the contractors of building demolition were conducted; observations on the circumstances of display area and labor conditions were made. The very first impression from these observations was that storage and display areas are on the main road, which have a positive impact on the market.

Few photographs could be taken since some of the contractors conduct their business without records or receipts they can get into trouble with the municipality; hence they were not very pleased with any kind of documentation, even with the interviews.

The workers on the deconstruction site in Söğütözü were more open to sharing their knowledge and providing some information about the process of disassembly. Furthermore the photographs were taken during the work process. It was done in the following steps. On the first day two concrete framed buildings of two stories each were examined and the fenestration units, door-sets were disassembled. After that they were transported to the warehouse of the contractors. On the following day the roofing tiles and the wooden structure of the building were taken out and stored separately on the site. Useful interior finishing was extracted and all the elements/components recovered from the structures were carried out. Different phases of the process were photographed by the author.

The figures for the feasibility work prices of UBM were gathered from the deconstruction contractors from Bentderesi, the prices of virgin timber materials were collected from the Siteler, where warehouses and factories for new furniture, furnishings and building materials are located in Ankara. The first table was compiled according to these figures. Moreover, the data of cost estimation of five-story 2650m² building was gathered and represented in tabular form. To clarify the results of the estimated savings when UBM will be used, were depicted in the last table.

CHAPTER 4

SURVEY OF DECONSTRUCTION AND RE-USE OF TIMBER COMPONENTS IN ANKARA

In this chapter are presented findings of various surveys carried out in Bentderesi locality in Ankara, which is a storage and display area of used building materials and the survey on dismantling works was conducted as a basis for investigation in terms of conditions and ongoing practices of re-use of building materials in the province of Ankara.

The objective of this study was not only to show the market of second use timber components in the region, but also to throw some light on the process of dismantling timber components, their transportation and storage in the warehouse. In order to achieve this, observations were made both on the deconstruction site and the market area. Results from the survey are explained in the following part.

4.1 Market for Used Timber

Market demand is the biggest motivator for deconstruction because it provides opportunities for contractors to participate. Marketability also increases the salvage value of materials in order to offset the costs of deconstruction and make it profitable. If the site is near a main vehicular route or a dense center, the chances for public interest are greater than a rural site. Re-use of timber materials is discussed from two angles, where the first are the demolition contractors and the disassembly of structures, and the second are the users of used materials and their usage types.

4.1.1 Types of Used Timber Components

Demolition or deconstruction of buildings can be seen as an urban source of used building materials. Used timber from demolition houses instead of being just waste to be disposed of, or crushing into chip to be used as fuel, can be utilized in new construction works, or renovation projects. The retrieval of used material is directly related to the re-use conditions that they are going to fulfill. Such building components can be divided into two groups, re-use of UBM elsewhere as they are, and re-used after repairs or alterations. The first group consists of components that were easily dismantled from the structure without much damage; e.g. fenestration, door, and timber girders which are not exposed to the whether conditions.

The second group contains such UBM’s that need repair, re-sizing or alterations before they are used again. It is possible to divide further into three sub-grouping namely:

- Components necessitating simple modification on site or at the time of re-use to fit the conditions like re-sizing of fenestration units or door components;
- Material that need remanufacturing with more sophisticated tools done in yards like alteration of dimensions of joist and rafters and the like, or removal of paint; and
- Material that could not be used anyway like timber chips used as fuel.

All repairs and alterations are carried out in the yards of deconstruction contractors, in a covered space or workshop with appropriate tools in Ankara (Figure 4.1 and 4.2) and other cities of Turkey (Figure 4.3 and 4.4). Moreover, larger companies employ carpenters for repair and alterations, whereas smaller concerns have a preference of using part-time carpenters. They may not waste time on renovating disassembled components altogether.

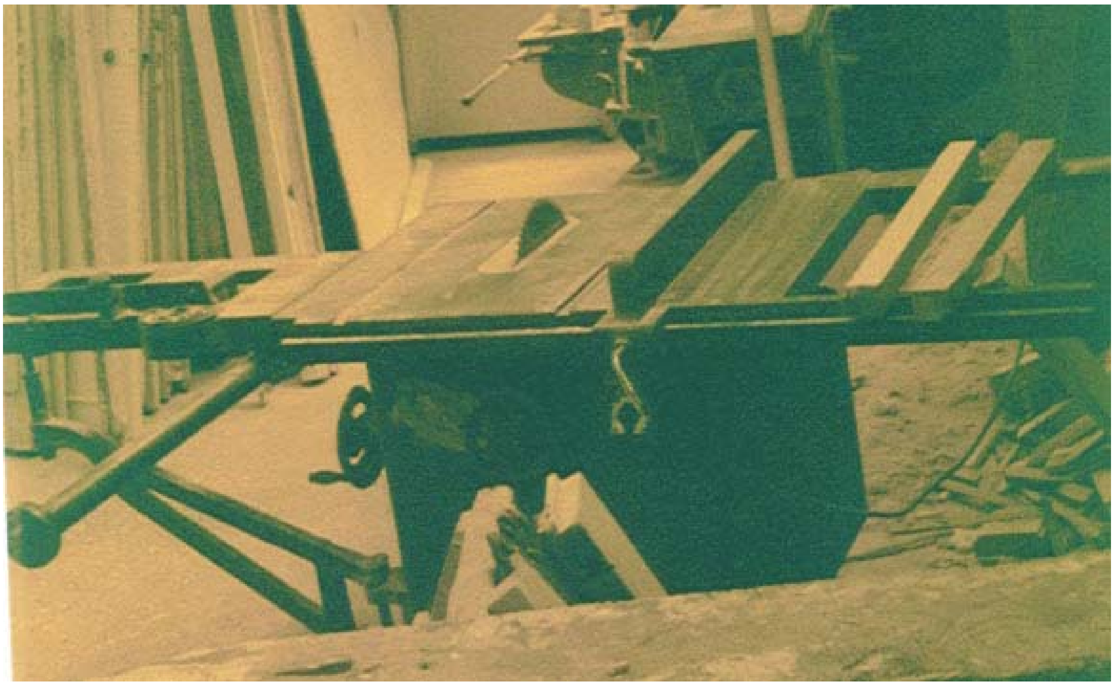


Figure 4.1 Tools for sawing and resizing of disassembled timber components in Ankara

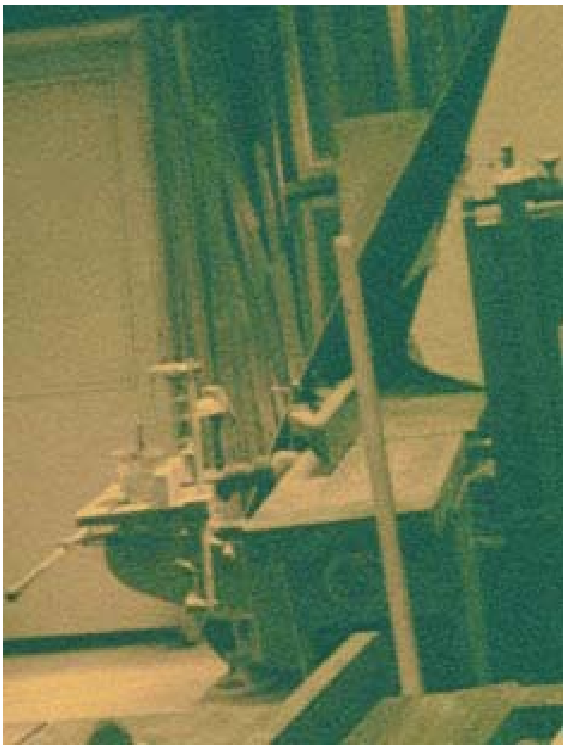


Figure 4.2 Tools for sawing and resizing of disassembled timber components in Ankara

Figure 4.3 Trimming and re-sizing second-hand chipboard for use elsewhere (Istanbul) (Elias-Özkan and Düzgüneş, 2002).

