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RESEARCH ON BUILDING DECONSTRUCTION

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EXECUTIVE SUMMARY

Deconstruction is the process of breaking an engineered system down into its constituents with the goal of preserving maximum value. The materials recovered via deconstruction work are most commonly reused or recycled. This material flow allows the consumer to preserve the imbedded energy in the materials by extending the useful life of the material with limited additional energy input. This alternative is more environmentally responsible and economical than harvesting and manufacturing raw materials for the production of virgin materials.

Products of the deconstruction process fall into one of three broad categories: reused, recycled and disposed. Reused and recycled materials typically amount to 85% of a building's total weight. This represents a huge opportunity to reduce growing problem of increasing tipping fees at landfills and societal pressures toward sustainability.

At this point in time, deconstruction is in its infancy but has tremendous potential for growth, especially in the United States. Although there are many advantages to deconstruction over traditional methods of demolition, many challenges must be conquered.

The benefits of deconstruction are far more significant than the costs associated with this approach. Deconstruction is capable of providing economic, social, and above all else, environmental advantages. The experiences and outcomes of current industry project trends illustrate the positive effects of deconstruction. Regardless of the fact that the gross costs of deconstruction are higher than traditional demolition, when the revenues from salvaged materials are factored into the equation, deconstruction can be significantly less expensive. Several social benefits are also associated with deconstruction, including an impact in the labor market.

A case study of a deconstruction project in Orinda, California was performed and the data obtained used for evaluation purposes. Overall, the results confirmed the theory that deconstruction is the better environmental choice. It can be stated with confidence that with further development of processes and deconstruction technologies, the economic, environmental, and social benefits of deconstruction will develop as an effective tool in working toward environmental sustainability.

1.0 ABSTRACT

Deconstruction is a process by which a structure is broken down into its components. Although deconstruction is still in its infancy, it is developing into a more economically and environmentally advantageous alternative to demolition. Two goals of deconstruction are to reduce the amount of materials in the waste stream generated by construction and demolition activities and to maximize the value of materials by utilizing (but not adding to) the embedded energy. It is an environmentally friendly and often cost effective solution to current issues of sustainability and environmental consciousness. By means of a case study analysis, deconstruction is shown to have less adverse environmental effects and greater economic value than demolition. As the construction industry embraces the process, technologies improve, and consumers realize its numerable benefits, deconstruction work will become more efficient and effective thereby lessening adverse impact of the life-cycle of construction materials.

2.0 INTRODUCTION

The Construction Materials Recycling Association (2005) best sums the current situation: "The C&D debris recycling market is a growing, vibrant, but relatively young industry that will continue to expand because of the continuing problems of decreased landfill space, increase environmental awareness, and the opportunity for entrepreneurs to profit."

In parts of the United States, notably California, increasing concern surrounding the potential of future landfill space shortages and increased tipping fees (fees for dumping waste) has fueled recycling efforts. Previously, solid waste planners had focused on recycling consumer products to reduce the waste stream. However, officials are now realizing the waste reduction potential that exists in the construction and demolition industry.

The construction industry consumes a massive amount of materials. At the same time, new material is being rapidly produced to meet the demands of increasing construction activities. Conversely, structures and engineered systems that are demolished to make way for the new construction contribute substantially to the waste stream. It is estimated that approximately 25% to 45% of the waste stream in North America is made up of construction and demolition waste (CMRA, 2005). Efforts to reduce this influx are underway.

Deconstruction is one possible solution that is proving to be an effective means for diverting construction and demolition waste away from landfills. “Deconstruction is simply the construction process in reverse” (Greer, 2004). As opposed to the traditional method of demolition in which all waste is hauled to landfills, deconstruction is a methodical process that aims to save a portion of the waste materials for reuse on other projects. This effectively prevents some construction and demolition waste from ever entering the waste stream. The reuse of old products also prevents the need for new ones to be manufactured or produced. Therefore, the decrease in the demand for new materials leads to a reduction in the volume in the production stream, further reducing potential future waste generation.

In the following pages of this report the deconstruction process will be described at length. Deconstruction itself will be described in detail with respect to topics including reasons to deconstruct, the process, materials flow management, technology, the costs and benefits, and a comparison with demolition. In order to develop a more thorough analysis and deeper understanding of deconstruction, a case study was also performed.

The primary objective of this report is to demonstrate that deconstruction is an economically, socially, and environmentally viable solution to the current problem of reducing the waste stream in the United States. A surprising amount of waste generated is the result of construction and demolition. Concurrently, threat of limited landfill space in the future, rising tipping fees, and increased environmental pressures necessitate a solution. Deconstruction is a better alternative to demolition, primarily in its consistency with recent trends in environmental life-cycle awareness. An EIO-LCA analysis and thorough evaluation of the economical and environmental implications will be included to show the benefits of deconstruction in comparison with demolition.

3.0 DECONSTRUCTION INDUSTRY OVERVIEW

The exhaustive extraction of raw materials and the emission of pollutants into our environment have both placed heavy pressures on the environment in which we live (Rentz & Schultmann, 2001). Due to an increased awareness of the problems these pressures create, and increased support of “green” endeavors to mitigate irreversible destruction of our finite environment, environment-friendly production and recycling management is becoming more and more important in the industrialized world (Rentz & Schultmann, 2001). To this end minimizing waste while increasing the recyclability and reusability of materials has generated a great deal of activity and interest, by becoming a major focus, specifically within the construction industry (Rentz & Schultmann, 2001).

It is no secret that the construction industry plays a major role in the creation of solid wastes worldwide. Recently there has been an emphasis on setting up advanced recycling technologies for demolition waste (Rentz & Schultmann, 2001). However, the technology being used for this purpose has begun to reach its ceiling of limitations. Because of this, significant progress must stem from improving the methods of demolition as opposed to the process technology (Rentz & Schultmann, 2001). Traditional methods of demolition hold little or no regard for either the separation of materials or the reuse/recyclability value of the materials being demolished. Traditional methods, i.e. knocking down a building with one fell swoop from a wrecking ball, or tearing down a wall with an excavator, often leads to the mixing of large amounts of mostly non hazardous materials with small amounts of hazardous materials and hence contaminating the whole lot (Rentz & Schultmann, 2001). Advanced approaches to demolition, or deconstruction, focus on the systematic disassembly of a building piece by piece so that materials can be preserved, separated, reused, recycled, and kept from contamination. "Selective dismantling instead of demolition helps the separation of different building materials and the reuse of recycled materials in superior utilization options" (Rentz & Schultmann, 2001). In contrast to the process of demolition, deconstruction is actually "the source separation of materials" (Bruening & Chini, 2004).

3.1 What Is Deconstruction?

Bruening and Chini (2004), of the University of Florida, define deconstruction as, "the systematic disassembly of buildings in order to maximize recovered materials reuse and recycling". They continue by saying that deconstruction seeks to maintain the highest possible value for materials in existing buildings in a manner that will allow the reuse or efficient recycling of the materials (Bruening & Chini, 2004). Diane Greer describes deconstruction as simply construction in reverse, an environmentally friendly and often cost effective alternative to demolition (Greer, 2004). Ted Reiff, the owner of the Alameda, California based deconstruction contractor "The Reuse People" explains "We literally take apart a building in the reverse order in which it was built" (Greer, 2004). When utilizing deconstruction techniques, significant amounts of materials can be salvaged, reused, or recycled (Greer, 2004). A deconstruction estimator with the Portland, Oregon based "Rebuilding Center" says that "a typical 1,500 square foot house, we recover 50 percent of the materials for reuse, 25 to 30 percent is recycled, and the remainder is trash" (Greer, 2004).

Deconstruction is emerging as a viable cost effective and environmentally friendly alternative to traditional methods of demolition around the globe (Bruening & Chini, 2004). The deconstruction industry is in its infancy but interest is growing rapidly as increasing amounts of time, money, and effort are being invested into research to improve techniques and tools for dismantling existing structures (Bruening & Chini, 2004). In addition to the development of improved deconstruction methods, designing for deconstruction is gaining more attention (Bruening & Chini, 2004). In some instances, Architects and Engineers are beginning to move away from the mindset that the buildings they design are going to stand forever and are realizing the value in designing a building that can be easily dismantled at the end of its useful life.

3.2 Why Deconstruction?

Many of today's existing buildings around the world will be in need of some form of maintenance, renovation, or decommissioning/demolition work in coming decades (Rentz & Schultmann, 2001). Although profitability will always be a chief concern in the historically tight margined construction industry, as resource extraction and waste emission production concerns grow to an all time high, environmental awareness is becoming increasingly important (Rentz & Schultmann, 2001). Deconstruction helps quell both of these concerns. When done properly, on the right projects, and under the right circumstances, deconstruction can be economically advantageous and good for the environment.

Some of the advantages of Deconstruction as adopted from Abdol Chini, are listed below (Bruening & Chini, 2004):

- Increased diversion rate of demolition debris from landfills
- Sustainable economic development through reuse and recycling
- Potential reuse of building components
- Increased ease of materials recycling

- Enhanced environmental protection, both locally and globally

Reusing and/or recycling much of the material recovered via deconstruction allows the consumer to "preserve the invested embodied energy of materials" and get more use out of the same material with limited additional energy input (except what is needed to dismantle, preserve, and repackage the material) as opposed to harvesting and manufacturing raw materials for the production of virgin materials at much higher energy costs to the consumer and the environment (Bruening & Chini, 2004).

The issue of increasing the diversion rates of construction and demolition (C&D) debris from landfills is an extremely significant one. It has become a priority for many localities across the United States as landfills approach their capacities and permitting for new landfills becomes ever more difficult (Greer, 2004). The Deconstruction Institute of America has estimated that a typical 2,000 square foot home produces 127 tons of demolition debris (Greer, 2004). The EPA has recently reported that demolition debris comprises as much as 48 percent of the 136 million tons of construction and demolition wastes produced in the U.S. or roughly 10 percent of the countries total waste stream (Greer, 2004).

As the numbers show, demolition debris is a significant part of America's waste stream. However, the most encouraging concept behind deconstruction is that with progress and significant improvements made down the road, there is the potential to have tremendous positive effects on reducing the waste stream. One conservative study estimates that 9 million tons of demolition debris (representing 17 percent of total demolition debris) can be diverted from the waste stream in the U.S. to be potentially reused and recycled (Bruening & Chini, 2004). The impacts of reducing demolition materials in the waste stream will be discussed further in latter sections of this paper.

3.3 Current Situation

Although there are many advantages to deconstruction over traditional methods of demolition, many challenges must be conquered. While these challenges are numerous, they can be overcome with a shift in thinking concerning changes in design and policy (Bruening & Chini, 2004). Some of these major challenges facing deconstruction are (Bruening & Chini, 2004):

- Existing buildings have not been designed for dismantling

- Building components have not been designed for disassembly
- Tools for deconstructing existing buildings often do not exist
- Disposal costs for demolition wastes are frequently low
- Dismantling of buildings requires additional time
- Building codes & materials standards often do not address the reuse of building components
- Unknown cost factors in the deconstruction process
- Lack of broad industry identity with commensurate standardized practices
- Buildings built before the mid-1970s with lead-based paint and asbestos containing materials
- Economic and environmental benefits that are not well established

As tools and techniques improve and subsequently productivity improves, labor costs should see a reduction. With these improvements, in time deconstruction will become more competitive with demolition (Greer, 2004). Deconstruction services are making use of equipment traditionally used for construction such as forklifts, skid steer loaders, and conveyor belts to mechanize the materials handling process (Greer, 2004). Efficiency is increasing. "Projects that used to take 4 weeks now take 2 weeks" (Greer, 2004). According to "The Reuse People" a typical wood construction residential home undergoing the deconstruction process requires approximately 1 working week per 1000 square feet of floor space (Reiff, 2005).

