BUILDING GREEN VIA DESIGN FOR DECONSTRUCTION AND ADAPTIVE REUSE

By

TAREK M. SALEH

A THESIS PRESENTED TO THE GRADUATE SCHOOL
OF THE UNIVERSITY OF FLORIDA IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE DEGREE OF
MASTER OF SCIENCE IN BUILDING CONSTRUCTION

UNIVERSITY OF FLORIDA

2009

To my parents, who nurtured my intellectual curiosity, academic interests, and sense of scholarship throughout my lifetime, making this milestone possible

ACKNOWLEDGMENTS

I would like to sincerely thank Dr. Abdol Chini, Dr. Robert J. Ries, and Dr. James G. Sullivan for helping me throughout the research and the writing process of this thesis. I would like to especially thank Dr. Abdol Chini for his continuous encouragement, professional feedback, and suggestions that greatly improved the quality of my research. I would also like to extend my sincere gratitude to Dr. Robert J. Ries and Dr. James G. Sullivan whose expertise in the topic of sustainable construction helped me formulate my suggestions to the topic. Finally, I would like to take this opportunity to express my deep appreciation to the entire faculty at the M.E. Rinker Sr. School of Construction at the University of Florida for sharing their knowledge and helping me greatly throughout my graduate career.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Abstract of Thesis Presented to the Graduate School
of the University of Florida in Partial Fulfillment of the
Requirements for the Master of Science in Building Construction

BUILDING GREEN VIA DESIGN FOR DECONSTRUCTION AND ADAPTIVE REUSE

By

Tarek M. Saleh

May 2009

Chair: Abdol Chini
Major: Building Construction

According to the United States Environmental Protection Agency (EPA), only 8% of the construction and demolition (C&D) waste is generated during the construction phase. However, 48% of C&D waste is generated during the building demolition at the end of its life cycle and 44% is generated during the renovation of the building structure. EPA has also estimated that the C&D comprise 25 to 30% of all waste produced in the US each year.

The preceding data suggests that it is essential to design a building for adaptive reuse as well as design for deconstruction. The overall goal of designing for deconstruction and adaptive reuse is to reduce pollution impacts and increase resources and economic efficiency at the end of the building's useful lifecycle.

This paper will discuss the imperative need in today's construction industry to create a design for deconstruction and design for adaptive reuse credits in United States Green Building Council's Leadership in Environmental and Energy Design (LEED) point system that allows projects that are designed for adaptability and deconstruction to earn points towards the green building certification. The growing customer interest in greener buildings as well as the state and local initiatives to downsize the construction and demolition debris add an additional value that the owner or developer can not easily put a dollar value on, but contributes greatly to the

achievement of the rising green sustainability objectives. Earning LEED points can be a substantial incentive for owners and architects to think about designing new buildings for adaptation and deconstruction.

CHAPTER 1
INTRODUCTION

Human beings and the Earth are an interconnected system. An impact that affects one, whether positively or not, will ultimately affect the other in the same manner, but not necessarily to the same magnitude or at the same pace. In the last few decades of the 20th century, the concern for the environment and the damage that the human race is inflicting on its multiple sectors has risen dramatically. Most of those concerns revolved around global warming and ozone depletion due to green house gas emissions, species extinction, acid rain, toxic waste sites, and growing landfills.

Helen Caldicott mentions that, “The earth has a natural system of interacting homeostatic mechanisms similar to the human body” [1]. For the human body to function properly, it works as a collection of subsystems that are dependent on each other. The failure of one organ will ultimately abrupt the function of the rest of the organs and may cause a complete failure of the entire system. The same domino effect, according to Caldicott, is applied to the earth’s ecosystem. For instance, the ozone layer is being depleted by the Chlorofluorocarbon or CFC gases. This depletion, in return, is causing abnormalities in the functionality of the earth’s ecosystem, from raising the temperature of the earth causing global warming, to the penetration of ultraviolet light rays through the earth’s atmosphere causing human skin cancer and dying corps.

The human race is at an ever-ending quest for modernizing its life. Nevertheless, this quest has become the bulk of many serious types of global impacts. Most of the decisions that have been made in the past did not take into consideration the short and long term environmental damage caused mostly due to the poor access of information. The disregard to the environment’s welfare since the industrial revolution was displayed clearly in the uncontrollable rates of extraction of raw materials, to processing, shipping, installation, use, maintenance, and eventual disposal. The major evolution in agriculture, manufacturing, production, and transportation that occurred since the start of the industrial revolution in the late 18th and early 19th century had a profound affect on the socioeconomic and cultural conditions through most of the 20th century.

Because of its exponential population growth, humankind has gone in just a few decades from playing a small part in degrading the natural environment, to becoming a major contributor to the ecological devastation of the earth's ecosystem and natural resources. The growing human population has resulted in extraordinary levels of demand for raw materials, water, and energy sources, thus creating unprecedented exchange rates between the ecosphere and the human economic subsystem [2].

Daniel Chiras states that, "In a typical day on planet earth, 116 square miles of tropical forests will be destroyed. In the third world, where much of the cutting occurs only one tree is planted for every ten cut down; in the tropics of Africa, the ration is 1 to 29. Seventy square miles of dessert will form in semi-arid regions subject to intense population pressure, overgrazing, and poor land management. 250,000 newborns will join the world's population. Each new resident requires food, water, shelter, and a host of other resources to survive. One and a half million tons of hazardous waste will be released into the air, water, and land. Fourteen percent of species will become extinct, mostly as a result of tropical deforestation." [3].

The question that presents itself today is," Can the human race survive its own actions?" The magnitude of the human-influenced blemishes is accelerating the deterioration of major eco-systems and is now capable of seriously disturbing the global life support functions that are essential to the maintenance of life itself [2]. Scientists and researchers are certain that if the industrial countries do not take drastic measures to stop or at least minimize the depletion of natural resources, and in return reverse the cumulative effect of the global population, the results of the human's irresponsible trend in abusing nature will be catastrophic on many species including the human race itself.

Problem Statement

In the late 1980's and early 1990's, scientists started realizing the damage caused by the ecologically irresponsible human decisions and its magnitude on the environment. It became evident that all the industrial activities have a certain level of contribution to the environmental damage, some of which were sever enough to push the damage to the point of no return. It also became evident that the developing countries had to implement and adopt environmental practices that support sustainable development.

In order to produce goods such as appliances, cars, toys, packaging, and even buildings to match the growing needs of the world's expanding population, continuous consumption of the earth's natural resources becomes inevitable. With the earth's population expected to reach 14 billion human beings by the end of this century, the resources that the earth can offer to meet the population's demands is being narrowed down considerably leading not only to environmental degradation, but also to political instability and worldwide contention.

Webster and Costello ask, "The question, then, is how do we meet the growing demand for consumption while tempering this demand for finite resources?" [4].

The building's life cycle consists primarily of the construction phase, the renovation and maintenance phase, and the end-of-life phase. According to the United States Environmental Protection Agency (EPA), the building construction industry uses large quantities of natural resources [5]. Construction and demolition (C&D) debris is a waste stream generated by new construction, renovation, and demolition of existing buildings. Only 8% of the C&D debris is generated during the construction phase. However, 48% of C&D debris is generated during the building demolition at the end of its life cycle and 44% is generated during the renovation of the building structure.

EPA has also estimated that the C&D debris form 25 to 30% of all waste produced in the United States each year. The construction activities consume 60% of raw materials and produce 160 million tons of C&D waste annually [5]. The amount of the C&D debris produced accounts for one third of the nation's non-hazardous solid waste generated each year. Also, roughly 60% of the C&D waste generated, or an estimated 96 million tons, end up in landfills every year, thus significantly contributing to the U.S. solid waste management challenge. Only 40% of C&D is being recycled every year.

The trend in construction industry today is to partially or even completely demolish a building either when it is no longer serving its purpose and thus modifications to the structure are needed or when simply the building's useful life has expired and a new construction must take place. The demolition process is usually done using heavy mechanical equipment and can be accomplished in a matter of hours.