Figure 4.4 Workshop for repairing used timber fenestration and door sets (Izmir) (Elias-Özkan and Düzgüneş, 2002).

Timber elements like joist, planks, posts and boards, unlike fenestration and door-sets, which may require repair, are first de-nailed and then sawed to remove any rotten or damaged parts. Additional works are removing the lead-based paint and acetone protective chemicals that are hazardous materials and need to be disposed off more carefully.

Timber elements mentioned above are sold directly from the deconstruction site, so as to save on additional transportation cost, or else from the contractor's warehouse or yard directly to the user. Contractors of USB are located in Bentderesi Avenue one of the busiest main roads in Ankara. This not only facilitates the unloading of deconstructed components from trucks, as it is shown in Figure 4.5, but also increases their sales sell. Small storage area and economic criteria force merchants, to sort materials according their heaviness, average time of being sold, re-use value. It should be noted that all kind of disassembled timber components are re-used, one-way or another. The range is varied from joist, planks, posts, boards, floor, ceiling finishing and façade coverings to fenestration, door-sets, kitchen cabinets etc.

The general scope is residential houses not higher than five-story, which do not need any special workmanship and so disassembly cost is low. These are concentrated on the old residential houses in Ankara like Balgat, Sögütözü, Dikmen, Aydinlikevler. Rarely, the deconstruction contractor works on industrial building only if it is worthy enough to be done.

An informal interview was carried out at first with the contractors, then with the workers from both contractors' warehouse and different deconstruction sites. The contractors and workers are not willing to share information of their business.

Figure 4.5 Disassembled timber components waiting on the pavement to be stored in Bentderesi.

4.1.2 Suppliers

Demolition companies are present in all big cities of Turkey. The demolition companies in Ankara, which are situated on Bentderesi Avenue concentrate mostly on recovering timber components from the buildings they demolish; i.e. boards, rafters, battens and joists, doors, fenestration, in addition to steel reinforcement, aluminum components, roofing tiles, bathroom fixtures and kitchen cabinets. These materials not only bring in a quick profit, but also take up less space than bulky materials, such as used brick and concrete. The number of workmen employed can vary from as few as four to as many as fifteen. The duration of disassembly process depends on size and complexity of the project and the team. The conditions of the workers in the warehouse, however, were not very healthy. Although they work in unsafe circumstances both on the work site of demolition and the storage area, they were neither well paid, nor were they insured. Furthermore, they are not regular workers throughout the year.

Usually the deconstruction contractors do the job for the price of the recovered materials that is no payment is made. This is preferable in most of the cases where the structure covers the expenses of the work. However if the building contains much profitable components contractor have to pay for disassembling process. Or this can be just as opposite if the materials are not in good condition to be sold. The contract that is undertaken depends on the potential and/or the re-use value of recovered construction materials. Consequently this is a business and the practice is an agreement between two parties.

4.1.3 Buyers and Users

In the region of Ankara, like in other two big cities Istanbul and Izmir, re-use of disassembled components are chosen for their economy instead of environmental benefit. The understanding of environmental benefits stay behind the economic opportunity. However, the entire business of deconstruction-sale has positive effects on local social context, both by providing low-cost materials and generates a new work opportunity to local unskilled workers. In addition it also helps to preserve the historic craftsmanship of traditional timber arts of Ankara. The concern for economy is the main driving force. The users of UBM and different ways of their reclamation are explained in the following parts.

(i) Squatter's

Architects do not generally consider timber material removed from old buildings as an architectural component, but the range of users is not as narrow as expected. The most frequent customers are squatter's, because of the budget limitations of the users second hand timber components are preferred. The price of second hand material is three times cheaper than virgin one, and some times there is no need for new material and old material can be just as useful e.g. roof tiles or structural timber members for roofing.

The material is used as it is in the window examples where it is enough to fit the fenestration in to the wall the void is arranged accordingly or with simple reprocessing of timber components; like resizing, repainting or removing the old lead based paint. The condition of components and need for additional processing doubles the price. In addition, the squatter settlements proximity to the market in Bentderesi eliminates or decreases transportation costs.

(ii) Villagers from the region of Ankara

Though the transportation expenditure increases with distance another type of customer is the rural dweller from the villages near Ankara. This higher transportation costs can be tolerated due to the low cost of the used material and also increasing the number of components carried so as to decrease the transport cost per piece. In rural areas together with constructing the house similar to the squatter's, with the help of used timber and some additional components like sanitary ware, old timber is also used for building separate toilet stalls, stables and hen-coops. Load bearing and partition timber members, fenestration, doors, floor and façade covering are the main timber materials that are re-used. Used doors have different use like a partition non-load bearing separator wall, which is also done in single students' flats in Balgat, Ankara, and also converted into table tops.

(iii) Merchants from Southeastern and Eastern Anatolia

Another buyer is the used building material merchant from southeastern and eastern Anatolia. Such merchants come from far away towns and villages to buy truckloads of disassembled materials. Almost all kinds of recovered building material from timber joist and planks to door-sets as well non-timber based elements; like bathroom fixtures, steel components etc., fall into the scope of that particular business area. This is an indication of the market for re-used materials hundreds of kilometers away from their point of removal; also the cheap prices of used materials make it worthwhile to carry them to far-off places. Their customer range is not different from that in Ankara, thus villagers, house contractors and if there are any squatters and touristic places. This type of buyer looks for used building materials in good condition, which can withstand long trips and can be sold at a high profit.

(iv) Building Contractors

In big cities there is always a shortage of housing. The contractors of housing construction need timber elements for formwork and scaffolding. Although some big companies have adjustable steel elements for this purpose still many others prefer to use timber. This is because of the high initial cost of the steel formwork as well as the possibility of it being stolen from the yards, which have no security guards. This formwork and scaffolding materials can be obtained from used timber materials in view of the fact that used timber elements are cheaper then virgin one where the virgin materials is not a necessity. Besides, roofing structure of a housing can also be constructed from used materials. Sometimes with the intention of minimizing the cost of construction and saving the total amount of waste produced during the construction stage, formwork and scaffolding timber elements are preferred in roofing.

Also the many of deconstruction contractors use recovered timber in their warehouse to built a shelter for door-set and window units as well as de-nailing and resizing area like in Figure 4.6. Furthermore, they built a shelter for themselves form used timber components and or from some ornamented timber joists and rafters. Not always it looks like old structure waiting to be demolished. It depends both to the quality of timber components as well creativity of the yard owner.

Figure 4.6 Re-use of reclaimed timber in the display area of contractors in Bentderesi.

(v) Interior Decorators

In some old houses the craftsmanship of timber elements is very valuable as it represents an era of old Turkish houses. Wooden gates, timber column, exposed joist and beams wardrobes, and ceiling paneling from traditional houses have fine ornamentations that signify the craftsmanship and way of life of a period gone by. Buyers of such material use them in oriental decoration project of hotels, pubs, restaurants or office buildings. The supplies shed light on the Ankara housing for restoration and repair works.