While many people are enthusiastic about the potential of deconstruction because of its environmental benefits, the fact of the matter is that if it isn't beneficial economically, its ultimate potential is very limited. Economic factors are really beginning to drive the industry in the right direction (Greer, 2004). As Julie Larson, of the nonprofit Green Institute in Minneapolis, says, "A large motivator is the tax benefit homeowners get from donating salvaged building materials to non-profits" (Greer, 2004).

4.0 Deconstruction Process

4.1 Basic Principles in Deconstruction

"Deconstruction is a means to an end, it exists for the purposes of the appropriate recovery of building elements, components, sub-components, and materials for either reuse or recycling in the most cost-effective manner" (Guy, 2004). Deconstruction has gained popularity in recent years because of several advantages, such as reducing the volume of waste transported to landfills and the tax benefits reaped by the owners of structures that are deconstructed. More so, deconstruction has been researched, developed, and promoted by environmental and engineering professionals. Accordingly, deconstruction has proven to be effective in achieving goals of reuse and recycling building materials while reducing the waste stream. Up to this point this practice has not yet reached its full potential in the construction industry.

Two professionals actively pursuing deconstruction in the Hampton Roads area of Virginia, Pinkoski and VanDyke (2005), have developed seven "Keys to Debuilding".

(1) *Get management buy in* – The perception that deconstruction is expensive and time consuming is pervasive. Without a forward-thinking educated decision maker, a deconstruction project might not see the light of day.
(2) *Do Your Homework* – Gathering as much information as possible on the process, providers of deconstruction services, and outlets for salvaged materials and recycling facilities improves the odds of a successful project.
(3) *Educate* – Sharing the information gained by doing your homework with management, contractors, coworkers, the public and other interested parties will assist with project planning and may convert some skeptics.
(4) *Communicate* – Effective communication between the contractor, subcontractors and the Department of Public Works is critically important. Communicating expectations, data requirements and unexpected circumstances are essential to correcting problems in order to complete a successful project.
(5) *Get the right tool for the job* – Find a contractor with actual experience doing deconstruction who has established partnerships with C&D recyclers, used building materials facilities, not-for-profits, and other organizations that reuse salvaged materials. This policy will lessen the learning curve and make for more effective project execution.
(6) *Measure your success* - It is impossible to track success without an accurate diversion rate and actual costs. Identifying metrics and methods of data collection on the front end will lead to a clearer measure of performance.

(7) *Spread the word* – Promoting lessons learned from deconstruction projects will help expand markets for salvaged materials, create a deconstruction mindset in the industry, reduce the learning curve for others interested in the process, and encourage additional projects.

Designing for deconstruction is another principle that has received much attention. If deconstruction were taken to its hypothetical maximum, a building would be broken down into the original components used in its initial erection. However, when designing for deconstruction, it is unreasonable to plan for this degree of deconstruction. For example, windows may become obsolete by the time the building's service life has ended. Likewise, small components such as nails, bolts, or wiring may have negative cost effects. In actuality, it may cost more to remove and separate the hardware compared to its value for reuse. Thus, there exists design for reuse and design for recycling, of which both are dependent upon the components and types of materials used (Guy, 2004).

To expand on the different forms of design for deconstruction, several notions outline the concept of hierarchical design (Guy, 2004).

(1) *Design for reuse*
(2) *Design for remanufacturing*
(3) *Design for recycling*

These concepts exist with the "intent to work within a series of constraints based upon the scale of buildings and components, temporal forces between differing building elements, functional and service requirements of the building, relative importance of building elements in terms of both first costs and life-cycle costs, the physical forces at work in a building, the chronology of construction, deconstruction of the building, and the components and raw materials of the building" (Guy, 2004).

4.2 Basic Process of Deconstruction

Simply stated, deconstruction is the construction process in reverse. Yet there is clearly more to the practice. Ultimately, the structure should be broken down into components that can be reused first (Reiff, 2005). Reuse takes priority over recycling because there is less additional energy required to make the salvaged component ready for use in another application. A study of the deconstruction process for the current 2x4 construction system by Nakajima, et al. (2005) is described below. The deconstruction tools and techniques also vary depending on the type of structure and materials. Different materials such as steel, timber, and concrete along with the tools and methods of deconstruction for each are discussed further in this section.

4.2.1 Detailed Study of Dismantling and Deconstruction of a 2x4 Construction System

To analyze the whole deconstruction process of 2x4 wooden houses, the deconstruction process of a single, detached 2x4 wooden house was investigated. The house was built in 1980 and has been used for twenty years. The total floor area of the house was approximately 1600 square feet, and it took nine days to deconstruct the whole house, including the foundation.

The processes of deconstruction are as follows:

(1) Remove the window glass by hand.
(2) Remove the joiners by hand.
(3) Remove the wallpaper and gypsum board by hand.
(4) Remove the roofing materials by hand.
(5) Remove the insulation materials by hand.
(6) Remove the steel materials by hand.
(7) Dismantle the structure by machine.
(8) Dismantle the foundation by machine.

Gypsum boards were removed by hand using the traditional deconstruction tools. Almost one-fourth of the total deconstruction time was spent in the process of removing the gypsum boards. The wooden frame of the house was dismantled with the aid of the dismantling machine. It took four days to dismantle the wooden frame. Most of the dismantling work was done by the hand-separation process. Timbers and other materials were separated on-site, according to their type (Nakajima, et al., 2005).

4.2.2 Tools and Techniques

Corresponding to the various materials and components used in construction are the different means, methods, tools, and techniques required to deconstruct the structures. The tools and techniques used, as well as some difficulties associated with deconstruction, for steel, masonry, concrete, and timber are described in this section.

4.2.2.1 Steel

There are a number of different processes for removing steel from existing structures for reuse or recycling. Crushers and pulverizers have been developed to remove reinforcing steel bars (rebar) from reinforced concrete structures. Heavy-duty magnets can be used to remove reinforcing steel during the process of crushing reinforced concrete.

Several opportunities for further development of tools and techniques exist in this area. For example, a tool with an automated ability to remove bolts from connections could increase the number of sections available for reuse instead of recycling. Currently, the ends of beams are usually distorted in the removal process requiring that these damaged ends be cut off. The National Federation of Demolition Contractors and the Institution of Demolition Engineers are two organizations that can assist the industry in further development of such tools and techniques (Hobbs, 2001).

4.2.2.2 Masonry

As is the case with all materials and structures, hand deconstruction results in the highest quality of reclaimed materials. By using this meticulous method, contractor profits are maximized from the sale of components to reclamation yards and recycling facilities (or the maximum tax benefits are realized for the homeowner who donates the components to a not-for-profit organization). This reality has been very evident in the case of masonry and brick.

In some cases, the contractor hand-cleans the bricks and in other cases the reclamation yards remove the mortar themselves. However, the increased use of ordinary Portland cement (OPC) in place of lime-based mortars has presented a problem for brick reuse. The lime-based mortars are much easier to separate from the brick. Therefore, there exists a "need to investigate practical and cost-effective removal techniques for OPC mortars" (Hobbs, 2001).

4.2.2.3 Concrete

In most cases, concrete frames in concrete buildings are cast-in-place and cannot be deconstructed for reuse in their original form. Pre-cast concrete components such as beams, columns, stairs, and hollow-core floor slabs can be deconstructed provided the joints are simply supported. Unfortunately, most joints are cast-in-place and that concrete is stronger than the pre-cast components it joins. New uniform jointing methods are being developed which hopefully will be designed for deconstruction.

Pre-cast concrete flooring systems are commonly used in construction and are one of the simplest concrete components to deconstruct. However, in some cases they are covered with a 50 mm cast-in-place concrete layer in order to provide a monolithic slab, which prohibits deconstruction.

One tool that is commonly used in repair applications holds promise in deconstruction. High-pressure water-jetting can cut concrete while leaving both the reinforcing steel and concrete clean and reusable. Heating methods such as thermal lances may be used increasingly in the future because they can cut through reinforced concrete while leaving the majority of the concrete element intact (Hobbs, 2001).

4.2.2.4 Timber

Most existing timber components contain nails and screws. These must be removed for safe handling before reuse or recycling. This is most often done by hand and generally is only economically warranted for high value items like large section beams and old growth timber. Lower value components such as studs and small section joists must be free of nails and screws before they are chipped in recycling operations.

Research and development is required in the area of timber reuse and recycling. Although large amounts of timber are demanded and required in a majority of residential construction projects, reclaimed lumber is not permitted for use in structural applications because of the nailed and screwed connections. Furthermore, re-coding the wood is expensive and not economically feasible at this point. The Scandinavians have developed one method to remedy this problem. They reclaim defect free timber for reuse or recycling by identifying ‘connector free zones’ within the timber cross section that can be easily removed using a rip saw (Hobbs, 2001).

5.0 MATERIAL-FLOW MANAGEMENT

5.1 Material Classification

Products of the deconstruction process fall into one of three broad categories: reused, recycled and disposed. In current practice, reused and recycled materials can typically make up about 85% of a building's total weight (Reiff, 2005). Reused materials have been carefully broken down into products with estimated environmental impacts. The most detailed classification presently embraced by the Deconstruction Institute is embedded in the Building Materials Reuse Calculator. This consists of a tool developed by New York Waste Match, based on BEES (Building for Environmental and Economic Sustainability) 3.0, a program of the National Institute of Standards and Technology.

According to "The Reuse People", reused materials generally include (TRP Presentation, 2005):

- Appliances
- Architectural Pieces
- Bricks
- Cabinets & Vanities
- Doors
- Electrical
- Flooring
- Granite & Marble
- HVAC
- Lumber
- Plumbing
- Plywood & Oriented Strand Board
- Roofing Tiles
- Structural Steel
- Windows

Typical recycled materials include (TRP Presentation, 2005):

- Aluminum
- Asphalt
- Asphalt Shingles
- Carpet Padding
- Cast Iron
- Concrete
- Concrete Block
- Copper

- Glass
- Scrap Steel
- Stucco (when untreated)
- Wood (when untreated)

Typical disposed materials include (TRP Presentation, 2005):

- Ceramic Tile (because of glue)
- Drywall (because of paint)
- Plaster
- Stucco (when treated)
- Wood (when treated)

5.2 On-Site

Material flow problems in deconstruction arise from the long lifecycle of buildings where the present condition of materials is often unknown. Schultmann (2003) suggests that an appraisal of all materials and their condition should be conducted prior to deconstruction. This survey is known as a building audit and is performed by a certified appraiser, hired by the homeowner (Reiff, 2005). The product of the appraisal survey is a bill of materials. Ideally, detailed information from the building's construction plans, description, and history should also be assembled (Schultmann, 2003). In practice, this information is rarely available for old buildings and the bill of materials from the appraisal serves as the major information source for planning (Reiff, 2005).