The fact that demolition takes place via heavy equipment such as cranes and wrecking balls, and its lack of intensive hand-labor makes the process a bit aggressive and violent. This means that most of the building materials might not be able to withstand the intensity of the process. As a result, the material will get destroyed and their capacity for reuse will be demolished along the way. The most common end-of-use option for building materials that undergo the demolition process is down-cycling. Down-cycling, typically degrades the materials quality and economic value.

In order to minimize the renovation and demolition waste that is generated and maximize the reuse of buildings and the salvaging of building materials for reuse and recycling, alternatives to the current construction designs and demolition practices need to be introduced. Experts in the construction industry have devised design principles, guidelines, and strategies for adopting deconstruction and for adaptive reuse as designs trend in the industry. The benefits of these two concepts are detailed in a later chapter in the study.

Nevertheless, the concepts of adaptive reuse and deconstruction designs need to be closely connected to profitability. Adaptive reuse and deconstruction designs should translate into faster sales, higher occupancy rates, and reduced refurbishment costs. If developers can be thoroughly convinced of such benefits, they will participate enthusiastically and add their creativity to the design concept [6].

When investing in a construction project, the owner, stakeholders, and investors are looking to gain a return on their investment. After all, like any business, construction is about making a profit. Aside from their environmental advantages, designing for adaptive reuse and deconstruction add short term economic and possibly environmental costs to the project, but on a bigger scale of the lifecycle of the project, the long term benefits of utilizing those two concepts outweigh any initial costs. Designing a building for adaptive reuse or deconstruction greatly complements the trend of building green. And what better way to reward a project design team that took the extra step in being environmentally friendly than to economically and socially capitalize on their efforts by allowing them to earn points in the currently most successful green building assessment system, Leadership in Environmental and Energy Design for New Construction (LEED-NC)

Today, projects can only earn points in LEED-NC for deconstruction or adaptive reuse through the Innovation and Design category. However, the environmental, economic, and even social outcomes of designing for adaptive reuse or deconstruction deserve a better recognition. The United States Green Building Council (USGBC) should recognize the magnitude of these outcomes and capitalize on them by offering credits for designing for adaptive reuse and deconstruction in the Material and Resources category in its LEED-NC assessment system.

Objectives

It is evident that the construction industry today is an integral contributor to the wellbeing of the environment and subsequently the welfare of the human race. One of the sustainable construction goals is reducing or even completely eliminating the use of landfills for disposing of building material waste. However, the current construction and demolition practices minimize the possibilities of reusing a building or even recycling or reusing the different building materials, elements, and components at the end of the building's useful life.

Deconstructing a building aims at recovering the building materials while maintaining their quality at the end of the building's useful life; therefore reusing different salvaged building materials and recycling of the waste. Reusing a building targets its reconfiguration to accommodate a different use thus considerably reducing the consumption of resources and waste generation. Not only that deconstruction and adaptability ultimately lessen the world's depleting energy and natural material resources, they also contribute to preserving the cultural and historical values inherent in different materials and buildings.

As a result, the objective of this study is to propose two separate credits, for a total of six points, for designing for adaptive reuse and deconstruction in the Material and Resources category in the LEED-NC assessment system. By doing so, owners, investors, and stakeholders will be more willing to invest in pursuing these points and in return expanding their environmental gains and benefiting from the long-term return on their investment.

Scope

The growing customer interest in greener buildings as well as the state and local initiatives to downsize the renovation and demolition debris add an additional value that the owner or developer can not as easily put a dollar value on, but contributes greatly to the achievement of the rising green sustainability objectives. Designing for adaptive reuse and/or deconstruction has potential economic incentives added on to the environmental ones.

Therefore, the scope of this research includes shedding light on the multiple benefits of adopting designing for adaptive reuse and/or deconstruction as common design principles in the construction industry. The benefits include earning points in the proposed designing for deconstruction and the designing for adaptive reuse categories in the LEED-NC assessment system.

Also, this study consists of a number of design practices that have been recommended by experts to facilitate deconstructing or reusing the building. Such design practices introduce different environmental end economic incentives that will peak the stakeholders, investors, and owners' interest in pursuing adaptability and deconstruction as a widespread building design trend. Finally, this study addresses the use of Building Information Modeling (BIM) as a digital method of preserving the deconstruction and adaptive reuse design information for future reference.

CHAPTER 2
BACKGROUND

The emphasis on the environmental concerns has shifted in the last few decades from smaller items such as plastic bags, air conditioners, and motor vehicles, to structures in the built environment. Buildings have been classified as a major contributor to the carbon dioxide (CO_2) emissions during their lifecycles and even after their demolition. In response, architects and engineers started devising different construction techniques that are constantly evolving to minimize the environmental effects of buildings and construction materials, improve the buildings' energy efficiency, and reduce the buildings' CO_2 emissions. Selecting building materials, whether new or used, has an environmental profile that contributes to their different environmental impacts.

Environmental Concerns

Two of the environmental concerns that need to be thoroughly addressed when designing a building are closing the materials loop and the embodied energy and CO_2 emissions.

Closing Materials Loop

In order to promote sustainability and reduce the environmental impacts by reducing the consumption of finite resources, experts in sustainable construction agree that the most efficient way to reach that goal in the construction industry is to close the materials loop. The closed-loop is a recycling concept that should be the ultimate goal of the recycling industry in order to maximize the usefulness of the existing used materials and reduce the need to extract and produce raw and virgin materials. Charles Kibert states that construction is a unique sector in the industry because the buildings it produces have unique character that differs them from other industry products when it comes to closing the materials loop [7]. Many building materials such as metals can potentially be recycled and reprocessed into materials that can be used in different industry sectors other than construction projects.

However, according to Kibert, there are distinct construction materials that are explicitly used only in the construction industry, such as aggregates and gypsum drywall, and thus their reuse and recycling are limited only to construction [7]. As a result, closing the material loop in the construction industry tends to be a bit more challenging than the case in other industries due to the cycle uniqueness of some construction materials. Kibert addresses the following factors as being major contributors to making closing the material loop in construction relatively difficult:

- Buildings are custom designed and custom made by large groups of participants
- No single manufacturer is associated with the end product
- Aggregate, for use in sub base and concrete, brick, clay block, and other products derived from rock and earth are commonly used in building products
- The connections of building components are defined by building codes to meet specific
- objectives (e.g. wind load, seismic requirements) not for ease of disassembly
- Historically, building products have not been designed for disassembly and recycling
- Buildings can have a very long lifetimes exceeding those of other industrial products; consequently, materials have long "residence" period
- Building systems are updated and replaced at intervals during the building's lifetime (e.g. finishes at 5 years intervals, lighting at 10 year intervals, HVAC systems at 20 year intervals)

Embodied Energy and CO_2 Emissions

Embodied energy, measured in KJ/Kg, is the energy required to extract, process, manufacture, and even to transport a product. It is considered over the material’s life cycle from extraction all the way to installation. Values can range from 275GJ per ton for aluminum to 0.1GJ per ton for gravel aggregates [8]. Sheet aluminum requires an estimated 200 GJ per ton as compared with sheet steel which has an embodied energy of roughly 34 GJ per ton [9]. Timber has a low embodied energy of approximately 13GJ per ton, while chipboard, which is more highly processed, has a higher embodied energy of about 36GJ per ton.

CO_2 emissions are generated during energy consumption, and embodied CO_2 is based on specific energy sources of a process. It is usually measured in Kg of CO_2 per Kg of material. For instance, material that require higher electric energy to process result in higher CO_2 emissions than those that require low grade heat energy. Most of the power used in the aluminum industry in Scandinavia for example comes from hydro-electric schemes and therefore have no embodied CO_2 in its manufacturing [9].

However, according to a study in the United Kingdom, "Energy consumption itself does not contribute an environmental burden. It is often more useful to consider a material in terms of its embodied CO_2 rather than embodied energy; as it is the CO_2 emission that contributes to greenhouse gases and lead to global warming." [10].This is true when global warming is the criteria in question; however, when resource use is being examined, then the embodied energy becomes relevant.

CO_2 emissions leading to green house gas that cause climate change typically occur with embodied energy. In addition to all the raw materials that need to be extracted, the extraction process itself, moving this much earth and refining it, and transporting thousands of tons of construction material from their source to the construction site requires significant energy inputs.