4.2 Recovery of Timber Components

Before deciding on the process of dismantling the building to recover removable components, the contractor surveys the site and takes decisions according to the condition of the materials and the approximate value of their second use. There is no grading system for the recovered components to show their physical conditions. During this process the important thing is that no tools of scientific nature are used to make accurate calculation on the materials that are going to be re-used. Although Elias-Özkan (2002) states that for official contracts the contractors estimate the amount of building materials according to standards set by the Ministry of Works,

most of them decide the total scope of work on the basis of the contractor's experiences and perceptions. In fact, no matter what their condition is all of the timber materials are dismantled and used in one way or another, i.e. as they are, or after repairs; sometimes they can cut up for other use and lastly if the timber is damaged beyond repair it is used as fuel to burn.

4.2.1 Problems of Deconstruction and Recovery of UBM

As the dismantling is in progress, several problems can be encountered. Some of them arise from the overall design of the whole building and how the parts are brought together the connections of the components, and the type and techniques of construction. Other problems may occur due to faulty workmanship, the ambiguity of connections of timber components, ease of access and their location are the main issues. The finishing generally conceals the structural elements and their connections, which extends the dismantling time. Still, just a few blows on the wall can usually remove the plaster from the timber structure and it can be assessed.

Unnecessary nailing, both by design and/or as a result of faulty workmanship, not only slows the disassembly work but also damages the material. Since the number and the location of nails are not predetermined, overuse of nailing is very common. On the other hand, the main problems encountered with bolted connections and the intermediary iron components in the dismantling process are time limitations of dismantling, and additional tools needed to remove nuts and bolts. Because de-nailing and repairs are done in the warehouse after the deconstruction job is finished no additional workmen are necessary to do this, the extra time required to remove the bolts on the site is seen as a financial burden.

Furthermore, the location and height of the timber units are not as important in the deconstruction process as in renovation and maintenance work. Since the whole building is going to be dismantled and demolished, it is only a matter of removal steps and time. To be more specific, the inaccessible connections of the roof structure at the beginning can be easily detached after removal of roof tiling. Also high location of the components needs important care only in special taller nonresidential building, which is out of the scope of the survey. Limitations in deconstruction of higher buildings are the safety and insurance of the crew that is not considered on most work sites in Turkey. The materials and components first are dismantled and grouped on the same place, like on the roof example, then are brought down with the help of some simple equipment like pulleys, or even manually.

4.2.2 Defects in Used Timber

Disassembled timber may undergo some problems and so physical properties may change. Defects and cracks in used timber components can occur at either or both of the stages of its lifetime i.e. during its first use in a building; construction, maintenance, repair and re-arrangements, or during the dismantling process of the structure; disassembly, de-nailing and repair, re-sizing for their retrieval.

(i) Damage During First Use of Material

Contact with water or damp due to water leakages and/or flooding at any time of occupancy of the building, in addition to extended use, may cause decay and deformation of timber components. Two examples of that kind of timber damage are illustrated in the Figure 4.7 and 4.8. Although the damage or wear and tear is directly related to the type of the timber used, insects cause substantial damage to untreated components. These defects not only affect its appearance and color, but also decrease or even exhaust its bearing and shearing properties, which may lead due to collapse of the component or of the whole structure during its life or while dismantling is going on. Also the more holes there are on the timber components after de-nailing, the less is its reuse value and structural properties. Conversely fewer nail holes preserve material and increase reuse value while minimizing the time needed for disassembly.

(ii) Damage During Dismantling Process

In Turkey when buildings out live their usefulness they are usually demolished. The workforce employed to demolish the building is normally unskilled, hence it is not very sensitive about recovering materials with the least damage. Tools like adze, sledgehammer, pliers, pickaxe, shovel, mallet and crank are used to dismantle the components that if not used carefully can damage the material. Use of brute force and improper tools can give significant harm both to the physical properties and original form of the material. Furthermore time limitations on the work site decrease the need for careful dismantling and hence the amount of the re-usable timber.

Lack of experience will lower productivity and increase damage while removing components. These defects are, broken or cracked edges due to wrong use of disassembly tools; and too many nail holes at the edges of timber components. The damaged ends are cut off in order to obtain the real re-usable length of the timber, which is a not less that two meters in length. The arsenic in the treated materials, though it is harmful to the environment if it is thrown away, but since its removal is very complex it is not usually removed. Such timber is repainted and re-use or cut-off to be burned without taking any precautions.

Figure 4.7 Defects on timber components occurred during its first usage.

Figure 4.8 Defects on timber components occurred during its first usage.

4.2.3 Storage of Recovered Materials

The disassembled materials, as they are not always sold immediately, have to be stored temporarily in the work-site and for longer time in the display area. Accordingly free space is needed not only for de-nailing, repair and re-sizing, removing lead-based paint or asbestos contained treatments before reclaiming timber elements, but also to separate and store different materials apart from each other to be distinguished by the potential user. Clean, well organized, and accessible storage and display area while increasing the possibility of selling UBM, decrease the area needed. In the case of Ankara, the safety of work team of the deconstruction process and their insurance are not taken into the consideration, and because of the area constrains safety in display area is ignored. These are clarified in the following paragraphs.

(i) At the work site

The area around the building that is going to be deconstructed can facilitate the pace of operation. A typical operation requires space for processing of materials, which include a de-nailing station and disassembly area for large sections of the building. Other required spaces include storage areas for processed materials and container areas for recyclable materials. On the contrary, small site hinders maneuverability, thus lowering productivity, limit amount of on site storage and processing (sorting and de-nailing) spaces. Proximity of other structures in urban sites and plantation, which is demonstrated in Figure 4.9, will also restrict workspace and maneuverability like in the case of the building in Sögütözü case. Larger sites allow workers to position processing areas closer to their immediate work area. This reduces time, and therefore the cost.

Figure 4.9 Site limitation.

In Ankara, material recovered from buildings is rarely stored on the deconstruction site. Because of site and time limitations selective dismantling is preferred. Figure 4.10 and 4.11 exemplify selective dismantling of timber components and roofing tiles in Sögütözü work site, respectively. Since de-nailing resizing is done in the warehouse the material is carted off to the warehouse. Although the same crew does the whole deconstruction work, instead of storing all distinct components around the structure, because of time, site and economy constrains it is preferred storing on the site to be transported to the permanent storage and display area, i.e. different kinds of materials are removed separately and loaded directly on the truck on the work site, which saves time and money, for example fenestration units, door-sets, timber components and roofing tile storage (Figure 4.12 and 4.13). The materials are rarely sold from the site to minimize transport times. However, selling the recovered materials on site has the advantage of reducing transportation costs and also fuel emission, which protect the environment.