After appraisal, construction elements in the building are labeled for reuse, recycling and disposal by the dismantling crew (Reiff, 2005). Material flow on site proceeds in a series of phases (Schultmann, 2003). At the first phase, materials are located in a given construction element (e.g., wooden exterior wall). A sequence of dismantling activities separates the materials into smaller elements or groups (e.g., strip drywall on the inside and PVC shingles on the outside to expose the structural frame). Elements of the groups are further separated into components (e.g., structural frame is broken up into shear studs, beams, joists, corner bracing) and then sorted into containers. For reuse, sorting happens by material type and size. For recycling, sorting is by material only. It is important that potentially hazardous materials are identified in advance and treated separately not to contaminate the job site or other reusable materials (Schultmann, 2003).

5.3 After Construction

The building industry represents one of the most resource intense industries in the world. Buildings usually undergo transformation due to reasons including requirement or fondness changes of user, degradation of materials, or needs of more technology dependent components (Durmisevie, 2002). However, the building transformation in this industry still follows traditional building methods which are usually related to the time consuming construction processes, significant energy and material use and massive waste production (Durmisevie, 2002). Furthermore, improperly designed buildings along with the increasing complexity of building systems, quality and types of materials, and connecting devices make the recovery of materials for reuse and recycling in adaptation and removal of buildings extremely difficult. As a result, the life cycle of most buildings is presented as a linear system, which means one directional material flow from material extraction, manufacturing, transportation, construction, operation, demolition, and finally waste disposal (landfill or incineration) (Durmisevie, 2002).

It is known that earth's resources are limited, but paradoxically human prosperity in this modern society is based on consumption of the earth's limited resources. Thus, an urgent societal problem is to further extend the life cycle of used materials. From a system point of view, one approach can be to move away from a linear system towards a circular arrangement (Fletcher, 2000). Under this approach, material flows in the life cycle of buildings are closed. Instead, natural resources are conserved as the "wastes" become the new sources of materials. Generally speaking, other than disposal (landfill and incineration) there are three end-of-life scenarios which can close up the material flow into a circular system: reuse, recycling, and remanufacture (Rieff, 2005).

5.3.1 Reuse

This scenario seems to have better environmental performance since it is an attempt to extend the life of a building or the building components (Durmisevie, 2002). Instead of demolishing the whole building, this process tends to impact the least amount of change to the existing building components by carefully dismantling each constituent. Ideally the best situation in the end of the life cycle is the reuse of the whole building or the components in a new combination. This practice does not change the material form and thus uses the least energy and extra material when closing the loop of the component or building life cycle (Reiff, 2005). After the deconstruction of a building, some parts of the salvaged components and materials can be sold on-site, taken to the warehouse, or consigned to other resellers and sold to the public. Other materials may either be shipped to low-income markets or donated to other nonprofit agencies (Rieff, 2005).

There are two major types of constraints in the reuse scenario (Geyer et al., 2004, Reiff, 2005).

(1) Limited Feasibility of Deconstruction

Currently, the prevailing end-of-life treatment of a building is demolition, leading to disposal, rather than recovery of the components for reuse. Moreover, most buildings are not designed for deconstruction (Fletcher, 2000). Even though it is possible to deconstruct a building, deconstruction always requires more manual work and is thus more labor, cost, and time-intensive (Geyer et al., 2004). Although, deconstruction on private buildings, such as homes, qualifies owners for tax deductions, most commercial projects are not eligible for this benefit (Reiff, 2005). Aside from the incentive of donating the salvaged materials, time issues always play a determinant role when it comes to the project schedule. Since demolition is typically the first process in a new construction development, it must be commissioned by the developer of the new project. The main priority for the developer is usually to remove the end-of-life structure as quickly as possible, which creates an incentive to demolish rather than to deconstruct it (Geyer et al., 2004).

(2) Limited Market Demand for Reused Materials

In general, reused materials or components are treated as inferior in quality thus, without the incentive of cost savings, most customers are likely to choose new materials, which are perceived as more convenient and lower risk (Geyer et al., 2004). What's more, used material components are inherently fixed in size and form. Unless it is pre-designed into the new project, most of them cannot be easily used again without proper transformation (Reiff, 2005).

5.3.2 Remanufacture

This strategy involves reconfiguration of the existing component or system to restore its condition to “as good as new” (Durmisevie, 2002). This may involve reuse of existing components, replacement of some component parts, and quality control to ensure that remanufactured product will meet new product tolerances and capabilities (Durmisevie, 2002).

5.3.3 Recycling

This scenario is composed of three major processes. The first process group is deconstruction of end-of-life buildings followed by the second, separation of used materials. Finally, in the third process group, the used materials are reproduced and transformed to new products then reintroduced into the life cycle of buildings (Durmisevie, 2002).

There are various potential constraints of the recycling scenario. The vast majority of buildings are demolished when they reach the end of their lives or when a new construction project is planned to replace the existing structure. In fact, demolition is the start, not the end, for most construction projects (Geyer et al., 2004). The time for demolition is usually limited. Additionally, present structures and components are not designed to be reused or recycled since the components cannot be easily dismantled and separated once the building is demolished (Fletcher, 2000). Contingent on the contamination, a considerable part of the recycled materials is limited to low quality use or even landfilling (Durmisevie, 2002).

6.0 COSTS AND BENEFITS OF DECONSTRUCTION

The costs and benefits of deconstruction can be categorized into economic, environmental, and social aspects. While the most obvious benefit is to the environment, some firms have demonstrated the favorable economics of this process. At the same time, other projects have resulted in unforeseen social benefits. The following sections will breakdown the main benefits and costs associated with deconstruction by looking at the existing market and the various companies promoting the advantages of this innovative strategy.

6.1 Costs (Environmental & Economic)

Demolition has major environmental costs in the United States. According to the EPA there are over 136 million tons of building related construction debris generated annually (Steward, et. al, 2004). Within this total, 125 million tons (80%) are taken from demolition and renovation sites, while 11 million tons (8%) originate from new construction projects (Steward, et. al, 2004). These quantities account for at least one quarter of the total landfilled waste in the U.S. (Hilmoe, 2001). Clearly any impact on these numbers can have significant effects on the waste stream of the country. Deconstruction is one method that has a proven impact on the amount of waste generated annually.

In the residential sector, deconstruction is capable of mitigating many of the environmental costs associated with the demolition of homes. The typical 2000 square foot home in the US produces 127 tons of demolition debris (Greer, 2004). Historically, the debris from residential demolition has been transported and dumped into landfills. As the population continues to increase, it can be assumed that the creation of material debris from the construction industry will also place mounting tension on the environment. If a common practice of deconstruction is adopted, the diversion of materials from landfills may have the potential to reverse the dominant industry trend of "bash and trash" (Webster & Napier, 2003).

Along with environmental costs, there are also economic expenses associated with deconstruction. Both traditional demolition and deconstruction share several common costs. Among these expenditures are labor, transportation, and disposal fees. Wages are typically higher in the demolition business compared to the lower paid deconstruction workers. However, due to extensive time requirements of the process, the cost of labor is one of the highest deconstruction costs. In one Florida case study the cost of demolition was $5.36 per square foot, while deconstruction cost $6.47 per square foot (Guy & Mclendon, 2001). The 21% difference was founded in the cost of labor. Conversely, transportation costs are also similar. Tipping fees pose a significant cost for demolition and deconstruction. These fees can range from $65 to $80 per ton (Greer, 2004). It should be noted that significantly less waste is disposed of in deconstruction, therefore reducing the overall cost of disposal.

Other costs associated with deconstruction focus on the time-cost trade-off of financing and loan interest. When compared to demolition, deconstruction can take up to 10 times as long (Reiff, 2004). Attributed to this longer operation cycle are the following activities and their related time durations (Guy & Mclendon, 2001):

- Deconstruction Activity (26%)
- Processing Material (24%)
- Disposal and Cleaning (17%)

- Demolition (10%)

If effective scheduling and estimating are not implemented properly, the cost of labor and financing can damage the financial feasibility of the project. Alternatively, delays in deconstruction activities have the potential to push back the progress of other contractors or affect the overall project schedule. As a result the deconstruction contractor might impact future business opportunities. Moreover, the time that reuse materials are held in inventory can make or break a project budget. Clearly, in order to influence these cost factors, the ideal project must include a short deconstruction process and fast turnover of materials.

6.2 Benefits (Environmental, Economical and Social)

As mentioned previously, the benefits of deconstruction are far more significant than the costs associated with this approach. When the right strategy is employed, deconstruction is capable of providing economic, social, and above all else, environmental advantages. By looking at the experiences and outcomes of current industry project trends the positive effects of deconstruction are illustrated.

One obvious consequence of deconstruction is the reduced amount of material debris deposits in land fill locations. For the average 1500 square foot residential deconstruction project an estimated 50% of the materials are reused, 25-30% are recycled, and the remainder is trashed (Greer, 2004). Data in other areas estimates that closer to 90% of the building materials can be recovered via reuse and recycling (Webster, 2003). Consequently, these reductions in disposal can have the following environmental outcomes (Steward, et. al, 2004):

- Reduced energy usage
- Extended material life
- Reduced pollution flows in lower manufacturing
- Reduced waste to land fills
- Reduced scarcity of rare diminishing materials

The EPA goes further to state that “deconstruction could be a source to mitigate global warming through solid waste reduction (Webster & Napier, 2003). Undoubtedly if deconstruction continues to gain in popularity, the amount of diverted materials could have positive effects on the environment.

Some companies in the deconstruction industry have discovered benefits through potential reuse of building components. Located in various regions throughout the country are retail outlets for salvaged building materials. In Portland, one company claims to sell 1.8 million pounds of materials each month (Greer, 2004). Generally, it is these facilities that determine the profitability of deconstruction. In fact, one of the primary determining factors in the deconstruction economic equation is the revenues generated from the resale of the salvaged materials. By locating markets with the appropriate demand, retail firms have realized the environmental and economic potential of deconstruction.

Even though the gross costs of deconstruction are higher than traditional demolition, when the revenues from salvaged materials are factored into the equation, deconstruction can be significantly less expensive. According to The Reuse People, on average, deconstruction costs 30-50% less than demolition (Reiff, 2005). This difference is calculated by taking the overall costs of the deconstruction operation and adding the value of the salvaged materials. For most projects this profit is realized in the tax deduction of the material value. In the Bay Area the average salvage value of building materials is $84,000, which can yield a $29,000 tax savings for individuals in the 35% bracket (Greer, 2004). The majority of these materials are taken directly from the job site, or they are donated by contractors, landlords, retail stores, and homeowners. When a deconstruction project realizes the optimum value of materials, the economics become feasible.

Several social benefits are associated with deconstruction. Primarily, deconstruction has had the greatest social impact in the labor market. Deconstruction provides the opportunity for individuals to receive on the job training which can assist in further career advancement. According to the demolition industry 200,000 buildings are knocked down each year (Seldman & Jackson, 2000). Consequently, there is great potential for deconstruction to offer entry level positions to accommodate the high labor demand of the process. Wages in the deconstruction industry can range from $9 to $17 per hour providing adequate income for generally young unskilled individuals (Seldman & Jackson, 2000). Some companies have even offered medical benefits and life insurance to employees (Seldman & Jackson, 2000).