Figure 2-1 below displays a comparison of embodied CO_2 between the most frequently used building materials according to a study done by the Department of Trade and Industry[1].

[1] The DTI was a United Kingdom government department which was disbanded with the announcement of the creation of the Department for Business, Enterprise and Regulatory Reform and the Department for Innovation, Universities and Skills on the 28th of June 2007.

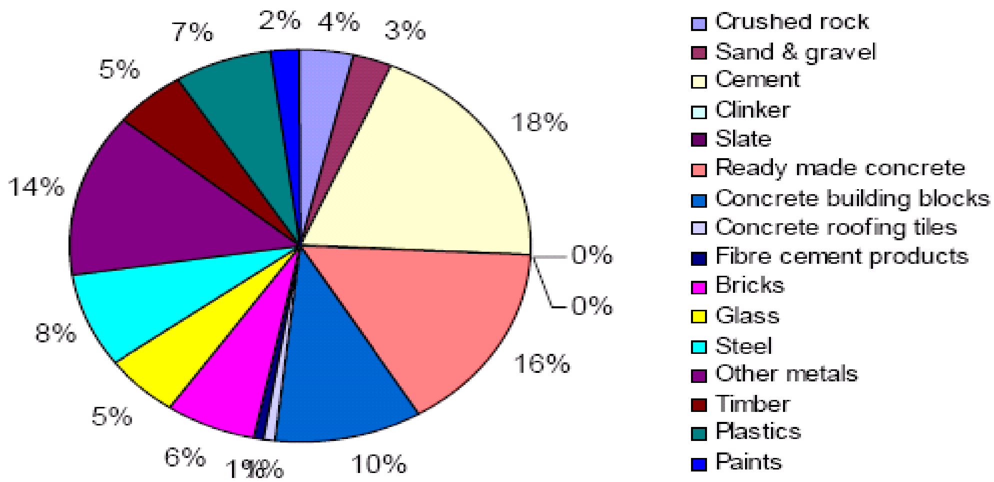


Figure 2-1. Embodied CO_2 in Different Construction Materials [Adopted from Lazarus, N. *Potential for Reducing the Environmental Impact of Construction Materials*, 2005]

Figure 2-2 shows the maximum transportation distance that reclaimed material can be moved without losing the environmental advantage due to the increase in the embodied energy required for transportation.

What the industry needs is a new mental model that weighs the used construction materials as valuable resources worth harvesting in a manner that preserves there embodied energy and the CO_2 already invested in those materials [12]. Nevertheless, the subsequent process of harvesting used construction materials itself should not cause inordinate amounts of CO_2 and embodied energy otherwise the very purpose of salvaging construction materials will be defeated.

The building construction industry in the United States will continue to grow thus consuming large amounts of natural resources and generating massive amounts of solid waste. However, this dilemma can be viewed as a great opportunity to employ sustainable construction practices on a large scale thus preserving the natural resources and diverting solid waste from landfills. According to Phillip Crowther , “The recycling and reuse of materials can significantly reduce the environmental burden of our society.” [13].

Maximum transport distances for reclaimed materials to have environmental benefits over new

Material	Distance (miles)
Tiles	100
Slate	300
Bricks	250
Aggregates	150
Timber	1000
Steel products	2500
Aluminium products	7500

Figure 2-2**.** Maximum Transport Distances [Adopted from Lazarus, N. *Potential for Reducing the Environmental Impact of Construction Materials*, 2005]

Green End-of-Use Options

In general, architects and engineers should extensively aim at determining the destiny of a building, its components and materials at the end-of-life. Depending on a variety of prevailing conditions in the design, Figure 2-3 illustrates the hierarchy of possible applications that are potentially the building and the materials' "green" end-of-use options.

This hierarchy is established based on the energy costs of collecting, transporting, and processing through the various scenarios. For example, material ruse is more advantageous than material recycling due to the fact that it requires less processing, less energy, and imposes less environmental burden.

The end of the building's useful life generates a stream of used materials that can be reprocessed for new construction. The selection of materials for reuse or recycling should not start at the end of the building's life cycle. It should start at the design stage. Architects and engineers should keep the whole life cycle of the building in mind and select construction materials based on their capacity to be reused or recycled after the building has served its purpose [4]. Buildings should be disassembled in a manner that preserves the quality of the construction materials thus allowing them to be recovered for reuse or recycling.

Building reuse

- Renovation
- Relocation
- Adaptive use

Component reuse

- Similar/different application
  In situ
  Elsewhere
- High/low value use

Material reuse

- Similar/different application
  In situ
  Elsewhere
- High/low value use

Material recycling

- Upcycling
- Recycling
- Downcycling

Figure 2-3. Hierarchy of Possible End-of-Use Options [Adopted from Macozma, D. *Understanding the Concept of Flexibility in Design for Deconstruction*, CIB Publication no. 272, Germany, 2002]

Building Reuse

Building reuse can be done on a big scale when saving buildings from total demolition. It involves relocation, renovation, and adaptive reuse of the building stock. Even though building reuse requires a great deal of design and planning, the results are substantial savings as well as environmental and economic benefits. Building reuse revolves around repairing a building to accommodate a new use rather than tearing it down. Ideally, building reuse saves natural resources including raw materials, energy, and water resources required to build new. It also prevents pollution that might take place as a byproduct of extraction, manufacturing, and transportation of virgin materials, and avoids creating solid waste that could end up in landfills.

Component Reuse

Component reuse requires maintaining the majority of the interior non-structural elements such as interior walls, doors, floor coverings, ceiling systems and so on to be used in a similar or different application at the end of the building’s useful life. Component reuse requires designers and architects to come up with innovative design strategies that facilitate the disassembly and reassembly of these non-structural components while maintaining their quality and the structural integrity of the building. Component reuse is an essential factor in measuring the sustainability of the structure.

Material Reuse

A direct reuse of the materials after the deconstruction of the structure in new or existing structures allows them to retain their current economic values, reduces the embodied energy required to recycle, and minimizes the need to extract new mold raw and virgin materials by reducing carbon footprint and cutting into resource use. Material reuse at the end of its life cycle should be a top priority for architects and engineers when selecting construction materials. Immediate reuse of intact building components from deconstructed materials retains the material's quality and current economic value in addition to minimizing the resources for reprocessing [15].

Material Recycling

Increasing the recycled content of building materials yields diverting waste from landfill and generating a market for reprocessed materials. As a result, it displaces the need for new materials. The degree of which increasing the recycled content actually has an environmental advantage is subject to the specific type and source of each material. Ideally, architects and engineers should perform a life-cycle analysis of each material involved in the construction of a project to determine the recycling capacity after the end-of-useful life of the structure. Recycling consists of three different routes: down-cycling, recycling, and up-cycling. Each one of these routes requires energy and result in waste and emissions depending on the material itself. The following literature states what each option of material recycling entails in the order of decreasing preference.

- Up-cycling - is the process of increasing the material's quality, potential for future reuse and economic value. The concept was first introduced by William McDonough and Michael Braungrat, the authors of Cradle to Cradle: Remaking the Way We Make Things [16]. Up-cycling transforms disposable materials into new materials of greater use and value thus reinvesting in the environment via reduction of waste and use of virgin materials. However, Up-cycling is not commonly practiced due to the very limited types of construction materials that can under take the up-cycling process and manage to increase in quality and economic value. Nevertheless, it is the architects and engineers responsibility to maximize in the design process the selection of types of materials that can be up-cycled after the building's useful life. For example, fly ash can be up-cycled to be used in the manufacturing of cement or the making of concrete [17].

- Recycling - Ideally, recycling is a process of sorting, cleansing, treating and reconstituting solid waste and other discarded materials for the purpose of using the altered form [18]. Recycling does not include burning, incinerating, or thermally destroying waste. Recycling is the very bulk of the closed-loop concept. In order to close the materials loop in construction, ideally all materials selected for the construction process at the design stage must have the capacity for recycling. Recycling is still currently a very ambitious objective because few building materials can be salvaged for recycling while maintaining their economic values and quality. Metals and plastics are perhaps the most commonly used materials in construction that can be fully recycled without virtually any loss in their basic strength and durability properties [19].