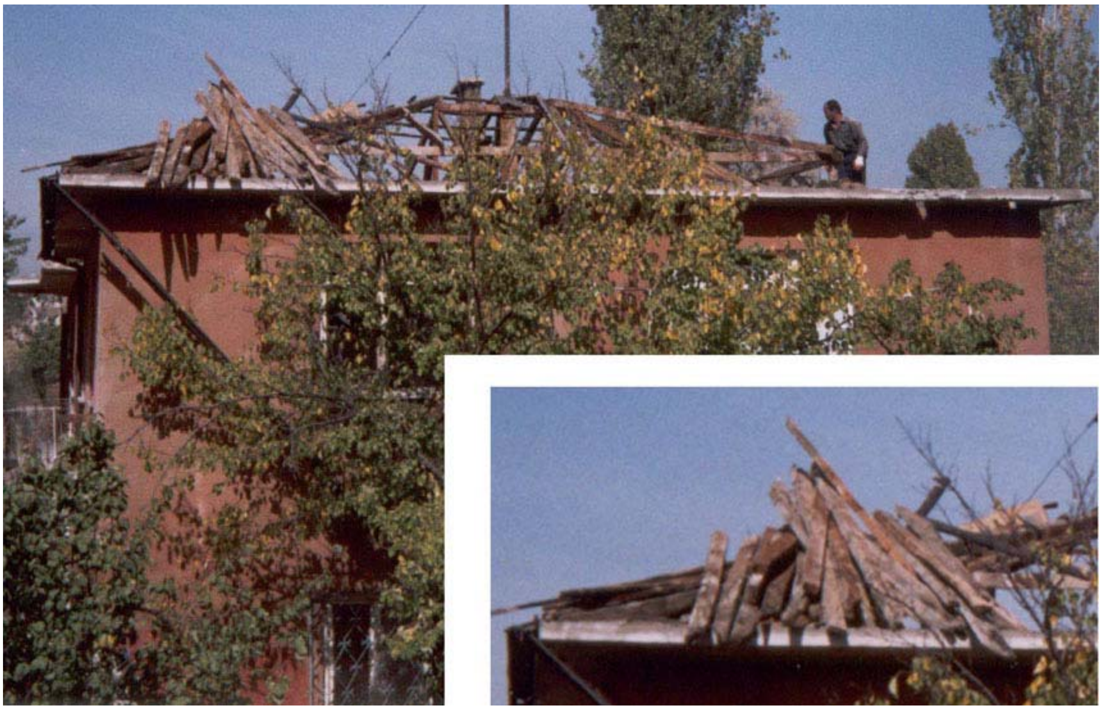


Figure 4.10 Selective dismantling of roof timber structural elements, lack of storage area on Site.

Figure 4.11 Selective dismantling of roofing tiles on the roof.

Figure 4.12 Timber stored on work site.

Figure 4.13 Roofing tiles stored on work site.

(ii) At the display area

Apart from the work site a space for de-nailing is provided at the warehouse also. The timber components are transported to the permanent storage area and unloaded and stored there until sold. If there is enough space on site for processing like de-nailing and resizing, the material is sent to the warehouse after it has been prepared for display. In Bentderesi locality yards or warehouses of demolition contractor measure around $600m^2$ only including the open and covered storage area..

In the contractors yard permanent storage and display area take important place, which Figure 4.14 depicts, since it is not known how long the material will take to sell off some criteria are important. Because of location of Bentderesi unloading is done from the road directly to the retail area and Figure 4.5 shows disassembled timber components unloaded on the pavement waiting to be stored. Separate display areas are left for distinct materials and components. The main distinction is made on the basis of the materials retail value and its durability. Roof tiles, sanitary equipment, and structural timber elements are stowed in the open area, whereas fenestration, floor coverings and doors are protected from direct rain and snow under a covered shed (Figure 4.15 and 4.16). In case of limited area the materials are exposed on the pavement, till extra space arises, which is Figure 4.17 shows.

Due to space limitations used building materials, especially timber joists and planks are stored without safety precautions, in Figure 4.18 the timber elements are stored vertically so as to occupy less covered space and facilitate the storage of as much material as possible. While the material is waiting to be sold it also undergoes de-nailing, resizing and repairs. Additional sorting is done parallel to keeping the site clean and ordered. The approximate waiting time is from two to seven months during summer. Unless precautions are taken in wintertime, timber components of any kind may be stolen for re-use by squatters or as kindling of fuel in winter. According to Odom (2003), at any given moment 10% and up of a used building materials store inventory is junk and another 10% more would never be missed. Tidiness is imperative in this business.

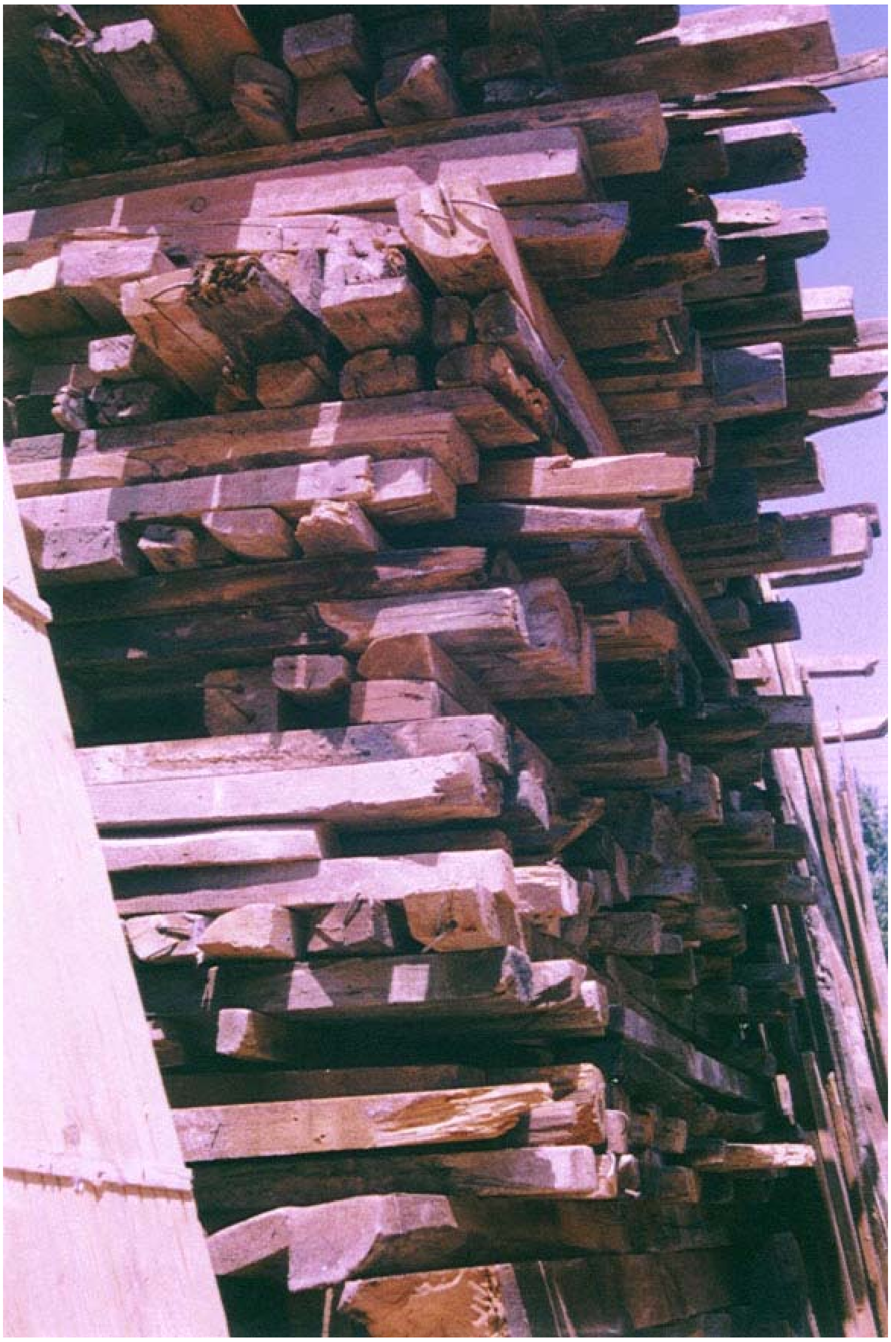


Figure 4.14 Permanent storage in warehouse in Bentderesi.