Other social advantages of deconstruction can be seen in the used materials market. Low income individuals can purchase materials at reuse centers for at prices 50% lower than new products (Guy & Mclendon, 2001). Furthermore, retail outlets offer employment opportunities for warehouse managers and sales staff. The process of reworking materials for resale could also require additional manpower. Overall, the deconstruction industry could have the most beneficial impact on the low income segments of society by offering low price goods along with the financial resources to pay for those products.

7.0 CASE STUDY

7.1 The Reuse People of California

The Reuse People of California (TRP) is a non-profit organization. It receives its materials as donations from homeowners who select deconstruction in place of demolition. In turn, TRP certifies the donation as tax deductible. Most often, TRP operates with demolition contractors who choose to offer deconstruction services to homeowners. In this case, there are contractual arrangements between TRP and the demolition contractor, between TRP and the homeowner, and between the homeowner and the demolition contractor.

At times it is more economical for TRP to license demolition contractors than to perform deconstruction themselves. This eliminates costs for TRP associated with insurance and workers' compensation. Under this arrangement TRP signs a memorandum of collaboration with the demolition contractor and provides a list of specifications. Accordingly, the demolition contractor is also obligated to deliver the materials within 15 miles of the closest TRP office.

In a typical deconstruction project the homeowner hires an appraiser to produce the bill of materials and the demolition contractor to conduct the deconstruction services. Prior to deconstruction, TRP marks items in the building. Later, when materials are delivered to the warehouse facility, TRP gives the homeowner a proof of the donation. Based on the marks and the price listed in the bill of materials, a donation value is established for the owner to apply to their tax credit claim.

Although time constraints can impede the application of deconstruction, the economic impacts can be extremely advantageous. The deconstruction process on average takes about ten times longer than demolition. It is also about twice as costly due to labor expenses. However, if deconstruction happens early in a project, the process can fit relatively easily into the overall construction schedule. Conversely, the tax credit for the homeowner has the potential to ensure that the price is competitive. For example, for a standard house, demolition would cost $7,000 in direct costs and $3,500 in overhead and profit. Deconstruction on the other hand would cost $15,000 in direct costs and $7,500 in overhead and profit. Historically, when applied to a typical house, the TRP can salvage about $60,000 worth of materials. For a homeowner in the 30% tax bracket, they can receive a tax deduction of $18,000. Thus, the net cost of deconstruction would come to only $4,500 for the homeowner, compared to $10,500 for demolition (Reiff, 2005).

7.2 The Case Study Reuse Project

In order to understand the deconstruction process in more detail, a project case study was examined. After contacting the Reuse People, a deconstruction project in Orinda, California, was selected for further data collection and analysis. A 3,200 square foot residence built in the 1930's was used as a case study to demonstrate the application of deconstruction. Although this home was not entirely deconstructed, the project was extensive enough to illustrate the methods and principles facilitating the process employed by TRP.

Figure 1. Entrance to Residence

The method used to collect the data for this case study was developed through site visits, interviews, photo documentation, TRP inventory lists, and bid worksheets. All of the salvaged materials intended for reuse were recorded on a line item inventory list (Refer to Appendix A for the inventory list used in the analysis). Portions of the worksheets were used to calculate disposal quantities, weights, and costs. Additionally, the bid worksheets determined overall estimated costs of the project. The various costs used to calculate the total bid price were:

- Disposal Cost
- Labor Cost (man-hours, bonuses, worker's compensation, etc.)
- Equipment Cost
- Overhead and Profit
- Adjustments

After adding up all of these expenses the total cost of deconstruction on this project was $32,000. It should be noted that this figure does not account for the appraised value to salvaged materials. According to TRP, if traditional demolition had been used, the cost would have been approximately $25,000.

In order to complete the project, a team of four laborers and one crew chief was required to be on-site for 3 standard work weeks. For the most part, the process of deconstruction used only basic hand tools. Accordingly, power tools were needed for certain activities such as cutting out door frames and window casings. Once the materials were removed from the home they were organized by similar categories and loaded on to a truck for transportation. To maintain consistent work flow and promote safety on the project, the same crew members remained on the site until all activities were completed.

Figure 2. TRP Crew Loading Truck

For this project the scope was not an entire tear down. Rather, portions of the structure would remain intact upon termination of the deconstruction activities. TRP was contracted to remove all materials except for the foundation, main structural framing, sub-flooring, roof trusses, and

Figure 3. Organized Roof Tiles

Figure 4. Roof Tiles Stacked for Shipping

exterior wall covering. Each of the materials removed was evaluated for their salvage potential, and then separated into disposable and re-usable allocations. Due to the difficulties associated with removal, the disposal materials mostly consisted of the wood flooring, carpeting, and drywall. Alternatively, a total of 167 items were determined to be re-usable. In Figure 5 a list of the most significant items salvaged for reuse is summarized.

Reuse Materials	Qty.
Armoire	1
Base Cabinet	11
Bookcase	7
Bricks	1500
Cabinet	10
Carpet (15' x 12')	3
Roofing Tiles	2000
Doors	24
Shower Faucet Yoke	5
Steel Casement Window	27
Toilet	3
Vanity with Sink and Faucets	3
Window Shutter	12
Wood Trim (Linear Feet)	500
Appliances	**Qty.**
Stove	1
Electric Oven	1
Refrigerator	1
Water Heater	1
Furnace with Compressor	1

Figure 5. Significant Items Salvaged for Reuse

Presently the entire inventory list is under review by appraisers. Therefore, the precise donation value of the materials could not be determined at the time this report was written. Assuming that reused materials would be used in replacement of new products, an approximate monetary value of the salvaged items was calculated. By comparing the reused item to the cost of a new product the value of the salvaged materials was determined. From the inventory list, the cost of each line item was established and aggregated together to arrive at a total economic assessment. The total of the estimated costs of the reused materials for this project was approximately $23,000. Considering that conservative prices were applied to the individual item costs, the total approximation will most likely fall well below the actual appraised donation value. According to historical data provided by TRP, a typical owner of a house of similar size can expect to recover over $100,000 in re-used materials (www.thereusepeople.org).

Figure 6. Exterior with Windows Removed

Figure 7. Interior Framing

8.0 RESULTS

This section will analyze the data obtained from the deconstruction case study in Orinda, CA previously described. To determine the associated environmental impacts of deconstruction and compare the results with demolition, EIO-LCA was used. Costs of services and materials were obtained in 2005 dollars and adjusted for a 2.5% annual inflation rate before being entered in the 1992 and 1997 impact matrices.

The costs of deconstruction and demolition services were $32,500 and $25,000, respectively. The environmental impacts of both services were obtained by entering these costs in the EIO-LCA sector titled "Maintenance & Repair of Farm and Nonfarm Residential Structures" under "Construction Ordnance". It is assumed they involve similar labor and equipment and could be classified as a service in the same industry sector. Since deconstruction costs more than demolition, its gross impacts were greater. To arrive at the net impacts of deconstruction, the impacts of the salvaged materials were subtracted from the gross deconstruction impacts. Table 1 summarizes the process.

	Deconstruction Impacts	Demolition Impacts
Cost of Service	+	+
Cost of Salvaged Materials	-	none
Net	?	+

Table 1. Process of Comparing Deconstruction and Demolition

The salvaged materials from the partial deconstruction of the house were first compiled in an inventory list by the contractor – The Reuse People – and sent over to our group. The salvaged materials were not priced in that inventory list, so market prices were researched from home improvement retailers such as Lowe's, Ikea, and Home Depot. For the clay tiles, prices of used Mission Style tiles were obtained from a specialty retailer for used tiles. The full inventory list with associated prices is shown in Appendix A.

Prices of materials were then aggregated by sector and entered into the EIO-LCA. Figure 8 shows current market prices of salvaged materials grouped by EIO-LCA sector. Tiles and windows are the two largest single material categories. Wood products together also form another large group, but they are spread across different sectors, as their manufacturing impacts are likely to be different.

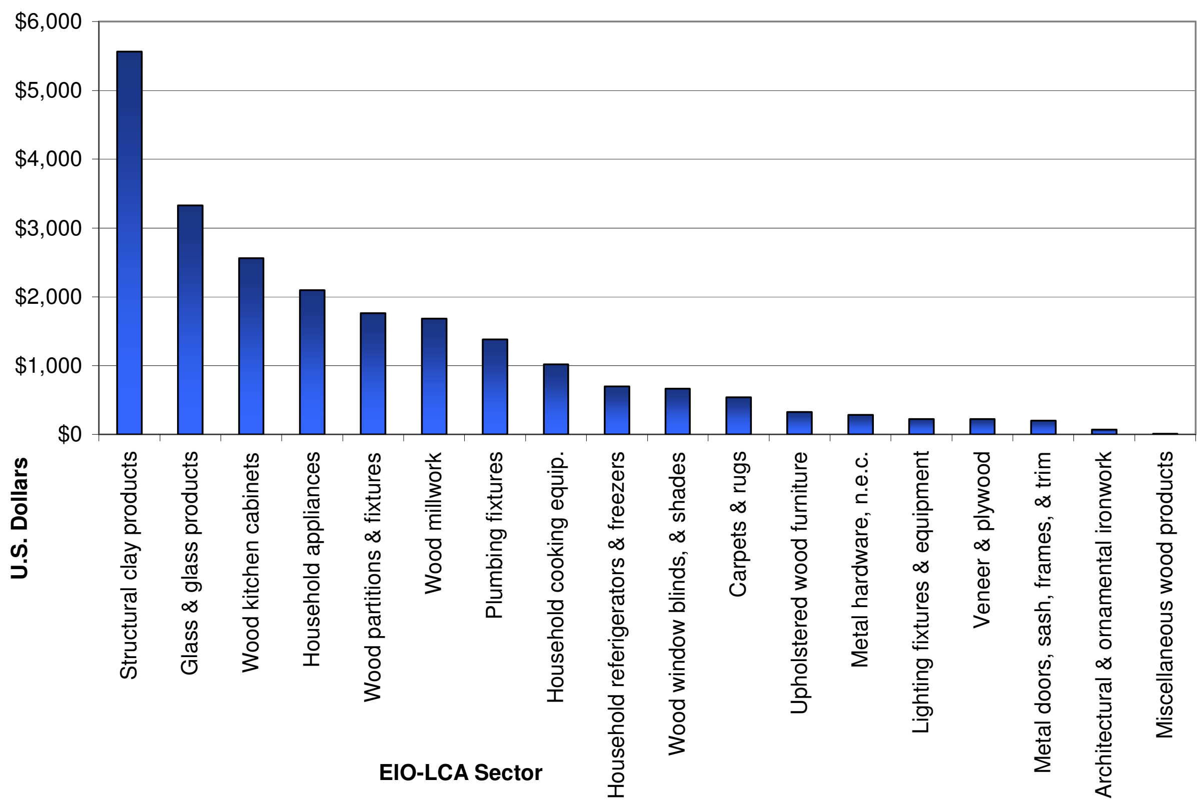

Figure 8. Material Cost by EIO-LCA Sector in 2005 Dollars

The net impacts of deconstruction after subtracting the salvaged materials are shown in Appendix B for 1992 and 1997 EIO-LCA. Figure 9 shows a summary of conventional pollutants broken down by sector. Because of its larger portion of total cost, the sector Brick & Structural Clay has also the largest impacts in each category. However, relative to its cost fraction, which is about 25%, the sector has a relatively larger portion (50%+) of particulate matter and sulfur dioxide releases. It has more than 25% of the carbon monoxide and nitrogen dioxide emissions, and is only underrepresented in emissions of volatile organic compounds. Therefore, salvaging clay tiles makes not only economic sense, but has substantial environmental benefits. Note also that wood products are overrepresented in the nitrogen dioxide emissions.