- Down-cycling - is a concept developed by Reiner Pilz of Pilz GmbH and Thornton Kay of Salvo Llp in 1993 [16]. The term refers to the reduction of quality, viability, and economic value after undergoing a recycling process. Down-cycling ranks last on the hierarchy of methods for material recovery when it comes to economic benefits; however it has the widest range of available resources of construction materials. Virtually all construction materials can be down-cycled into a lower-value application and thus down-graded into a lower quality and evidently lower economic value. For example, recycled concrete aggregate can be used as a sub-base material [19].

CHAPTER 3
GREEN BUILDINGS ASSESSMENT SYSTEMS

Introduction

Green construction evolved from a variety of concerns, experiences, and needs. Energy efficiency gained importance during the 1970s' oil crisis. Recycling efforts in the United States became significantly important in the 1970s and gained the attention of the building industry. Projects in water-scarce areas began to focus on water conservation. In the 1980s, a new concept emerged known as the "sick building syndrome". The sick building syndrome caused the rise of workers' health and productivity concerns especially form toxic material emissions.

The environmental impacts of new construction are significant. According to the United States Department of Energy, buildings nationwide consume 65.2% of total U.S. electricity consumption and more than 36% of total U.S. primary energy use [20]. Also, buildings in the United States are responsible for 30% of total U.S. greenhouse gas emissions in addition to the different atmospheric emissions from the use of energy lead to acid rain, ground-level ozone, smog, and global climate change [21]. Lenssen and Roodman mention that new construction worldwide consumes 40%, or 3 billion tons, of raw materials annually [22].

Green buildings are high-performance buildings that complement sustainable construction. Early green designs targeted one sustainable issue at a time in each building design. In the 1980s and 1990s, architects and engineers interested in environmentally friendly construction designs realized that there are key areas for achieving sustainable construction. Their designs started integrating sustainable site planning, water and energy efficiency, indoor environmental quality, and material conservation and reuse all at once in the same building design

Green Buildings Assessment Systems in the United States

Up until 1998, sustainable construction in the United States was subject to the architects and engineers' perception of what a green building design entails. Green buildings were perceived as environmentally friendly and resource efficient. However, there was no specific standard that determined the explicit criteria of what should constitute a green building. In 1998, the United States Green Building Council (USGBC) launched its new Leadership in Energy and Environmental Design (LEED) for new Construction. LEED-NC became the tool that indentified and compared different green buildings performance from the design, construction, operation, and maintenance's point of view.

There are several building assessment systems that are used worldwide to determine how environmentally friendly a building design actually is. Refer to appendix A for details on the different international assessment systems available.

Leadership in Energy and Environmental Design

The official definition of LEED according to the USGBC is," The LEED® (Leadership in Energy and Environmental Design) green building certification system is a feature-oriented certification program that awards buildings points for satisfying specified green building criteria" [23]. Currently LEED is the primary point-system building assessment method that rates the building's performance based on its environmental impacts, resource consumption, and building health in the United States. The USGBC decided that any green building assessment system should be market-driven instead of being required by regulations. Since LEED was developed using a transparent process open to the public, this allowed building owners and developers to be key players in the program's success. The incentive behind the USGBC's decision is that the building owners and developers will have to distinguish themselves in the market by having high building resale values, thus increase the competitiveness between comparable buildings.

The complexity of LEED is due to the fact that each of its criterions has its own unit of measurement and applies on different physical scales [24]. LEED was created with the intention of popularizing high performance buildings thus increasing the market demand for sustainable construction. Buildings that are awarded one of LEED's Platinum, Gold, Silver, or Certified ratings, is offered a label or plaque, which is the nationally recognized symbol demonstrating that a building is environmentally responsible, profitable, and a healthy place to live and work, indicating the building's rating and displaying its performance to the public.

Why LEED

According to the USGBC, a building pursuing a LEED certification is judged based on how many predetermined specific criteria in several categories the building successfully addresses. Buildings must pass inspections by accredited personnel; the building's energy systems must be independently tested, or commissioned, by a third-party [20]. LEED is based on accepted energy and environmental principles. It strikes a balance between known effective practices and emerging concepts. The rating system provides a framework to help move the United States' building industry to more sustainable practices. LEED certified buildings use key resources more efficiently when compared to traditional buildings which are simply built to code.

The LEED categories revolve around energy usage, water consumption, land area footprint, materials, and waste quantities [24]. Ideally, the higher the rating, the better the performance, thus increasing the building's marketability and value because of the low operating costs and healthy indoor environment typically associated with high performance green buildings. Also, an increase in the competitive market for sustainable construction among owners and developers will ultimately yield a high performance, high quality building stock.

In addition to the economic goals that green, and ultimately LEED certified, buildings can achieve, there are political goals that could be feasible with sustainable construction. Such political goals include but not limited to the Kyoto protocol on climate change. The protocol calls on the leading industrial countries, such as the United States, to significantly limit their greenhouse gas emissions relative to the limits issued in 1990 [24].

LEED-NEW CONSTRUCTION

LEED is not a single rating system that assesses the different sectors of construction all at once. It is a collection of systems each explicitly addresses and rates one specific area of the building industry individually. The LEED portfolio consists of:

- LEED-NC: New Commercial Construction and Major Renovations
- LEED-EB: Existing Building Operations and Maintenance
- LEED-CI: Commercial Interior Projects
- LEED-CS: Core and Shell Development Projects
- LEED-H: Homes
- LEED-ND: Neighborhood Development
- LEED-S: Schools

For the purpose of this study, the researcher focused on LEED-NC. It was originally developed for office buildings. It was established as a result of intense research and development over a four-year process between 1994 and 1998 [24]. LEED-NC is now a measuring tool for the performance of almost every type of construction including but not limited to health care facilities, lodging, volume building programs, four or more habitable story multi-family residents, campuses, retail stores, and laboratories. The USGBC depends on local building codes that identify a commercial building. The one type of buildings that LEED-NC doesn’t cover is single-family homes. LEED-NC is the USGBC’s most recent standard for commercial and institutional buildings and major renovations. It is a building rating or assessment system, not a green building standard.

The Point Distribution System

LEED determines building's performance based on accumulated number of points in various impact categories. Those points are then totaled into a single final score that determines the rating of the building. All the different LEED systems mentioned above award the building a final score that describes its performance.

According to Charles Kibert, "A single number representing the score of the building has the virtue of being easy to understand. But if a single number is used to assess or rate a building, the system must somehow convert the many different units describing the building's resource and environmental impacts (energy usage, water consumption, land area footprint, materials, and waste quantities) and conditions resulting from the building design (building health, built-in recycling systems, deconstructability, percentage of products coming from within the local area) into a series of numbers that can added together to produce a single overall score" [25].

Even though Kibert considers the single number method difficult and random, he suggests that its biggest advantage and perhaps its disadvantage is its simplicity. Therefore the USGBC developers adopted that approach and implemented it in creating the different LEED assessment systems.

Currently, green projects pursuing a LEED-NC certification are rated based on LEED-NC version 2.2. LEED-NC 2.2 consists of six major categories and seven pre-requisites, and a total of 69 points (see Table 3-1).

The project is a viable candidate for certification if it meets all pre-requisites and at least 26 points. The points reflect the weight experts place on the different major issues that each category entails (see Table 3-2). The weight of each LEED-NC credit is established, through the existing consensus process, as part of a systematic, continuous improvement cycle for LEED-NC based on advances in green building science and technology and an expanding base of experience and evidence.

Table 3-1. LEED-NC Categories Outline [Adopted from Kibert, C. *Sustainable Construction: Green Building Design and Delivery*, 2nd edition, 2008, p. 58]

	LEED-NC 2.2	
Category	Maximum Points	Number of Pre-requisites*
1. Sustainable Sites	14	1
2. Water Efficiency	5	0
3. Energy and Atmosphere	17	3
4. Materials and Resources	13	1
5. Indoor Environmental Quality	15	2
6. Innovation and Design Process	5	0
Total Possible Points	69	

*Pre-requisites are conditions that must all be successfully addressed for a building to be eligible for consideration for a LEED-NC rating

Kibert defends that point distribution for LEED-NC 2.2 because, “It is important to keep in mind that LEED was developed in an extensive collaboration process over a total of six years; hence, the outcome of this group thought process probably is fairly on target with respect to weighting the categories. Thus, in spite of its relative simplicity, it does an excellent job overall of taking complex information and converting it into a single number” [26]. Therefore, the more points the building scores in each category, the higher the LEED-NC rating will be (see Table 3-3).