Figure 4.15 Door-sets closed storage in the display area in Ankara

Figure 4.16 Door-sets closed storage in the display area in Ankara

Figure 4.17 Door-sets and kitchen cabinet open storage in the display area in Ankara

Figure 4.18 Risky storage of timber components in the warehouse in Bentderesi.

4.3 Feasibility of UBM

In Ankara, environmental aspect comes out automatically as an outcome of economic works without any special care. The reason of the situation is that the customers of used building materials are from low-income class, so suppliers have to diminish cost of deconstruction without any additional expenditure.

In order to observe deconstruction and re-use of recovered timber components in Ankara, informal surveys were done by the author with the supplier of UBM in Bentderesi location in October 2001, June 2003 and September 2003. More of the contractors, demolition yard owners that were interviewed by the author, are not very eager to talk about their business once they realize that the author is not a potential buyer. Furthermore the taxmen inspections and municipality fear are other constrains that limits them to talk about their business with strangers. Many of these yard owners illegally deconstruct structure since the work team insurance is regarded as additional cost on disassembly and demolition.

The net income figure presented by Guy (2001), show a bit different attitude according to the agreement between the owner and contractor explained in the section 4.1.2 on Suppliers since the price paid by owner is not taken as income in all contracts. However, in the structures that the recovery value of the materials and components is high the owner may ask for fee to allow for the deconstruction. Though the economic equation is changing, deconstruction contractors may have higher profit. Equation 4.1 illustrates the shape of deconstruction in Ankara as well as in Turkey. Price paid by owner may be added or discarded from total budget as well may not have any value effecting net income of deconstruction.

The net income for deconstruction is:
(Salvage Value) - (Pre-Deconstruction + Deconstruction + Processing + Transportation) ± (Price Paid by Owner) = **Net Income** (Eq. 4.1)

Pre-deconstruction stage consists of contractors visual grading of the building and it's approximate salvage value estimation. Next stage, deconstruction is a job of unskilled local workers which means expenses are very low. Many of demolishers do not insure the team though law restricts it. The time restriction forces processing to be done in warehouse instead of work site, which minimize the number of labor on site and provide incessant work for continual workers in yard. Transportation cost can only be diminished in case of selling recovered components from work site. Price paid by owner is changing with the condition of building, which is decided at the pre-deconstruction stage with corresponding negotiations. In any case used materials can compensate this price, if contractor accepts to undertake the work.

Salvage value, the most crucial part in the equation, depends on many factors, like crack and woodworm defeats, well-being and treatments on the material, etc. In order to provide an idea of the percentage of used building materials over virgin ones, prices and their comparison of various timber components were collected, provided from yard owners in Bentderesi, and catalogued (Table 4.1). These materials are listed in the first column while their sizing in column two. In subsequent two columns prices in local currency of virgin and used building materials are listed respectively, while their percentage is tabulated in the last column. Grading in timber components is done according to their sizes, i.e. grade 1, 2, and 3 are 5x5cm, 5x10cm, and 10x10cm respectively. Grade 4 is frontal timber 2x20cm in size. Fenestration units vary in length and height and its value changes accordingly. Their condition can differ from one another but the price stays between the interval margins. The price of door-set is mainly dependent on its condition and the renovation works if there is any.

Table 4.1 Prices of timber elements and components in Ankara.

Type of Materials	**Size**	**Virgin (.000TL/meter)**	**Used (.000TL/meter)**	**Savings**
Timber grade 1	5x5cm	375-500	200-250	50%
Timber grade 2	5x10cm	750-1.000	400-500	50%
Timber grade 3	10x10cm	1.500-2.000	750-1.000	50%
Timber grade 4	2x20cm	750-1.000	400-500	50%
Fenestration	Varying sizes	50.000-120.000	15.000-30.000	25%
Door-set	Standard unit	70.000-180.000	30.000-60.000	33%
Roofing Tile	Standard unit	130-400	50-120	30%

As it's seen from the table used building materials are at least twice as cheap as virgin materials. Building contractors for formwork and scaffolding, which are used several times, prefers single un-treated rafters and planks. The components like fenestration and door-set are estimated unpainted in new condition while treated in used ones. When there is no need of repainting the price declines ones more. Besides, the social aspect of UBM is important both from the point of new sector as deconstruction contractors and additional unskilled job opportunity to worker in Ankara, and generates other businesses to support deconstruction infrastructure.

Using reclaimed timber materials in new building, can clarify the picture. Therefore, a cost estimation, according to cost of codes of Ministry of Works, of five-story building of about 2650 m² total area is illustrated in the Table 4.2. The structure is made out of concrete, while several timber elements/components are used. The aim is to demonstrate the cost of new timber material in the structure, the prices of used timber components and total saving when UBM are preferred.

In the first two columns of Table 4.2 materials and their Turkish codes (of Ministry Works) are listed corresponding. Although roofing tile is not a timber-based material, it is taken into account in order to calculate the cost of the roof structure together with timber components as a whole system. The amount/quantity of materials are depicted in their own units, most are given per unit volume except bordering, which is given as cost per unit length and the last four as cost per item. The prices are in Turkish Liras (TL) as obtained from the demolition contractors in Ankara and their percentages on total building cost are illustrated in the columns 4 and 5. This is done for comparing different materials and their relative expenditure in the building.

In the reality, this building is constructed with elements and components that are all new, whereas column 6 gives the prices of used timber components separately. The price is calculated on the assumption that the same amount of UBM will be used instead of new material. The last column lists the saving of each material separately and the total savings in cost for the whole building by replacing the cost of new materials with that of UBMs. It can easily be noticed that the saved amount is higher than expenditure on UBM; i.e. savings are more than 50% of the original cost. Furthermore, components having different saving may be subtracted from the total price if it is used from new material and the rest are re-estimated. Whereas, the use of all UBM shown in the Table is not obligatory, it can be seen that the maximum savings from timber components can be attained by the use of recovered materials.

Table 4.2 Prices of timber elements of a 5-story building (2650m²).

Material	Turkish Codes	Amount	Price (millionTL)	Percentage (%)	UBM Price (millionTL)	Saving (millionTL)
Form-work	20.011	81,6 m3	22.072	6,20	11.036,0	11.036,0
Scaffold	21.054	17,0 m3	4.094	1,15	2.047,0	2.047,0
Scaffold 2	21.067	1,5 m3	1.602	0,45	801,0	801,0
Roof timber Elements	21.210	28,3 m3	6.052	1,70	3.026,0	3.026,0
Handrail	21.301	0,6 m3	320	0,09	160,0	160,0
Bordering	Special Code	410 m	5.340	1,50	2.670,0	2.670,0
Built-in wardrobe	Special Code	2,3 m3	27.768	7,80	13.884,0	13.884,0
Window	-	125 pieces	12.638	3,55	3.159,5	9.478,5
Door set	22.001	20 pieces	9.256	2,60	3.054,5	6201,5
Kitchen cabinets	-	20 pieces	39.872	11,20	9.968,0	29.904,0
Roof tile	18.211	9520 piece	1.246	0,35	373,8	872,2
Total			**130.260**	**36,6**	**50.179,8**	**80.080,2**
Buildings total			**356.000**		**275.909,8**	

In Table 4.3 are compiled the outcomes from the preceding table and demonstrated clearly. The total cost of building, cost of second hand timber elements/components and the percentage of timber members over the total cost are noted in this Table. Columns 2 gives cost of new materials used in the structures, while column 3 gives that of UBM. Percentages of the saving are depicted in the last column, which can through light on the construction and deconstruction industries about the feasibility of UBM.