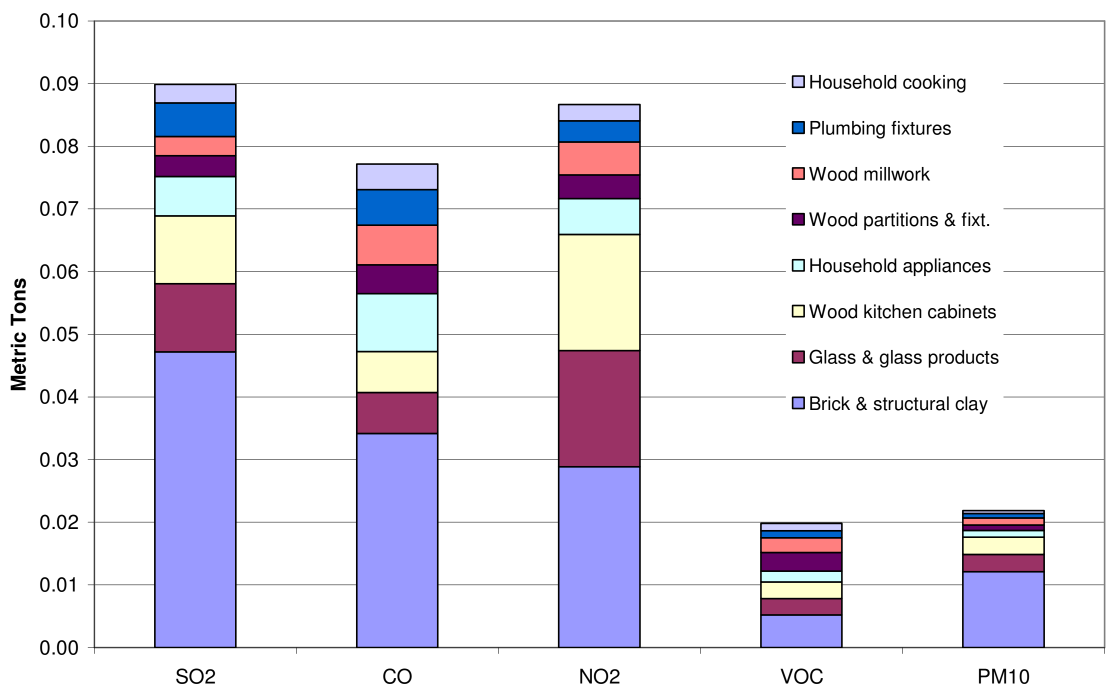

Figure 9. Conventional Pollutants by Sector (1992 EIO-LCA)

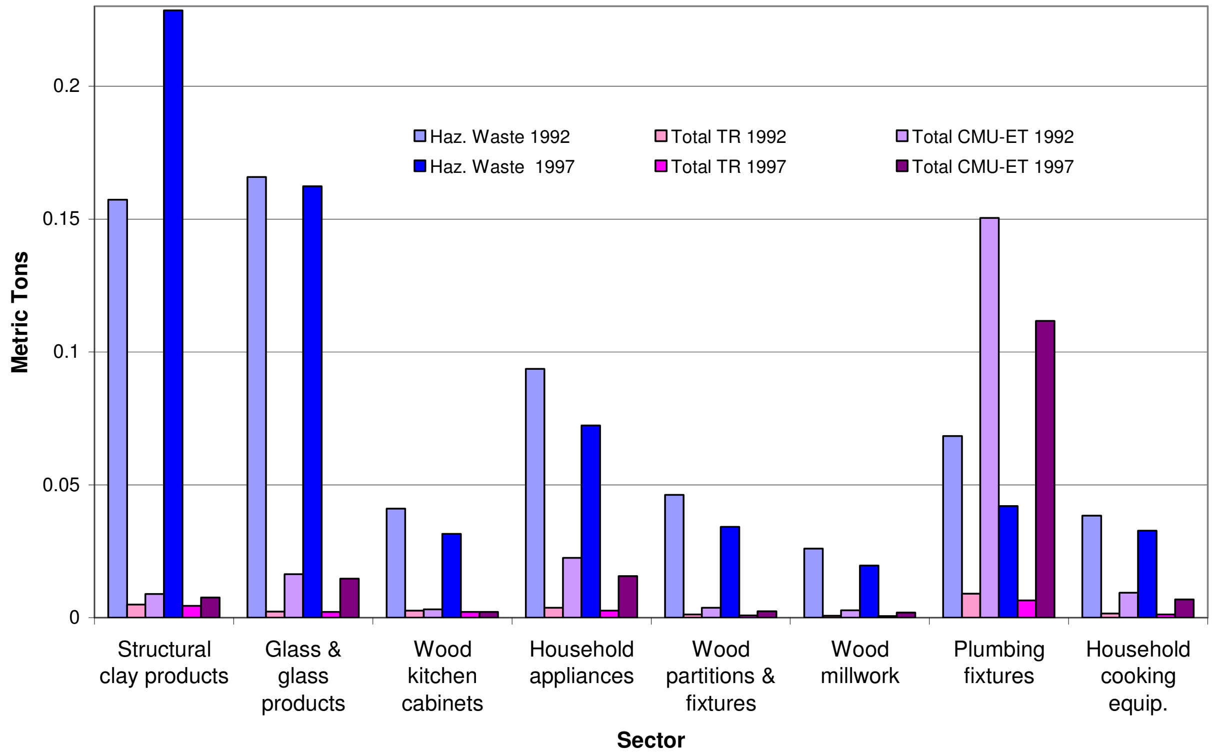

Figure 10. Hazardous Wastes, Toxic Releases, and Weighted Toxics by EIO-LCA Sector

Figure 10 compares toxic releases across the sectors of the salvaged materials from the Orinda project. Note that while clay tiles and glass have large portions of the releases because of their large fractions of total cost, their adjusted toxicities are low. In contrast, plumbing fixtures stand out as being very hazardous after adjusting with the CMU equivalent toxicity index. In any case, the savings of emissions from salvaging all materials are substantial.

Finally, Figure 11 and Figure 12 show the material impacts in terms of global warming potential and energy use, respectively. Again, structural clay products have a larger impact than their fraction of the total cost, as their production is very energy-intensive.

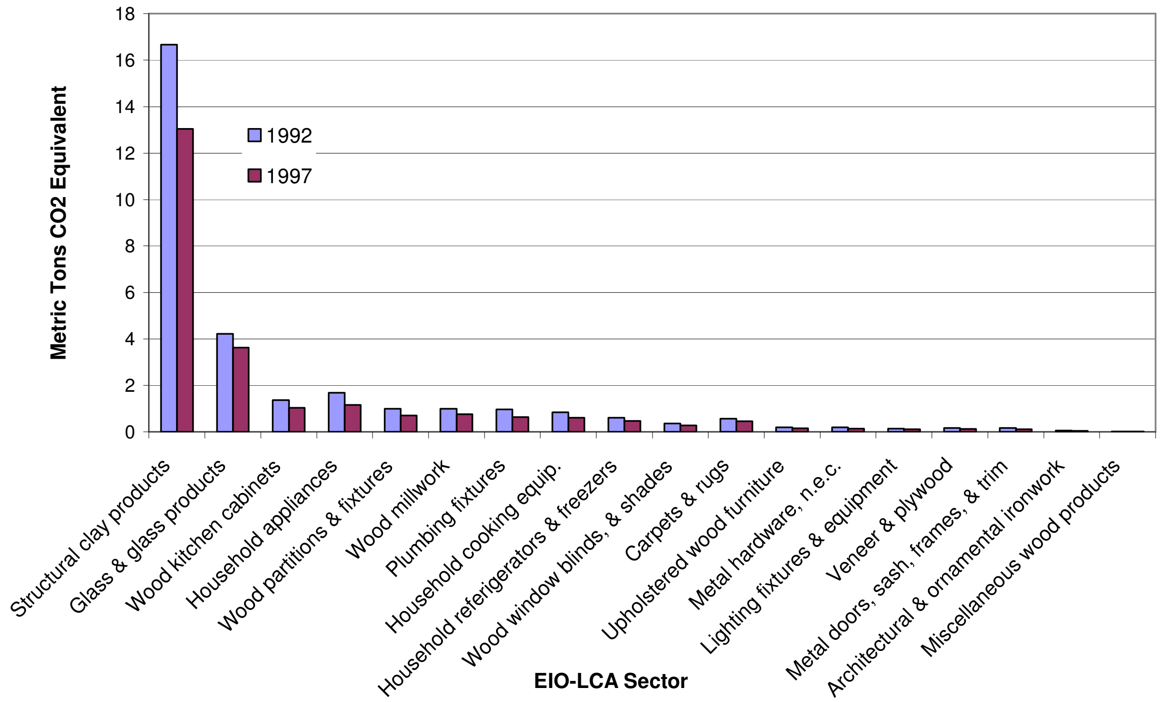

Figure 11. Global Warming Potential by EIO-LCA Sector

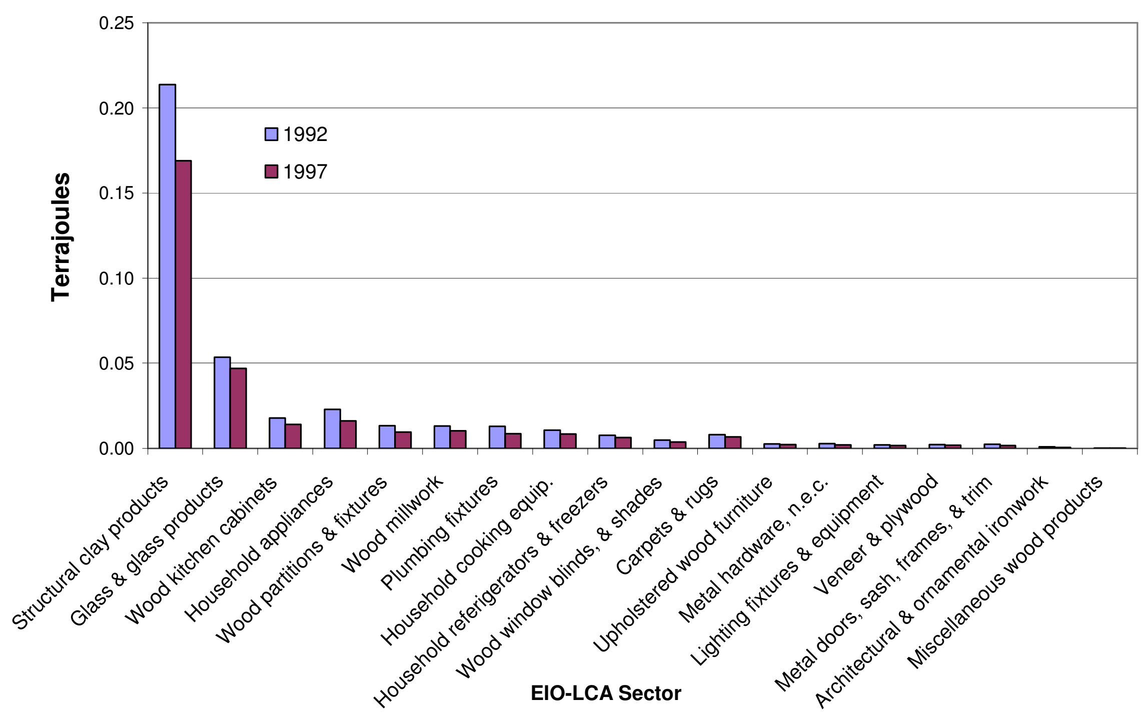

Figure 12. Total Energy Consumption by EIO-LCA Sector

Once the impacts of all materials were obtained, they were subtracted from the impacts of the deconstruction service itself. As expected, some net impacts turned out numerically negative, signifying net decreases in emissions from the process (Refer to Figure 13). By far the most significant differences are observed in hazardous waste releases. There are also two impact categories with net positive releases from deconstruction, albeit less than the releases from demolition: carbon monoxide and nitrogen dioxide. Finally, in one category (PM10), deconstruction is worse than demolition. This is possibly because the duration of deconstruction is a few weeks, as opposed to demolition, which may take only one day. Understandably, more dust would be produced over a more lengthy process, even if demolition is to produce a higher concentration of dust on any one specific day.