Table 3-2. LEED-NC Point Distribution [Data adopted from Coto, J.T. Building Systems Commissioning, www.sustainablemri.com/ppt/LEED%20NC%20v2.2%20-%20Jorge%20-%20MBO%20-%20SMRI.ppt, 2002]

Category	Percentage
1. Sustainable Sites	20%
2. Water Efficiency	7%
3. Energy and Atmosphere	24%
4. Materials and Resources	20%
5. Indoor Environmental Quality	22%
6. Innovation and Design Process	7%

Even though it might seem that the highest possible score is the usually the only one worth achieving, experience in using the LEED-NC 2.2 has revealed that it is fairly difficult to achieve the total points requited for a Platinum or even Gold rating simply because some of the points apply explicitly to specific locations or building types. Nevertheless, Kibert points out that a Silver rating is a very good assessment and a noteworthy accomplishment that is worth pursuing [26].

Table 3-3. Points Required for LEED-NC Rating [Adopted from Kibert, C. *Sustainable Construction: Green Building Design and Delivery*, 2nd edition, 2008, p. 58]

Rating	Points Required
Platinum	52-69
Gold	39-51
Silver	33-38
Certified	26-32
No Rating	25 or less

The Green Globes Building Assessment Protocol

Green Globes is a building rating system that is widely used in Canada and slowly making its way in the United States [24]. The structure of Green Globes is similar to the LEED-NC 2.2 structure. However, Green Globes address more issues such as project management, emergency response, planning, durability, deconstruction, adaptability, lifecycle assessment, and noise control. Green Globes rated and certified buildings are expected to:

- Use less energy
- Conserve natural resources
- Emit fewer pollutants in the form of greenhouse gases, airborne particulates, liquid effluents, and/or solid waste

Green Globes provides a rating of one to four *Green Globes,* depending on the percentage of the maximum 1,000 points allowed that the project actually achieves (see Figure 3-1). Similar to LEED-NC 2.2, Green Globes requires a third party assessment for the building to be rated and certified. The third party consists of verifiers with expertise in green building design, engineering, construction and facility operations. A verifier is an industry professional who has been trained on Green Globes protocol.

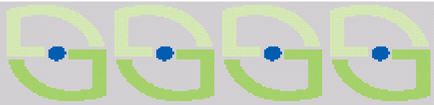
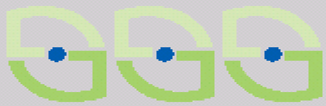
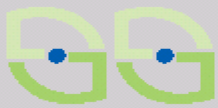
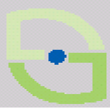
85-100%		Reserved for select buildings that serve as national or world leaders in reducing environmental impacts and efficiency of buildings.
70-84%		Demonstrates leadership in energy and environmentally efficient buildings and a commitment to continual improvement.
55-69%		Demonstrates excellent progress in reducing environmental impacts by applying best practices in energy and environmental efficiency.
35-54%		Demonstrates movement beyond awareness and a commitment to good energy and environmental efficiency practices.

Figure 3-1. Green Globes Ratings [Adopted from Green Building Initiative, *Green Globes Rating / Certification: Recognize and Market Achievements in Environmental Sustainability*, http://www.thegbi.org/green-globes-tools/ratings-and-certifications.asp, 2009]

According to the Green Building Initiative (GBI), "Building projects that have completed either the NC or CIEB[2] assessments, and scored a minimum threshold of 35% of the 1,000 available points, are then eligible to schedule a thorough third-party review of documentation and an on-site walk-through that will then lead to a formal Green Globes rating/certification. Buildings that successfully complete a third-party assessment are assigned a Green Globes rating of one to four globes." [61].

LEED-NC vs. Green Globes

In the USGBC LEED-NC process, the project team completes the project's documentation on-line and submits them through the web-based LEED-Online to be reviewed by a USGBC committee that is not at any point in direct contact with the project team. Unlike LEED-NC, the

[2] Continual Improvement of Existing Buildings

Green Globes system requires the verifier to actually visit the construction site, interact directly with the project team, and physically examine the project. After doing so, the verifier sends his or her recommendations to the GBI committee to issue the appropriate certification level [24].

Another major difference between the LEED-NC and the Green Globes certifications is that in LEED, the available number of points is fixed for all projects while in Green Globes, the available number of points is adjusted based on the project [24]. LEED attempts to rate both the project team and the project owner, and the final certification is a result of their combined efforts [24]. On the other hand, the points that are not applicable to a project are not included in the total potentially achievable points in the Green Globes certification. Green Globes attempt to rate the work of the project team and does not address issues that are outside of their control such as the location of the project which is considered an owner's issue [24].

Finally, in regards for deconstruction and adaptability, currently LEED-NC does not directly address those two concepts in as a stand-alone credit or as a multi-part credit. As mentioned previously, points for deconstruction and adaptability can potentially be earned in the Innovation and Design credit in LEED-NC. On the other hand, Green Globes covers the entire life-cycle of building materials by addressing this issue through its separate criterion addressing durability, deconstruction, and adaptability [28]. Green Globes considers materials over the course of their entire lives and takes into account a full range of environmental impact indicators including embodied energy, solid waste, air and water pollution, and global warming potential. The Green Globe process addresses the selection of low impact materials that have the lowest life cycle environmental burden and the lowest embodied energy.

CHAPTER 4
DESIGN FOR ADAPTIVE REUSE

What is Design for Adaptive Reuse

When a building loses its original function, it can be rescued from demolition by adapting it and changing its primary function, at the design stage, to a new use while retaining the majority of the architectural details, especially if the architecture is remarkable and remains in good condition. An old factory may become an apartment building or a rundown church may find a new life as a restaurant. Monuments, from the most important to the humblest ones, are on top of the list of these adaptive reuse policies where some of them are transformed into museums of themselves.

There are a number of reasons that cause building modifications, renovations, and even a complete destruction via classical demolition methods such as explosives or demolition ball. Reasons range from the change in ownership, alternate demography and residential units, to future growth and expansion. Therefore, the building no longer serves the purpose it was constructed for and thus its demolition or at least modifying its layout becomes inevitable.

The adaptability of any building depends on its design, form, materials, and the extent to which a building is appropriate for its purpose. The building's capacity for adaptability is usually affected by its structural design, the different services within, its finishes, the internal layout, and its external appearance. According to a study, a building's adaptive reuse is considered based on three levels [29]:

- Adaptability within user – the extent of which a building can adapt to support the needs of the existing users with minor and infrequent modifications or renovations
- Adaptability within use – the ease with which the building can adapt to the needs of different occupiers from the same user group without major refurbishment or upgrading

- Adaptability across user – the flexibility of the building to adjust to a whole new function and adapt to the requirements of a new use type, for example a switch from a commercial type to a residential type.

Designing for adaptive reuse requires designing for the recovery of the majority of the building's components i.e. exterior walls, roofs, foundations, decking, exterior skin and frames and so on. It also requires designing for recovery of the majority of the interior non-structural elements i.e. interior walls, doors, floor coverings, ceiling systems and so on. In short, designing for building adaptive reuse should ideally expose the building's structure to minor changes while undergoing major renovations and modifications. "Building reuse is a linchpin to managing solid waste. Despite the various benefits beyond contributing to sustainability that can be realized through building reuse, including direct and indirect cost savings, truncated construction schedules, and reduced site disruptions, little formal consideration has been given to this topic, which places professional engineers at a disadvantage when considering this as a design option." [30].