Table 4.3 Saving of timber elements of a 5-story building (2650m²).

	All New Price (millionTL) (a)	**Used Timber Price (millionTL) (b)**	**Savings 100x (a-b) / a**
Total cost of Building	356.000	275.909,8	**22,5**
Cost of Timber Component	130.260	50.179,8	**61,5**
Percentage of Cost	26,3	18,2	---

By using second hand materials as listed in the Table 4.2 instead of new materials a total amount of 80.080.200.000TL is saved. This figure represents a savings of 22,5% over the total cost and 61,5% savings in the cost of timber components and roofing tiles (Table 4.3). Using other second hand building materials also such as bathroom fixtures, brick tiles etc can increase these savings further.

CHAPTER 5

CONCLUSION

In order to preserve use of timber components, as well as other construction materials and our common environment, standardization of natural materials, similar to manmade components should be examined. This is in the hands of the architects and the building industry that they design and use standard timber components in construction so as to increase considerably its recovery rate and conditions. Parallel to such efforts, formulation of quality standardization systems, approved by the national institute of standards (TSE in Turkey); like standards of new materials, increase the proper use of UBM and may expand the second hand building materials sector in Ankara. For example, instead of usage of nails in joints of timber elements/components, which is now common practice in Turkey, the bolted connections should be preferred since they are more appropriate for deconstruction and re-use; avoid many holes on the components, preserve their bearing capacity and reduce damage during the building's service life and extensive defects. Although the use of bolts in earthquake zones is not recommended by certain experts, the components may be demounted and re-constructed in a different place for different usage with minimum damage. Though the design of the number and place of bolts needs additional time and effort, it can prevent damage to timber elements; i.e. cracks, squashes and too many nail-holes at the ends.

The efficient recovery of materials and minimization of environmental impact of C&D waste may be accomplished with increasing pre-deconstruction stage. The decision on type of deconstruction, time and cost estimation, worker ability and sensitivity on disassembly, influence the success of deconstruction. Tools and machinery used both on the work site and re-processing yard have direct effects on the condition of recovered materials. In Ankara, it is very difficult to talk about the safety on the work site; even insurance of the worker is not given importance. Although all these lessen the total expenditure, and so the cost of used material, the human rights are violated seriously.

Apart from the economy of deconstruction, proper disassembly of building materials can support the economic development of communities by providing employment opportunities, and good quality, energy efficient, low-cost building materials, and generates other businesses to support deconstruction. Although UBMs have many advantages for the society, environment and economy of the region, hteir re-use is not as widely spread throughout the construction industry in Turkey. The causes of this situation can be categorized as following:

- The belief amongst people that the “new” is always better than used one without any doubts;
- The intent of building contractors to pursue the customer and maximize the price of “new” buildings, which can be done more easily by using new building elements/materials instead of UBM;
- The absence of label of guaranty of the quality and physical and chemical properties of UBM for proper re-use in new construction;
- The advertisement of storage and display areas of deconstruction contractors and the introduction of UBM to potential customers.

In order to expand the UBM sector advertising can play an important role. Advertisements in the daily paper as well as the weekly paper, and classified advertising is essential to a small size store to keep the business name in the public eye and let the customer be informed about the materials and the yard owner. Also the website, though it is not as popular today, can come play an important role within the next few years.

Users may change the performance of timber-structured buildings, constructed with the ability of adaptation, without deconstructing whole structure or re-constructing some of its units. Simple partition walls are easily re-adapted to their new usage. This type of sustainability is before all deconstruction activity, but the case of Ankara cannot be regarded in that way. The construction technique in Turkey is extremely different; in addition timber components are used as secondary material after concrete framework is finished.

There is an urgency for finding systematic ways and means for re-use of timber from deconstructed buildings in order to save our history, preserve natural re-sources for the future and keep our planet inhabitable. There is still a lot that needs to be done to improve conditions for the recovery and re-use of building materials in Turkey. Researches on the market, material quality standardization, and environmental effects should be pursued.

LITERATURE CITED

Adams, K.T., "*How Do You Identify the Best Practicable Environmental Option for Construction and Demolition Waste?",* CIB World Proceedings of the 11th Rinker International Conference-2003, Florida, USA, p.226-238.

Abdullah, A. and C. J. Anumba, "*Decition Tools for Demolition Techniques Selection",* CIB World Proceedings of the 11th Rinker International Conference-2003, Florida, USA, p.55-72.

Chini, A. R. and L. Acquaye, "*Grading and Mechanical Properties of Salvaged Lumber",* CIB World Building Congress- Deconstruction Meeting- 2001, Wellington, New Zealand, p.138-161.

Chini, A.R. and Nguyen, H.T., *"Optimizing Deconstruction of Lightwood Framed Construction",* CIB World Proceedings of the 11th Rinker International Conference-2003, Florida, USA, p.311-321.

Crowther, P., *"Developing an Inclusive Model for Design for Deconstruction"*, CIB World Building Congress- Deconstruction Meeting- 2001, Wellington, New Zealand, p.1-26.

Dorsthorst , B.J.H. and T. Kowalczyk, "*Re-use of Apartment Buildings; a Case Study",* CIB World Building Congress- Deconstruction Meeting- 2001, Wellington, New Zealand, p.55-66.

Dumisevic, E., Ö. Cifcioglu, and C.J. Anumba, *"Knowledge Model for Assessing Disassembly Potential of Structures"*, CIB World Proceedings of the 11th Rinker International Conference-2003, Florida, USA, p.295-310.

Elias-Özkan, S.T., *"An Overview of Demolution, Recovery, Reuse and Recycling Practices in Turkey"*, CIB World Proceedings-Deconstruction Meeting-2002, Karlsruhe, Germany, p.128-138.

Elias-Özkan, S.T., *"Deconstruction of Earthquake-Damaged Buildings in Turkey"*, CIB World Proceedings of the 11th Rinker International Conference-2003, Florida, USA, p.138-150.

Elias-Ozkan, S.T. and A. Düzgüneş, "*Recycling of Construction Material and The Reuse of Building Components: An Overview"*, Proceedings of the CIB-W107 International Conference on "Creating a sustainable construction industry in developing countries", Cape Town, South Africa, 2002.

Erkelens, P.A., "Re-Use of Building Components (Towards Zero Waste in Renovation)", CIB World Proceedings of the 11th Rinker International Conference-2003, Florida, USA, p.125-137.

Giglio, F., A. De Cappa, "*An Instrumant for Controlling Impacts in Use and Dismission Phases"*, CIB World Proceedings of the 11th Rinker International Conference-2003, Florida, USA, p.83-93.