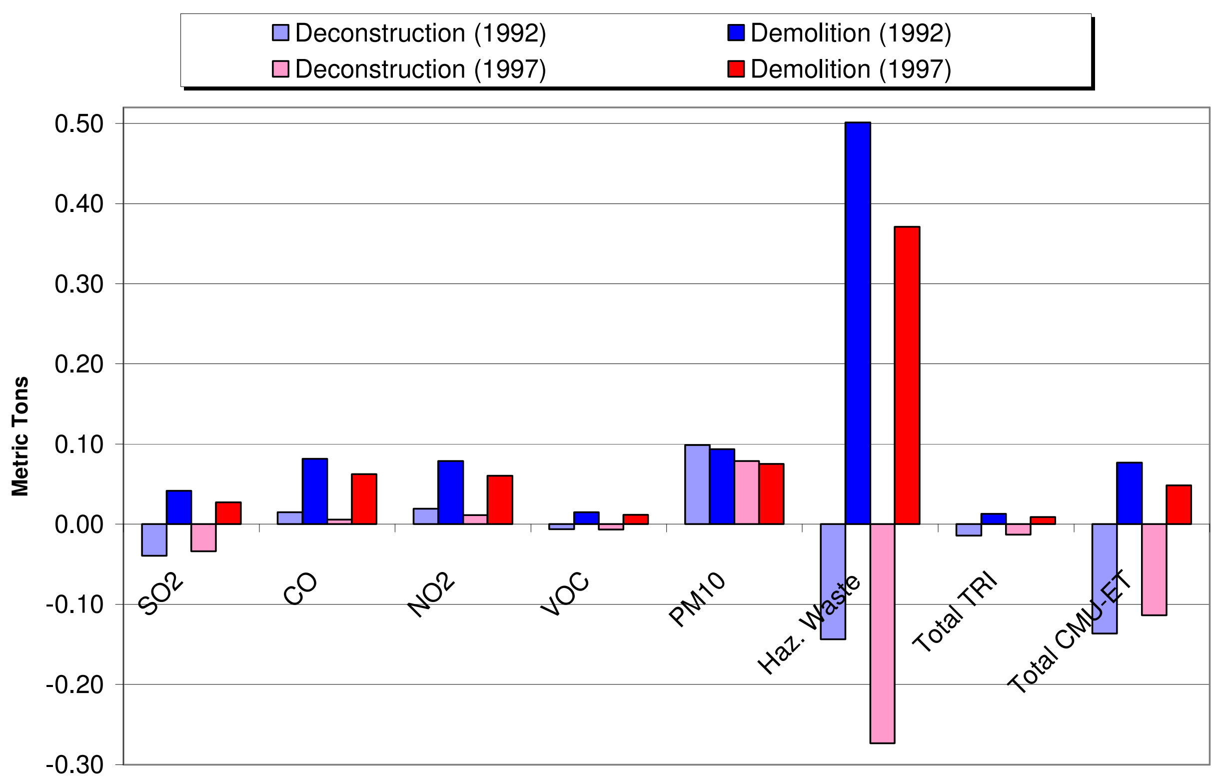

Figure 13. Deconstruction vs. Demolition –Case Study (Orinda, CA)

8.1 Sources of Uncertainty

Uncertainty is a concern associated with data collection and Life Cycle Assessment methodology conducted during the process of research. Various types of uncertainty are embedded in LCA related research. In order to preserve accuracy, it is beneficial to take information regarding uncertainty in account, especially when making decisions based on LCA analyses because statements and conclusions might be incorrect when data is uncertain (Norris 1996).

Three major uncertainties are discussed in this section. These issues are connected to limitations in EIO-LCA methodology, comprehensiveness of environmental impact category, and data quality.

Limitations in EIO-LCA Methodology

The EIO-LCA methodology uses the economic input-out put matrix of the U.S. economy to identify the elements in the entire supply chain of a product. Principally, the EIO-LCA identifies almost all sectors of the economy as direct and indirect suppliers. This feature of the model solved the typical problem on data availability in the traditional approach of LCA, SETAC-EPA model (Hendrickson and Horvath 1998). While the traditional LCA method assesses specific product types, EIO-LCA uses aggregated economic sectors to simulate the specialized processes of product manufacturing and service industries. In our research, when performing the EIO-LCA, there was not a sector in the model that characterized "deconstruction." Thus, this service was estimated by the sector, "maintenance & repair of farm and non-farm residential structures." This sector was assumed to share the most input similarities to deconstruction, with perhaps different environmental implications. For the same reason, each fixture is assigned to the closest sector with a certain degree of difference, which has the potential to lead to inaccuracies.

Comprehensiveness of Environmental Impact Category

The environmental impacts are not covered comprehensively in this study. For example, human health, resource consumption, ozone depletion, and indoor air quality are not discussed because of the limitation of EIO-LCA methodology.

Data Quality Assessment

Data quality assessment deals with uncertainty caused by imperfect data sources. The quality of data was evaluated from six aspects with a five-point scale rating system for each element (a score of 1 representing the highest data quality) as shown in Table 2 (Junnila and Horvath 1997). The results of assessing the quality of the data used in this research are presented in Table 3. The indicator score that represents the most uncertainty in this research is the representativeness of the deconstruction and demolition costs. The deconstruction cost came from a typical project and the demolition cost was estimated by a specialist in the industry. It is not sufficient that we can assert that the whole industry uses the same cost estimation methods. However, because deconstruction industry is just in its beginning stage, data from a case study was the best we could ascertain.

One other important source of uncertainty stems from the acquisition method of the fixture prices. Ideally theactually salvaged price of the fixtures should have been used in EIO-LCA analysis. However, due to the constraints of the project time and costs, a final appraisal for all fixtures' salvaged prices from various producers was unavailable. Since the added value of the fixtures in the housing industry is not high, the market prices and the producer price are assumed to be the same. Thus, the market prices of the fixtures were substituted to finalize the results of our research. (Source: anderson.com, consumersearch.com, crown-molding.com, homedepot.com, ikea.com, lowes.com, stackandstacks.com, weardated.com) Moreover, it was concluded that these salvaged materials are used to replace new products of equivalent quality. Therefore, after obtaining a range of quoted prices for the new products from different merchants, we chose a lower bound price as our targeted market price for the reused items. Thus, the assumptions in the method that we appraised the fixtures brings certain degree of uncertainty.

Indicator Score	1	2	3	4	5
Acquisition Method	Measured data	Calculated data based on measurements	Calculated data partly based on assumptions	Qualified estimate (by industrial expert)	Nonqualified estimate
Independence of data supplier	Verified data, information from public or other in dependent source	Verified information from enterprise with interest in the study	Independent source, but based on nonverified information from industry	Nonverified information from industry	Nonverified information from the enterprise interested in the study
Representa-tiveness	Representative data from sufficient sample of sites over an adequate period to even out normal fluctuations	Representative data from smaller number of sites but for adequate periods	Representative data from adequate number of sites, but from shorter periods	Data from adequate number of sites, but shorter periods	Unknown or incomplete data from smaller number of sites and/or from shorter periods
Temporal correlation	Less than three years of difference to year of study	Less than five years of difference	Less than 10 years of difference	Less than 20 years of difference	Age unknown or more than 20 years of difference
Geographical correlation	Data from area under study	Average data from larger area in which the area under study is included	Data from area with similar production conditions	Data from area with slightly similar production conditions	Data from unknown area or area with very different production conditions
Further technological correlation	Data from enterprises, processes and materials under study	Data from processes and materials under study, but from different enterprises	Data from processes and materials under study, but from different technology	Data on related processes or materials, but same technology	Data on related processes or materials, but different technology

Table 2. Pedigree matrix used for data quality assessment (Junnial and Horvath 2003)

	Acquisition Method	Independence of data supplier	Representa-tiveness	Data age	Geographical correlation	Technological correlation	Average
Material Prices	3	1	1	1	2	3	1.8
Deconstruction Cost	1	2	4	1	1	1	1.7
Demolition Cost	4	3	4	1	1	2	2.5
Maximum quality = 1, minimum quality = 5. Each value within each category is defined in Table 2.							

Table 3. Results of data quality assessment

9.0 CONCLUSION

Overall, deconstruction is by far the more environmentally friendly option. It can be stated with confidence that its positive effects would be even more pronounced, had this project been a full, rather than partial deconstruction. Deconstruction also makes economic sense for the owners, as the tax break they receive from donating materials more than covers the cost difference with demolition. On the part of the contractor, the deconstruction business is sustainable even while selling substantially below market price. Once considered a low-end market, the deconstruction industry is beginning to target customers of all tiers, such as the high resale value of classic tiles and windows has shown. As landfilling costs continue to increase, the cost of demolition is bound to rise, making the deconstruction tax break subsidy unnecessary, and rendering the business sustainable in a competitive environment. An infant industry with positive economic and environmental affects, deconstruction has a bright future in the booming housing markets of the western United States.