Why Design for Adaptive Reuse

The more flexible and adaptable the building is to different uses and occupiers, the longer its useful life will be and that has economic and environmental investments over time. In the past decade, the concept of buildings' adaptive reuse gained importance due to the rapid change in both private and public organizations types of work that demands more inventive and flexible work place designs. It was also due to the increase in rebuilding costs, the focus on the environmental drawback of new buildings, and the effects of obsolescence. Therefore, designing for adaptive reuse permits renovations based on parameters that preserve the structures' material values with more or less success in order to host a new function [31].

The largest financial, physical, and cultural asset in the industrialized world today is the existing building stock. Therefore, in order to establish and maintain a sustainable society, the existing building stock must be managed sustainably. The average age of a building in Tokyo is now 17 years [32]. In the United Kingdom, the commercial property market demonstrates the rapid change in demand, with activity in the private office sector rising from 3.3% in August of the year 2005 to 12.6% in December of the same year [32]. In Germany, only 15% of the buildings that survived World War II remain standing today [32].

The quality of a building will be measured by its potential to be transformed from a spatial to a material concept without negatively impacting its performance, the environment, and the economy [33].

Building Performance

Buildings that are not capable of adapting, with minor changes in their structures, to different circumstances from technological, demographic, or even environmental, are at risk of becoming obsolete and poorly utilized thus unable to serve a purpose at their current phase. This may require major renovations and in some cases complete demolition and new construction thus increasing the use of resources within the building sector by 20 to 30% [6]. Nevertheless, there are multiple ways that a building's performance can be enhanced via designing for adaptive reuse. Three of them are described below:

- More efficient use of space – Buildings designed for adaptability ideally have a much better use of space and materials during their life cycle. Designing for adaptability increases the flexibility of spaces allowing the occupants to use the floor areas more effectively. Also, designing for adaptive reuse accounts for convertibility which permits different sectors of the building e.g. attics, hallways, basements and so on to be converted to serve other purposes. Finally, expandability is also an asset for designing for adaptive reuse in a sense that the building is capable of accommodating higher densities within the same footprint and infrastructure. For example, if the average lifetime space utilization is improved by10%, and all buildings are similarly designed for adaptability, then the world needs 10% fewer buildings [6].

- Increased longevity – Studies have shown that most buildings get demolished for their inability to adapt to new technologies not for structural deterioration [6]. Designing for adaptability elongates the lifetime of a building without having to go through renovations that significantly affect the integrity of the structure and infrastructure thus minimizing the environmental impacts. Such impacts include the embodied energy needed to make reinforced concrete, or the energy needed to process different elements of a building like wood, metal, glass and landscaping material to create new construction. If adaptable designs can extend the average lifetime of buildings by 10%, (and possibly much more), then we can similarly reduce the total world investment in replacing these long-lasting elements of the building stock [6].

- Improved operating performance – Designing for adaptive reuse allows the building to adjust, at lower costs, to new technologies that become available. For example, the technologies for the HVAC systems have improved at least 20% thus doubling the efficiency of light and ventilation systems in the past decade. If a building has features that allow easier adoption of new and efficient technology, it is reasonable to assume an increase in average lifetime operating efficiency of 10% or more. This in turn would reduce the total environmental impact of operating the world's buildings by 10% which is considered a very significant improvement [6].

Environmental Benefits

The traditional demolition methods of buildings that can no longer serve their original purpose create large volumes of building material debris that usually end up in landfills. In addition to that, the demolition process itself is harmful to the environment because it can release contaminants or particulate matter that can potentially affect air and water quality. Also, the process of extracting new construction materials, manufacturing, and transporting them to the site increase the overall energy consumption and release green house gases that ultimately contribute to global warming.

In 2000, new buildings accounted for 40% of annual energy and raw materials consumption, 25% of wood harvest, 16% of fresh water supplies, 45% of landfill, 45% of carbon dioxide production, and 50% of total green house emissions in the industrialized countries [34].

One of the main advantages of reusing a building is the retention of the original buildings embodied energy [34]. Existing buildings have certain levels of embodied energy in the construction materials used. When reusing a building, the embodied energy of the building materials is retained, thus making the project much more sustainable than an entirely new construction. Therefore, new construction has significantly higher embodied energy costs compared to buildings that have been adaptively reused.

To illustrate, reusing an existing building significantly lowers the amount of raw materials needed for new construction thus positively affecting the air pollution by decreasing the amount embodied energy needed for the extraction, production, and transportation of the new materials. The Australian Green House Office (AGO) stated that the reuse of buildings has saved 95% of embodied energy that would otherwise be wasted via the classic demolishing of buildings [35].

Nils Larsson examined office buildings that were designed for adaptive reuse [36]. In his study, he narrowed down the factors that greatly influence the environmental benefits into two:

- The reduction in embodied and replacement energy
- The reduction in solid waste generation from renovation and demolition

He studied data quantifying the embodied energy and demolition energy used by office buildings published in other research papers such as Life Cycle Energy Use in Office Buildings and Demolition Energy Analysis of Office Building Structural Systems [37] [38]. Based on the data presented, Larsson pointed out two substantial advantages related to the office buildings' adaptability when compared to the environmental loadings of demolishing and reconstructing office buildings of the same footprint.

- A 15% reduction in embodied and replacement energy
- A 15% reduction in demolition solid waste

Economic Benefits

In contrast to the environmental benefits, some researchers argue against adaptive reuse with regards to its economic benefits. Hollyoake and Watt argue against adaptive reuse because it is more time consuming and labor intensive when compared to classic demolition thus, according to the researchers, demolition and new build is simply more cost efficient [35]. Bullen supports the arguments against adaptive reuse from an economic perspective. He stated that adaptive reuse can get expensive quickly because it may require certain structural modifications to accommodate a new spatial layout and internal comfort for the building's new use [35].

However, Wilkinson and Reed ask the following, "How do you determine whether a building is going to be more expensive or less expensive to carry out adaptive reuse?" [39]. Many researchers argue in favor of the adaptive reuse of buildings and consider its economic benefits as equally appealing as its environmental ones. Studies have shown that adapting a building for a different use significantly lowers the initial costs for the purchase and transportation of new materials for a new build [40]. The cost of labor is reduced depending on the complexity of the building and therefore reducing the amount of structural modifications required to accommodate a new function. Also, significant savings in time can be noticed in excavating and rebuilding major elements when reusing a building.

Gary Pokrant states that adaptive reuse is not only good for the communities involved, it is also a smart economic choice [41]. He argues that when a building is adaptable, renovations take place quicker and are significantly less expensive than demolition and new construction since the building's utilities, infrastructure, and major structural components are still in place.

All of the above, according to Pokrant, yields a more marketable project that gets a faster return on the money invested in building it. In addition to that, Pokrant writes that major economic and typically overlooked assets for adaptive reuse in the United States are the federal, state, and local incentives especially for rehabilitating historic structures. The incentives are in forms of financial and tax credits including the Federal Rehabilitation Tax Credit, the New Markets Tax Credit, Brownfields Tax Incentive, State Tax Credits, and Property Tax Credits. Furthermore, the Energy Tax Incentives act of 2005 provided tax increment financing, credits, and deductions for adaptive reuse projects that result in energy-efficient building improvements.

A study by the New South Wales (NSW) Heritage Council in Australia concluded that, "The combination of financial incentives and the commercially oriented nature of the adaptive reuse schemes outweighed any extra heritage costs and project risks. These sympathetic adaptive reuse schemes have created commercially viable investment assets for the owners." [34].

Case Study: TriPod: A Plug and Play Housing System

The TriPod (see Figure 4-1) is an 800 square feet prototype house that introduces the concept of "Plug and Play". Plug and play defines a series of "pods" with incremental size allowing structural flexibility to the occupants as their needs change. The pods contain the living spaces in a residence. They are "plugged" into the core to receive electricity and maintain a comfortable environment. The TriPod is an imaginative way of designing houses that go beyond the industry's monotonous housing designs. Its design is based on separating the served and servant spaces by creating a mechanical core that is capable of accepting multiple pods [27]. The idea behind the design is to allow the owners to adapt the house to their changing needs by adding or subtracting spaces without changing the structure of the house.