Guy, B., "*Building Deconstruction Assessment Tool", ",* CIB World Building Congress - Deconstruction Meeting- 2001, Wellington, New Zealand, p.125-138.

Guy, B. and M. Ohlsen, "*Creating Business Opportunities Through the Use of a Deconstruction Feasibility Tool", ",* CIB World Proceedings of the 11th Rinker International Conference-2003, Florida, USA, p.36-47.

Guy, B., S. Shell, Esherick, Homsey, Dodge & Davis Architecture, *"Design for Deconstruction and Materials Reuse",* CIB World Proceedings-Deconstruction Meeting-2002, Karlsruhe, Germany, p.189-219.

Guy, G.B., *"'Green' Demolition Certification"*, CIB World Proceedings of the 11th Rinker International Conference-2003, Florida, USA, p.395-411.

Hinze, J., "*Designing for Deconstruction Safety",* CIB World Proceedings-Deconstruction Meeting-2002, Karlsruhe, Germany, p.210-217.

Hobbs, G. and J. Hurley, "*Deconstruction and the Reuse of Construction Materials",* CIB World Building Congress- Deconstruction Meeting- 2001, Wellington, New Zealand, p.98-124.

Houlemard, M. and S. Cook, *"Envisioning The Ideal Building Removal Program (for Closed and Active Military Bases)"*, CIB World Proceedings of the 11th Rinker International Conference-2003, Florida, USA, p.412-419.

Kibert, C., "*Deconstruction's Role in an Ecology of Construction",* CIB World Proceedings-Deconstruction Meeting-2002, Karlsruhe, Germany, p.218-229.

Kim, J.J. and B. Rigdon, Sustainable Architecture Module: Introduction toSustainable Design, Michigan: National Pollution Prevention Center for Higher Education, 1998a, p. 1-28.

Kim, J.J. and B. Rigdon, Sustainable Architecture Module: Qualities, Use, and Examples of Sustainable Building Materials, Michigan: National Pollution Prevention Center for Higher Education, 1998b, p. 1-44.

Kim, J.J. and B. Rigdon, Sustainable Architecture Module: Recycling and Reuse of Building Materials, Michigan: National Pollution Prevention Center for Higher Education, 1998c, p. 1-128.

Lassandro, P., *"Deconstruction Case Study in Southern Italy: Economic and Environmental Assessment"*, CIB World Proceedings of the 11th Rinker International Conference-2003, Florida, USA, p.115-1240

Nakajima, S. and M. Futaki, "*National R&D Project to Promote Recycle and Reuse of Timber Constructions in Japan*", CIB World Building Congress-Deconstruction Meeting- 2001, Wellington, New Zealand, p.42-54.

Nakajima, S. and M. Futaki, "*National R&D Project to Promote Recycle and Reuse of Timber Constructions in Japan: The Second Year Result",* CIB World Proceedings-Deconstruction Meeting-2002, Karlsruhe, Germany, p.1-22.

Nakajima, S., M. Kawai, M. Hiraoka & M. Miyamura., "*Design for Easy to Deconstruct and Easy to Recycle Wooden Building",* CIB World Proceedings of the 11th Rinker International Conference-2003, Florida, USA, p.1-14.

Odom, B., "*Start Up and Development of a Full Scale Used Building* Materials Store and Salvage & Deconstruction Business in a Small Town", CIB World Proceedings of the 11th Rinker International Conference-2003, Florida, USA, p.176-185.

Özkan, S.T.E., Recovery and Re-Use of Demolution Waste: Recycling Rubble for Concrete Components, Unpublished Ph.D Dissertation, Ankara: METU:2000.

Schultmann, F. and O. Rentz, "*The State of Deconstruction in Germany",* CIB World Building Congress- Deconstruction Meeting- 2000, Florida, USA, p.1-26.

Schultmann, F., E. Garbe, A. Seemann and O. Rentz, "*Methodologies and Guidelines for Deconstruction in Germany and France",* CIB World Building Congress-Deconstruction Meeting- 2001, Wellington, New Zealand, p.27-41.

Story, J.B. and M. Petersen, *"Overcoming The Barriers to Deconstruction and Materials Reuse in New Zealand"*, CIB World Proceedings of the 11th Rinker International Conference-2003, Florida, USA, p.270-284.

Tinker, A.K. and Dr.R.A. Burt, *"Waste Management Practices in United States Green Building Programs"*, CIB World Proceedings of the 11th Rinker International Conference-2003, Florida, USA, p.386-394.

Thormark, C., "*Assessing the Recycling Potential in Buildings",* CIB World Building Congress- Deconstruction Meeting- 2001, Wellington, New Zealand, p.78-86.

Williams, T.J. & G.B. Guy, "*Deconstruction and Design for Reuse: Choose to Reuse",* CIB World Proceedings of the 11th Rinker International Conference-2003, Florida, USA, p.362-371.

WEB SITES

http://s14.cfaa.ufl.edu/centers/sustainable/

http://www.act.gov.au/nowaste/excharge.html

http://www.arrnetwork.com.au/workplace/sb_sab.main

http://www/cce/ufl/edu/

http://wwwcce/ufl/edu/affiliations/cib

http://www.cibworld.nl

http://www/recycledproducts/org/uk/nrf/

APPENDIX A

ORGANIZATION

These include US Environmental Protection Agency (EPA),

Florida Department of Environmental Protection (FDEP),

US Army Corps of Engineers Construction Engineering Research Laboratory (CERL),

USDA Forest Products Laboratory (FPL),

Alachua County Waste Management Division,

City of Gainesville Public Works Department,

International Council for Research and Innovation in Building Construction (CIB),

Recycle Florida Today Inc.,

Building Research Establishment (BRE),

French-German Institute for Environmental Research (DFIU),

Delft University of Technology,

Reconnx, Institute for Local Self-Reliance (ILSR),

Southern Waste Information Exchange, and Alachua County Visitors and Convention Bureau. Brad Guy.

Department of Labour's Occupational Safety and Health service (OSH) and deals with safe practice.