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APPENDIX A

ORINDA PROJECT FIXTURE INVENTORY DATA SHEETS

FIXTURE INVENTORY							
The ReUse People			**Owner:**	Sayers			
2100 Ferry Point, #150			**Street Address:**	15 Las Aromas			
Alameda, CA 94501			**City, State:**	Orinda, CA			
Toll Free: 888.588.9490			**FAX:**				
Main Office: 510.522.2722 Fax: 510.522.2986			**Date of Inventory:**	April 7, 2005			
www.thereusepeople.org			**TRP Contractor:**	TRP			
Area Manager: Ted			**Appraiser:**	Christensen			
ID #	**DESCRIPTION**	**Warehouse**	**Price**	**Source**		**Sector**	Costs
18	5 burner gas cook top	Alameda	$179.00	lowes.com	l	1	
19	Double electric oven	Alameda	$839.00	homedepot.com	h	1	$1,018.00
20	Sub Zero refrigerator & freezer - side by side	Alameda	$699.00	homedepot.com	h	2	$699.00
25	Ceiling light	Alameda	$20.00	homedepot.com	h	7	
39	Ceiling light	Alameda	$20.00	homedepot.com	h	7	
46	Ceiling light	Alameda	$20.00	homedepot.com	h	7	
63	Ceiling light	Alameda	$20.00	homedepot.com	h	7	
68	Ceiling light	Alameda	$20.00	homedepot.com	h	7	
98	Ceiling light	Alameda	$20.00	homedepot.com	h	7	
119	Ceiling light	Alameda	$20.00	homedepot.com	h	7	
130	Ceiling light	Alameda	$20.00	homedepot.com	h	7	
134	Ceiling light	Alameda	$20.00	homedepot.com	h	7	
141	Vanity light	Alameda	$34.00	homedepot.com	h	7	
136	Wall light	Alameda	$13.00	ikea.com	i	7	$227.00
81	Cast iron bath tub	Alameda	$230.00	homedepot.com	h	16	
80	Shower faucet yoke	Alameda	$59.00	homedepot.com	h	16	
116	Shower faucet yoke	Alameda	$79.00	homedepot.com	h	16	
146	Shower faucet yoke	Alameda	$49.00	lowes.com	l	16	
17	Stainless steel double sink with faucets	Alameda	$198.00	homedepot.com	h	16	
104	Toilet	Alameda	$98.00	homedepot.com	h	16	
144	Toilet	Alameda	$98.00	homedepot.com	h	16	
151	Toilet	Alameda	$98.00	homedepot.com	h	16	
75	Toilet	Alameda	$98.00	homedepot.com	h	16	
166	Utility sink	Alameda	$78.00	lowes.com	l	16	
143	Wall sink with faucets	Alameda	$127.00	homedepot.com	h	16	$1,383.00
79	Shower door	Alameda	$105.00	homedepot.com	h	17	
115	Shower door	Alameda	$95.00	homedepot.com	h	17	$200.00
48	Iron railing	Alameda	$69.00	homedepot.com	h	18	$69.00
157	Fireplace screen	Alameda	$16.00	lowes.com	l	19	
41	Fireplace screen	Alameda	$18.00	lowes.com	l	19	
31	Fireplace screen (2 pcs)	Alameda	$23.00	homedepot.com	h	19	
158	Fireplace tools	Alameda	$18.00	homedepot.com	h	19	
72	Magazine rack	Alameda	$40.00	stackandstacks		19	
88	Shoe rack	Alameda	$40.00	stackandstacks		19	
133	Shoe rack	Alameda	$20.00	ikea.com	i	19	
76	Soap dish	Alameda	$5.00	homedepot.com	h	19	
145	Soap dish	Alameda	$9.00	homedepot.com	h	19	
71	Toilet paper holder	Alameda	$13.00	homedepot.com	h	19	
107	Toilet paper holder	Alameda	$8.00	ikea.com	i	19	
77	Tooth brush holder	Alameda	$3.00	homedepot.com	h	19	
108	Towel bars (2 sets)	Alameda	$14.00	ikea.com	i	19	
154	Towel bars (2)	Alameda	$15.00	lowes.com	l	19	
70	Towel bars (3 sets)	Alameda	$19.00	homedepot.com	h	19	
109	Wall sconce	Alameda	$7.00	ikea.com	i	19	
155	Wall sconce	Alameda	$16.00	lowes.com	l	19	$284.00
	Bricks	Alameda	$540.00				
168	Mission "C" roof tile - 1930's - palletized	Alameda	$5,022.32			27	$5,562.32
74	Glass shelf	Alameda	$37.00	homedepot.com	h	32	
105	Glass shelf	Alameda	$37.00	ikea.com	i	32	
106	Glass shelf	Alameda	$37.00	ikea.com	i	32	
23	Steel casement window	Alameda	$111.00	lowes.com	l	32	
24	Steel casement window	Alameda	$111.00	lowes.com	l	32	

27	Steel casement window	Alameda	$111.00	lowes.com	l	32	
36	Steel casement window	Alameda	$111.00	lowes.com	l	32	
37	Steel casement window	Alameda	$111.00	lowes.com	l	32	
38	Steel casement window	Alameda	$111.00	lowes.com	l	32	
42	Steel casement window	Alameda	$111.00	lowes.com	l	32	
43	Steel casement window	Alameda	$111.00	lowes.com	l	32	
61	Steel casement window	Alameda	$111.00	lowes.com	l	32	
67	Steel casement window	Alameda	$111.00	lowes.com	l	32	
73	Steel casement window	Alameda	$111.00	lowes.com	l	32	
83	Steel casement window	Alameda	$111.00	lowes.com	l	32	
84	Steel casement window	Alameda	$111.00	lowes.com	l	32	
95	Steel casement window	Alameda	$111.00	lowes.com	l	32	
97	Steel casement window	Alameda	$111.00	lowes.com	l	32	
103	Steel casement window	Alameda	$111.00	lowes.com	l	32	
118	Steel casement window	Alameda	$111.00	lowes.com	l	32	
127	Steel casement window	Alameda	$111.00	lowes.com	l	32	
128	Steel casement window	Alameda	$111.00	lowes.com	l	32	
129	Steel casement window	Alameda	$111.00	lowes.com	l	32	
135	Steel casement window	Alameda	$111.00	lowes.com	l	32	
138	Steel casement window	Alameda	$111.00	lowes.com	l	32	
140	Steel casement window	Alameda	$111.00	anderson.com	a	32	
149	Steel casement window	Alameda	$111.00	anderson.com	a	32	
152	Steel casement window	Alameda	$111.00	anderson.com	a	32	
160	Steel casement window	Alameda	$111.00	anderson.com	a	32	
162	Steel casement window	Alameda	$111.00	anderson.com	a	32	$3,325.50
169	500 lf of original wood moldings	Alameda	$1,166.25	crown-molding.com		36	
40	Fireplace mantel	Alameda	$139.00	homedepot.com	h	36	
156	Fireplace mantel	Alameda	$379.00	homedepot.com	h	36	$1,684.25
6	Base cabinet	Alameda	$93.00	ikea.com	i	37	
7	Base cabinet	Alameda	$93.00	ikea.com	i	37	
8	Base cabinet	Alameda	$93.00	ikea.com	i	37	
9	Base cabinet	Alameda	$93.00	ikea.com	i	37	
10	Base cabinet	Alameda	$93.00	ikea.com	i	37	
11	Base cabinet	Alameda	$93.00	ikea.com	i	37	
12	Base cabinet	Alameda	$93.00	ikea.com	i	37	
13	Base cabinet	Alameda	$93.00	ikea.com	i	37	
15	Base cabinet	Alameda	$93.00	ikea.com	i	37	
16	Base cabinet with sink, faucet and tile top	Alameda	$114.00	ikea.com	i	37	
14	Base cabinet with top	Alameda	$152.00	ikea.com	i	37	
112	Cabinet	Alameda	$50.00	ikea.com	i	37	
113	Cabinet	Alameda	$50.00	ikea.com	i	37	
121	Cabinet	Alameda	$95.00	ikea.com	i	37	
50	Cabinet	Alameda	$95.00	ikea.com	i	37	
51	Cabinet	Alameda	$95.00	ikea.com	i	37	
52	Cabinet	Alameda	$95.00	ikea.com	i	37	
53	Cabinet	Alameda	$95.00	ikea.com	i	37	
54	Cabinet	Alameda	$95.00	ikea.com	i	37	
47	Cabinet door	Alameda	$20.00	lowes.com	l	37	
111	Medicine cabinet	Alameda	$40.00	ikea.com	i	37	
142	Medicine cabinet	Alameda	$48.00	lowes.com	l	37	
21	Pantry cabinet	Alameda	$93.00	ikea.com	i	37	
22	Pantry cabinet	Alameda	$93.00	ikea.com	i	37	
2	Wall cabinet	Alameda	$81.00	ikea.com	i	37	
3	Wall cabinet	Alameda	$81.00	ikea.com	i	37	
4	Wall cabinet	Alameda	$81.00	ikea.com	i	37	
5	Wall cabinet	Alameda	$81.00	ikea.com	i	37	$2,562.00
30	Paneling - 20 pcs with trim	Alameda	$222.60	lowes.com	l	38	$222.60
28	Wood cold air return	Alameda	$10.00	homedepot.com	h	41	$10.00
124	Armoir	Alameda	$329.00	homedepot.com	h	44	$329.00
167	Bi-fold doors	Alameda	$43.00	lowes.com	l	46	
55	Bookcase	Alameda	$50.00	ikea.com	i	46	
56	Bookcase	Alameda	$50.00	ikea.com	i	46	
57	Bookcase	Alameda	$50.00	ikea.com	i	46	

58	Bookcase	Alameda	$50.00	ikea.com	i	46	
59	Bookcase	Alameda	$50.00	ikea.com	i	46	
122	Bookcase	Alameda	$20.00	ikea.com	i	46	
126	Bookcase	Alameda	$77.00	ikea.com	i	46	
123	Door	Alameda	$50.00	ikea.com	i	46	
125	Door	Alameda	$50.00	ikea.com	i	46	
131	Door	Alameda	$50.00	ikea.com	i	46	
132	Door	Alameda	$50.00	ikea.com	i	46	
139	Door	Alameda	$36.00	lowes.com	l	46	
163	Door	Alameda	$40.00	lowes.com	l	46	
85	Double louvered doors	Alameda	$50.00	homedepot.com	h	46	
86	Double louvered doors	Alameda	$51.00	homedepot.com	h	46	
26	Double panel door	Alameda	$25.00	lowes.com	l	46	
29	Double panel door	Alameda	$25.00	lowes.com	l	46	
45	Double panel door	Alameda	$25.00	lowes.com	l	46	
49	Double panel door	Alameda	$25.00	lowes.com	l	46	
62	Double panel door	Alameda	$25.00	lowes.com	l	46	
64	Double panel door	Alameda	$25.00	lowes.com	l	46	
65	Double panel door	Alameda	$25.00	lowes.com	l	46	
69	Double panel door	Alameda	$25.00	lowes.com	l	46	
82	Double panel door	Alameda	$25.00	lowes.com	l	46	
87	Double panel door	Alameda	$25.00	lowes.com	l	46	
89	Double panel door	Alameda	$25.00	lowes.com	l	46	
91	Double panel door	Alameda	$25.00	lowes.com	l	46	
99	Double panel door	Alameda	$25.00	lowes.com	l	46	
101	Double panel door	Alameda	$25.00	lowes.com	l	46	
114	Double panel door	Alameda	$25.00	lowes.com	l	46	
117	Double panel door	Alameda	$25.00	lowes.com	l	46	
120	Double panel door	Alameda	$25.00	lowes.com	l	46	
44	Entry door	Alameda	$144.00	lowes.com	l	46	
137	Louvered doors (2)	Alameda	$50.00	lowes.com	l	46	
150	Louvered doors (2)	Alameda	$86.00	lowes.com	l	46	
100	Pocket door	Alameda	$73.00	lowes.com	l	46	$1,762.50
92	Interior window shutter	Alameda	$35.00	homedepot.com	h	48	
94	Interior window shutter	Alameda	$35.00	homedepot.com	h	48	
96	Interior window shutter	Alameda	$35.00	homedepot.com	h	48	
102	Interior window shutter	Alameda	$35.00	homedepot.com	h	48	
32	Interior window shutter	Alameda	$35.00	homedepot.com	h	48	
33	Interior window shutter	Alameda	$35.00	homedepot.com	h	48	
35	Interior window shutter	Alameda	$35.00	homedepot.com	h	48	
34	Interior window shutter - 2	Alameda	$70.00	homedepot.com	h	48	
66	Interior window shutter - 2	Alameda	$70.00	homedepot.com	h	48	
60	Interior window shutters - 2	Alameda	$70.00	homedepot.com	h	48	
148	Interior window shutters (2)	Alameda	$70.00	homedepot.com	h	48	
159	Interior window shutters (2)	Alameda	$70.00	homedepot.com	h	48	
161	Interior window shutters (2)	Alameda	$70.00	homedepot.com	h	48	$665.00
90	Carpet 12x15	Alameda	$540.00	weardated.com		50	$540.00
164	40 gallon gas water heater	Alameda	$497.00	homedepot.com	h	55	
165	Furnace with compressor	Alameda	$1,600.00	consumersearch.com		55	$2,097.00
1	Exterior door w/window	Alameda	$144.00	lowes.com	l	32 & 46	
93	Exterior door w/window	Alameda	$144.00	lowes.com	l	32 & 46	
147	Exterior door w/window	Alameda	$147.00	lowes.com	l	32 & 46	
78	Vanity with sink and faucets	Alameda	$114.00	homedepot.com	h	16 & 37	
110	Vanity with sink and faucets	Alameda	$114.00	homedepot.com	h	16 & 37	
153	Vanity with sink and faucets	Alameda	$114.00	lowes.com	l	16 & 37	
		Total	**$22,640.17**				$22,640.17
	No liquids are inventoried or transported						