The TriPod design utilizes modularity and adaptability at every level. When a family grows or shrinks in size, their housing needs change. The TriPod's adaptability allows the home owners to add or take away rooms or even swap for different sized rooms. The design is based on two parts: the core and the pods (see Figure 4-2).The core is considered the back bone of the house formally and functionally. It consists of all the mechanical and distribution systems that are vital for serving the main circulation space within the house such as ducts and pipes. Since the technology for the mechanical and distribution systems is always evolving, the core is designed to accommodate new equipment without major disturbance to the surrounding house components.

The flexible and dynamic nature of the TriPod is evident from the smallest detail to the overall concept of the design [27]. For example, the design includes raised access floor that allows the distribution systems to be easily accessible for changes to be made and pods to be attached. The material pallet integrates the interior space and yet separates the core and pods elements. The bolts, joists, and connections of the core and pods, and the different mechanical and distribution systems are exposed to the interior.

Figure 4-1. The Interior of the TriPod [Adopted from Lifecycle Building Challenge, TriPod: A Plug and Play Housing System, http://judging.lifecyclebuilding.org/entries/view/63, 2008]

The TriPod's modular structural system allows different pods to be "plugged" or "unplugged" into the core as the owners needs change. Modular construction means adapting a modular width to all the elements within the house from insulation, framing, openings, and down to the interior finishes. At the end of the house's useful life, all the materials can be broken down into their original form and recycled. The Tripod's construction demonstrated that the adding or subtracting of those pods can be done within hours (see Figure 4-3). Even though the recycling content of the different building materials is high, the plug and play concept reduces the frequency of the house demolition.

The entire structural system of the TriPod is steel including structural steel beams and columns, steel studs and joists, and insulated metal panels. The roof, floor, and walls are structured using light gauge steel to support structural insulated panels (SIPs).Roughly 95 percent of the structural connections are removable fasteners. The SIPs are screwed to the steel frames and their seams are finger joints sealed with butyl sealant to facilitate future disassembly and reuse without damaging the panels [27]. No insulation between the steel studs is needed because the SIPs provide all the insulation necessary.

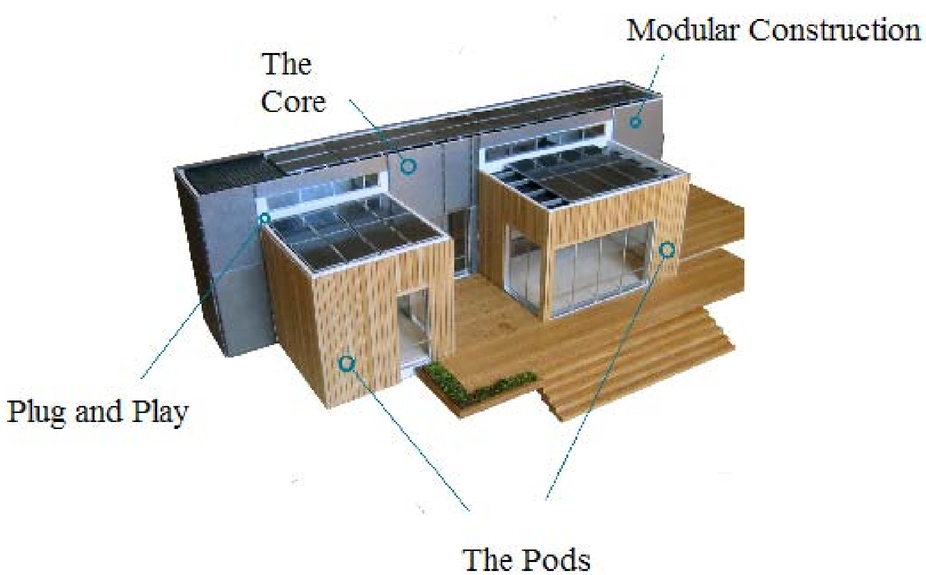


Figure 4-2. The Different Systems of the TriPod [Adopted from Lifecycle Building Challenge, *TriPod: A Plug and Play Housing System,* http://judging.lifecyclebuilding.org/entries/view/63, 2008]

The design includes an air to air heat pump that increases the efficiency of the mechanical systems. It also features supper-insulated windows that collect the heat from the sun while the operable clerestory windows allow the stack effect cooling system in the winter. Different energy efficient appliances such as convection cooktop, refrigerator, and dishwasher also reduce energy consumption. LED lightning minimizes the amount of energy needed to light the house at night. The design maximizes the amount of daylight inside thus reducing the need for further illumination during the day. The Tripod's photovoltaic panels collect energy from the sun and use it to generate electricity thus eliminating the need for fossil fuel and allow the house to be a 'zero energy' house.

Figure 4-3. The Plugging and Unplugging of the Different House Pods [Adopted from Lifecycle Building Challenge, TriPod: A Plug and Play Housing System**,** http://judging.lifecyclebuilding.org/entries/view/63, 2008]

Environmental Implications

Since the house is modular and prefabricated, it can be assembled and disassembled quickly and with minimal damage to the construction site when compared to traditional construction. The TriPod has been designed to achieve super energy efficiency on multiple levels [27]. It has multiple design features that maximize its energy efficiency by minimizing energy leakage thus reducing the need to use more energy over its lifecycle.

All of the above design features reduced the TriPod's electricity usage by 10-25% when compared to traditional houses of the same footprint.

The TriPod's designers compared energy simulations that they ran on both a traditional benchmark house and the TriPiod. The houses were put in multiple locations in the United States in order to be exposed to different climates but at the end the designers used the Pittsburg, PA location for the result analysis. Since the TriPod is designed to be a ‘zero energy’ house, the designers assumed that it will not consume any electricity from a coal burning power plant. The designers also relied on prior research[1] to measure the amount of green house gas based on each kWh that a power plant generates. Finally the TriPod’s annual energy consumption was compared to that of a traditional benchmark house at the same location to determine the amount of green house gas that was diverted by using the TriPod’s design. The results were the following:

- 73 tons reduction in Carbon Dioxide
- 0.56 tons reduction in Sulfur Dioxide
- 0.16 tons reduction in Nitrogen Oxide

Economic Implications

According to the TriPod designers, the housing industry in the United States is splintered with no significant change in years [27]. The TriPod house provides an innovative method that promotes web-based network between different plug-and-play house owners. Through this network, the owners have the ability to exchange modular parts directly and facilitate the process of the physical detachment and/or attachment of the different pods in a timely fashion.

On a smaller level, the owners of plug-and-play homes will be able to enjoy different economic benefits, such as a 10-25% reduction in utilities bill. The designers are confident that high energy efficiency design of the TriPod will pay off at the end.

Adaptability and Building’s Quality

The quality of a building is greatly determined by its ability to maintain occupiers’ demands over time with minimal costs of reconfigurations. A building that has been custom

[1] The designers used articles such as “Estimating Seasonal and Peak Environmental Emissions Factors” by the State of Wisconsin Department of Administration: Division of Energy

designed with high specifications may require frequent and expensive modifications compared to a building with a low specification design using high quality materials [29].The internal specifications and the external appearance of a building are the two targeted areas when it comes to maintaining the occupiers' demands. Over-specifications of internal and external finishes may result in higher modifications and renovations costs, thus reducing the capital return on reusing the building. A more adaptable design would be one that provides accommodation to changes in user requirements while maintaining cost-effective modifications in the building's layout and services with minor impacts to the building's external appeal and interior non-structural elements.

Russell and Moffatt suggest that when a building is designed to be aesthetically pleasing and includes, "beautiful and durable cladding, unique and handcrafted detailing, high quality interior finishes, operable windows, numerous well-lit rooms, and so on" then the owner might not care much for designing the building to adapt to different future needs [6]. Russel and Moffatt point out that when owners request to design their ideal building, they are in most cases willing to adapt their needs to the existing building, not the other way around. This behavior can be foreseen as an alternative to designing for adaptive reuse since it also extends the life cycle of the structure and improves the use of space.

As a result, the Russel and Moffatt conclude that designing for adaptable reuse can be more popular in buildings with less quality design and construction features. Confirming Russell and Moffatt's conclusion, Stewart Brand suggests that buildings can be divided into two categories [42]. The first category he called the "low road" buildings. The "low road" category consists of buildings and structures that owners did not invest in designing them for high quality thus they will have no remorse in adding adaptability features to the design and possibly altering the building's layout to adjust for future change in purpose. Brand mentions that when a building is "devoid of aesthetic value", they tend to have a high life cycle if the owners decide to invest in designing for adaptive reuse.