APPENDIX B

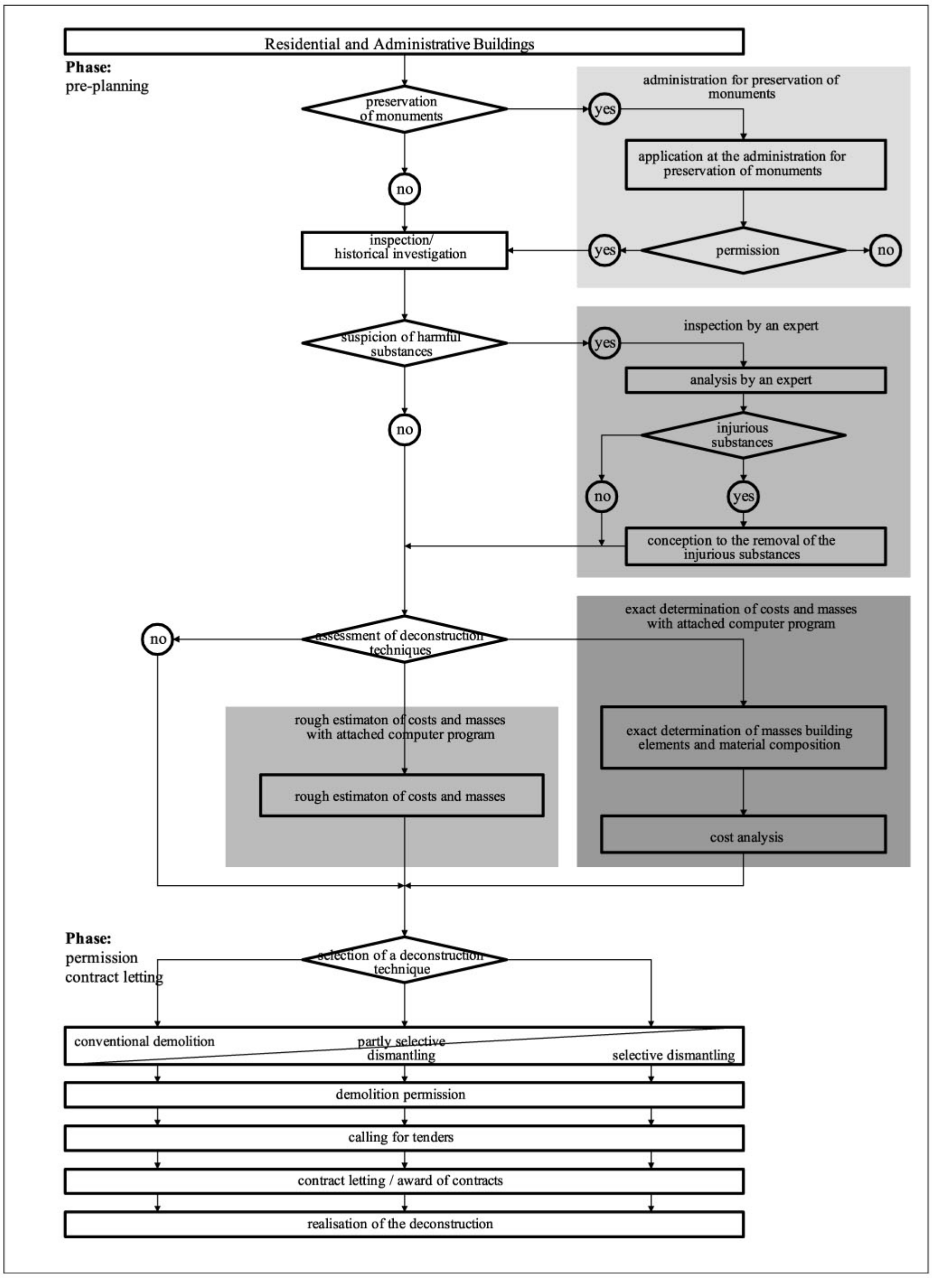


Figure B1: Flowchart of planning, permission and contract letting of the deconstruction of a building.

Source: Schultmann, Garbe, Seemann and Rentz, 2001.

APPENDIX C

Table C1: Universal Barriers to Deconstruction

Barrier	How this relates toNZ	Solutions
1 Legislations:		
Current standard specifications	Standards give the impression that new materials must be specified.	Development of standard specifications etc, which incorporate reused/recycled components Document and publish examples of the successful use of reused and recycled components Government and local council as examples in new development.
2 Markets:		
The high cost of transport and storage of recycled components and materials	Small, dispersed population.	Market networking. Direct sales from site.
Uses for some salvaged materials are undeveloped	Finding uses for some recycled or salvaged materials is difficult	Increased research focusing on problem materials.
Designer/public/builder attitude: 'new is better' and new buildings are permanent.	The majority of building materials specified and used in NZ are new. Design for deconstruction uncommon	Education for architects in life cycle onsiderations and holistic design principles. General education of public, designers and builders. Easy to use guides in the use of salvaged materials/design for deconstruction. Publishing and compilation of research into quality aspects of reused goods.
The lack of a grading system for reused components	Native timbers and bricks are generally used in non structural situations.	Development of a grading system Training in the grading of reused materials. Liability issue addressed
Guaranteed quality/quantities of reused materials are difficult.	Smaller areas of NZ are more geographically isolated. The scale of economy is not large enough to sustain a large salvage market.	Increased networking of salvage businesses/builder's merchants. Increased deconstruction *NZ:* See NZ specific barriers section
Lack of information and tools to implement deconstruction.	There is a lack of NZ specific documents or information kits for the implementation of deconstruction, specific feasibility studies or clear NZ example cases.	Compilation of guides, development of implementation ideas. Clear ways to implement NZ Waste Strategy targets are needed. Increased pilot studies and test cases Strategic planning to address barriers.

Source: Story, 2003

Table C1 (continued)

3 C + D Industry:		
Lack of communication and networking in the C&D industry	Unregulated, and largely uncooperative, hierarchical C&D industry in NZ.	Greater communication, networking and collaboration. Increased conferences, email discussion groups, networking, professional articles publications etc.
lack of design for deconstruction	International research is not always applicable to NZ. There is a lack of example cases built in NZ. Design for deconstruction is not taught at architecture schools	Education of architects and designers through CPD / competitions / conferences / exhibitions / case studies etc. Education at architecture schools. Development and sharing of teaching resources and case study examples. *NZ:* Republication of the NZIA life cycle environmental impact charts on the internet
Difficulty in securing funding for research	The Ministry for the Environment. The Science and Innovation Policy	Governments and funding agencies need to make waste minimization a priority.
4 Economics Factors:		
The tightening up of Health and Safety legislation	Increased OSH regulations may effectively prevent the hands on nature of deconstruction through time delays and additional safety equipment costs.	*NZ:* Cooperation between OSH and environmental architecture advocates ensuring maximum safety and environmental practice. Subsidies for implementation of OSH requirements in deconstruction.
The benefits of deconstruction are long term and collective	Current climate of first cost only economic development.	Enforceable legislation and increased requirements in building consent approvals Government set measurable and monitored targets Increased education on environmental building impacts for developers.
Lack of financial incentive for deconstruction		Implementation of economic incentives and deterrents to encourage deconstruction.
Market pressures - the current climate of 'as fast as possible'	Limited time to salvage maximum materials in the demolition stage. Deconstruction takes longer.	Subsidies to demolition contractors – transitional only Salvage operations to work along side but independently of demolition contractors. Transferal of environmental responsibility to developers.
It is difficult to access or apply economic assessment tools for deconstruction or LCA in some cases.	There are no NZ specific deconstruction evaluation tools or national feasibility studies.	Collection of existing tools in one place. Possibly website. Development of non region-specific tools or more flexible parameters. *NZ:* The development or adaptation of deconstruction economic viability tools for NZ A deconstruction economic viability feasibility study for NZ
Deconstruction needs a more skilled workforce than demolition	Unregulated demolition Industry Lack of case jobs to train on.	Increased opportunities for training and transition from traditional demolition to deconstruction. Cooperation between the construction and demolition sectors.

Source: Story, 2003

Table C1 (continued)

5 Technical Issues:		
Lack of documentation	Records of materials used in construction are not kept.	Better recording of materials used Storage of records in the actual building
Increased use of insitu technology, chemical bonds and plastic sealants etc.	Commonly used in new buildings in NZ. Most concrete structures have insitu components.	Research viable alternatives to these techniques. Development of ways to separate these bonds
Most existing buildings are not designed to be deconstructed.	This is true in NZ.	Research and development to find ways to effectively deconstruct these buildings. Implementation of design for deconstruction techniques into learning establishments a priority.

Source: Story, 2003