APPENDIX B

STATISTICAL MATERIALS

1992 Sector				1	2	3	4	6	7	8	9	10	11
#	**Description**	**Cost 2005**	**Cost 1992**	**SO_2 mt**	**CO mt**	**NO_2 mt**	**VOC mt**	**PM^{10} mt**	**GWP MTCO2E**	**Total TJ**	**Haz. Waste 1992 mt**	**Total TRI 1992 mt**	**Total CMU-ET 1992 mt**
27	Brick & structural clay	$5,562.32	$4,035.02	0.047221	0.034153	0.028833	0.005183	0.012091	16.666395	0.213629	0.157192	0.005054	0.008906
32	Glass & glass products	$3,325.50	$2,412.39	0.010842	0.006543	0.018563	0.002627	0.002753	4.21961	0.053536	0.165752	0.002324	0.016387
37	Wood kitchen cabinets	$2,562.00	$1,858.53	0.004274	0.007178	0.006411	0.005034	0.001442	1.3588	0.017853	0.041095	0.00263	0.003105
55	Household appliances	$2,097.00	$1,521.21	0.006279	0.009252	0.005724	0.001794	0.001092	1.678175	0.022782	0.093701	0.003691	0.022468
46	Wood partitions & fixt.	$1,762.50	$1,278.55	0.003327	0.004585	0.003752	0.002911	0.000837	0.998763	0.013191	0.046179	0.001248	0.003703
36	Wood millwork	$1,684.25	$1,221.79	0.003038	0.006311	0.00524	0.002362	0.001147	0.99538	0.013049	0.026023	0.000719	0.002797
16	Plumbing fixtures	$1,383.00	$1,003.26	0.005389	0.005703	0.003383	0.001151	0.000699	0.968235	0.01296	0.068323	0.009068	0.150425
1	Household cooking	$1,018.00	$738.48	0.002981	0.004097	0.00263	0.001156	0.000505	0.846863	0.010595	0.038469	0.001626	0.009424
2	Household referigerators & freezers	$699.00	$507.07	0.002233	0.003055	0.001895	0.000703	0.000361	0.604461	0.00763	0.040529	0.001372	0.006269
48	Wood window blinds, & shades	$665.00	$482.40	0.001511	0.002112	0.001249	0.000448	0.000233	0.35885	0.004814	0.016992	0.000607	0.002232
50	Carpets & rugs	$540.00	$391.73	0.00202	0.001569	0.001836	0.000695	0.000806	0.570577	0.008096	0.058761	0.000842	0.000797
44	Upholstered wood furniture	$329.00	$238.66	0.000663	0.000742	0.000713	0.000391	0.000308	0.192815	0.002551	0.010834	0.000233	0.000508
19	Metal hardware, n.e.c.	$284.00	$206.02	0.000984	0.001206	0.000642	0.000203	0.000127	0.196864	0.002692	0.012004	0.000667	0.004898
7	Lighting fixtures & equipment	$227.00	$164.67	0.000575	0.00079	0.000516	0.000157	0.00009	0.146658	0.001981	0.006889	0.000252	0.001573
38	Veneer & plywood	$222.60	$161.48	0.000641	0.001509	0.000925	0.000481	0.000241	0.165681	0.002235	0.004708	0.000098	0.000188
17	Metal doors, sash, frames, & trim	$200.00	$145.08	0.001014	0.001698	0.000633	0.000187	0.000125	0.16899	0.002358	0.005957	0.000364	0.001871
18	Architectural & ornamental ironwork	$69.00	$50.05	0.000291	0.000492	0.000194	0.000054	0.000042	0.065352	0.000906	0.00179	0.000131	0.000585
41	Miscellaneous wood products	$10.00	$7.25	0.00002	0.000039	0.000032	0.000024	0.00001	0.006416	0.000084	0.00019	0.000008	0.000012
	Total Effects	$22,640.17	$16,423.64	0.093303	0.091034	0.083171	0.025561	0.022909	30.208885	0.390942	0.795388	0.030934	0.236148
53	Gross Deconstruction	$32,500.00	$23,576.16	0.053876	0.106166	0.102547	0.019388	0.121772	16.954254	0.216102	0.651922	0.016682	0.099828
53	Demolition (1992)	$25,000.00	$18,135.51	0.041443	0.081665	0.078882	0.014914	0.09367	13.041623	0.166231	0.501474	0.012832	0.07679
	Deconstruction (1992)			-0.039427	0.015132	0.019376	-0.006173	0.098863	-13.254631	-0.174840	-0.143466	-0.014252	-0.136320
	Deconstruction vs. Demolition			**YES**	**YES**	**YES**	**YES**	**NO**	**YES**	**YES**	**YES**	**YES**	**YES**

Years	**13**
Discount Rate	**2.50%**

Figure 14. 1992 EIO-LCA Analysis

1997 Sector				1	2	3	4	6	7	8	9	10	11
#	**Description**	**Cost**		**SO_2 mt**	**CO mt**	**NO_2 mt**	**VOC mt**	**PM^{10} mt**	**GWP MTCO2E**	**Total TJ**	**Haz. Waste 1997 mt**	**Total TRI 1997 mt**	**Total CMU-ET 1997 mt**
		2005	**1997**										
27	Structural clay products	$5,562.32	$4,565.26	0.036336	0.028567	0.022447	0.004588	0.009775	13.038682	0.168879	0.228512	0.004491	0.007555
32	Glass & glass products	$3,325.50	$2,729.39	0.008862	0.006303	0.01638	0.002475	0.002539	3.627318	0.047004	0.162318	0.002168	0.014679
37	Wood kitchen cabinets	$2,562.00	$2,102.75	0.003022	0.006478	0.005352	0.00432	0.001317	1.036972	0.014035	0.031521	0.002137	0.00223
55	Household appliances	$2,097.00	$1,721.11	0.004068	0.00669	0.004198	0.001431	0.000804	1.158146	0.016188	0.072354	0.002663	0.015714
46	Wood partitions & fixtures	$1,762.50	$1,446.57	0.002223	0.003551	0.002851	0.002363	0.000679	0.705641	0.009563	0.034161	0.000886	0.002441
36	Wood millwork	$1,684.25	$1,382.34	0.002173	0.005724	0.00442	0.002093	0.001083	0.767791	0.01034	0.019581	0.000544	0.00197
16	Plumbing fixtures	$1,383.00	$1,135.09	0.003196	0.004071	0.002243	0.000824	0.000488	0.630648	0.008672	0.041965	0.006545	0.111616
1	Household cooking equip.	$1,018.00	$835.52	0.00218	0.00336	0.002142	0.001016	0.00042	0.600858	0.008346	0.03274	0.001268	0.00692
2	Household referigerators & freezers	$699.00	$573.70	0.001744	0.002653	0.001666	0.000655	0.000321	0.4624	0.006419	0.037887	0.001165	0.005087
48	Wood window blinds, & shades	$665.00	$545.80	0.001105	0.001678	0.000996	0.000387	0.000195	0.271774	0.003731	0.013949	0.000474	0.001578
50	Carpets & rugs	$540.00	$443.20	0.001574	0.001397	0.001507	0.000593	0.000696	0.450816	0.006666	0.049004	0.000697	0.000645
44	Upholstered wood furniture	$329.00	$270.03	0.000519	0.000671	0.000598	0.000344	0.000305	0.154439	0.002117	0.00878	0.000199	0.000428
19	Metal hardware, n.e.c.	$284.00	$233.09	0.000666	0.000922	0.000483	0.000162	0.0001	0.141818	0.001984	0.008787	0.000454	0.003344
7	Lighting fixtures & equipment	$227.00	$186.31	0.000409	0.000631	0.000408	0.000132	0.000072	0.108669	0.001508	0.005626	0.000192	0.001181
38	Veneer & plywood	$222.60	$182.70	0.000478	0.001303	0.000759	0.000427	0.000221	0.125962	0.001747	0.003679	0.000082	0.000152
17	Metal doors, sash, frames, & trim	$200.00	$164.15	0.000616	0.001143	0.000414	0.000136	0.000085	0.103203	0.001499	0.003978	0.000219	0.001091
18	Architectural & ornamental ironwork	$69.00	$56.63	0.00017	0.000312	0.000126	0.000038	0.000028	0.040183	0.00057	0.001182	0.000079	0.000341
41	Miscellaneous wood products	$10.00	$8.21	0.000016	0.000038	0.000028	0.000021	0.000009	0.005122	0.00007	0.000137	0.000008	0.000017
	Total Effects	$22,640.17	$18,581.84	0.069357	0.075492	0.067018	0.022005	0.019137	23.430442	0.309338	0.756161	0.024271	0.176989
53	Gross Deconstruction	$32,500.00	$26,674.26	0.035661	0.081185	0.078593	0.015169	0.097844	13.161275	0.1588	0.482587	0.01122	0.063236
53	Demolition (1997)	$25,000.00	$20,518.66	0.027431	0.062449	0.060456	0.011668	0.075264	10.123944	0.122153	0.371217	0.008631	0.048642
	Deconstruction (1997)	$9,859.83	$8,092.42	-0.033696	0.005693	0.011575	-0.006836	0.078707	-10.269167	-0.150538	-0.273574	-0.013051	-0.113753
	Deconstruction vs. Demolition			**YES**	**YES**	**YES**	**YES**	**NO**	**YES**	**YES**	**YES**	**YES**	**YES**

Years	**8**
Discount Rate	**2.50%**

Figure 15. 1997 EIO-LCA Assessment