On the other hand, the second building category according to Brand is, "high road" buildings. This category consists of buildings that are custom made to fit exactly the owners' ideal building features and thus requires unusual care and attention throughout its lifetime. That type of buildings, according to Brand, has a low capacity to physically adapt to changes simply because they were not designed for that purpose.

Adaptability Constraints

If adaptability is to be a useful design concept, it must be possible to properly distinguish those features of new buildings that will significantly increase their capacity for change. This high degree of uncertainty undermines the present value of any potential benefits from adaptable building designs [6]. There are a number of obstacles in the current construction industry that prevent designing for adaptive reuse from being fully appreciated such as:

- Many designers and owners work under the assumption that the designed building will unlikely experience significant change
- The market place offers little incentive for owners and developers to invest in long term adaptability
- The impenetrability to accurately predict the future requirements of buildings
- The uncertainty in foreseeing the future functionality of adaptability features in existing buildings
- The difficulty in expecting the type of changes and how abrupt they may occur in the future i.e. technological, environmental, demographical and so on

Part of the problem of designing for adaptive reuse is the fact that only few buildings that exist today have been intentionally designed for reconfiguration and therefore there is little practical evidence on how designing for adaptive reuse increases the environmental and economic benefits of the building. Also, the developer who invests in adaptable building structure may not realize the full economic benefits such as maximizing the return from capital expenditures due to the high life expectations of buildings that exceed 50 years in some cases.

However, the risk taken in investing in design for adaptive reuse can cut in both directions. Studies have shown that the costs of incorporating design for adaptive reuse, ideally, are significantly less than the costs for traditional modifications and alterations in buildings not designed for adaptability. Therefore, cost savings can be weighed against the difficult predictions of when and what building modifications will be needed [6].

There are several kinds of changes that may play an integral role in influencing designing for adaptive reuse among owners, architects and engineers. Two of the more integral kinds are the following [6]:

- Incorporating incentives into new public policy directed at sustainable urban development
- Committing businesses to the basic principles of sustainability and thus adjusting their behavior accordingly.

This study sheds light on the first method of promoting designing for adaptive reuse among the different construction sectors by suggesting an incentive that might be environmentally and more importantly economicly appealing. This research suggests incorporating designing for adaptive reuse as a multi-credit category in LEED-NC. The economic, environmental, and social benefits of a building's adaptive reuse are substantial and therefore need to be addressed directly in LEED-NC assessment system. For detailed information on the proposed category refer to chapter 7 of this study.

Guidelines for Adaptability

Maintaining the majority of the interior non-structural elements such as interior walls, doors, floor coverings and ceiling systems require more creativity in the design for adaptive reuse. Designing a building for adaptability can reduce the generation of significant construction waste during building renovation. When designing adaptability, structures ideally should become extensively transformable. In fact, they would come with an ‘instruction manual’ describing how elements like the bathroom, balcony or walls can be removed and replaced.

The idea is to separate the structure from the internal walls, cladding, and the multiple services existing within. Doing so will facilitate the simultaneous convertibility of the building. Different parts of the building will no longer be dependent on each other; therefore, dismantling one will not affect the other. It is especially important to uncouple the layers of the building that have different lifetimes.

The Theory of Layers

It is a common misunderstanding that a building changes as a single entity over its life time. However, according to Francis Duffy, the founder of DEGW, a firm in London that specializes in advanced office designs; there are four separate fundamental layers that govern how a building changes with time [43]. Each layer has its own service life and repair and replacement periods. According to Duffy, the service life is defined as the time period that a certain building layer is expected to last based on the upgrades and modifications resulting from the occupants’ changing needs and demands.

The Shell layer is the foundation or structure of the building. It is considered the framework of which the different services and space-making components can be attached or de-attached in an adaptable way. The Services layer includes the electrical, hydraulic, HVAC, elevators, and different communication systems. The Scenery layer is the internal partitioning system, the ceiling, and the finishes. Finally the Set layer is the different components and elements that the building occupiers need to move freely to accommodate their daily, weekly, or even monthly needs.

Even though Duffy developed his theory of building layers as an analysis tool for office buildings, the theory is effectively applicable to different types of buildings, though the life spans might change slightly. Duffy's concern was providing internally adaptable buildings so that the building itself does not have to be exposed to major renovations or even replaced when the internal spaces no longer can accommodate the occupants needs. Duffy wrote that, "Our basic argument is that there isn't such a thing as a building…a building properly conceived is several layers of longevity and built components" [43].

To complement designing for adaptive reuse, the theory of layers suggests that architects and engineers should separate the parts of the building with short service life from parts with longer service life. This means that when, for instance, the services of the building are no longer functioning in a contemporary way, it will be easy to replace the services only, instead of upgrading, replacing, or even demolishing parts of the building.

A study prepared by Canada Mortgage and Housing Corporation (CMHC) found that the most important principle in designing for adaptive reuse is the independence of different systems and layers within the building. It strongly emphasized that the more independent and uncoupled that different systems are, the more adaptable the building is.

Nevertheless, keeping different building systems independent from each other should not interfere with the functionality of the building as a system in terms of controlling heat, air, moisture, light, and sound. One challenge that architects and engineers face when designing for adaptive reuse is designing a high performance building while maintaining the independency of the systems and features that enhance adaptability such as redundancy, robustness, and ease of access, repair and replacement.

Convertibility Features

Russell and Moffat suggest that the conversion from residential units to commercial ones is more difficult and thus uncommon [6]. This study suggests that residential units can be converted into apartment-hotels easier than converting them into office use or retail. The study relates the difficulty of such conversion to the rigidity of the apartments' layout and structure. Russell and Moffat propose changes in apartment building designs that suite the North American context and thus facilitate the adaptability of residential units into commercial ones:

- Increase the floor parameter from the typical 21m (68.89ft) to roughly 25m (82.02ft)
- Set the structural bay spacing at about 9 or 10m (31ft)
- Increase the floor-to-floor height from about 2.9m (9.51ft) to about 3.35m (11ft)
- Place the core and vertical services strategically

Strategies for Adaptability

Designing for adaptive reuse lengthens the building's life and improves the chances of reuse by proposing a yearly inspection plan and suggesting repairing techniques if necessary.

It involves the reconditioning of the existing structure to modern day requirements. Green design techniques and technologies can be incorporated at the design level to update the building's performance and to create a healthy space in which to live and work. Architects and engineers are recommended to consider some of the following guidelines in their design for adaptive reuse [6]:

Foundation

- Design foundations to allow for potential vertical expansion of the building - rational analysis should be done to arrive at a reasonable estimate for possible future expansion;

- Include installation of isolation joints or other features that avoid the potential for differential settlements and for progressive collapse due to accidental loading;

Superstructure

- Design building to rely on a central core for lateral load resistance and to allow local modifications to the structure while maintaining complete structural integrity;

- Focus on using a wide structural grids with a minimum width of 6m or roughly 20ft - the redundancy in structural strength that a wide grid introduces can increase adaptability considerably;

- Design the lower few floors for heavier (e.g. 4.8 KPa) live load - the increased capacity will enable the building to easily accommodate all of the likely conversions with no structural modification;

- Add sufficient height to lower floors to enable a range of uses;

- Devise a structural floor system that accommodates a number of mechanical and electrical service distribution schemes based on different occupancies;

Envelope

- Design the building envelope independent of the structure - i.e., functionally discrete systems, with the interfaces designed for separation;

- Provide, in the design, means for access to the exterior wall system from inside and outside of the building;

- Design a versatile envelope capable of accommodating changes to the interior space plan;

Services

- Maximize the use of hybrid HVAC systems, with a balance between centralized components and distributed components - designed to provide the flexibility of changing the central system fuel and capacity, while allowing for easy upgrading of localized conditioning units and distribution network;

Interior Spaces

- Design spaces for a loose fit rather than tight fit;
- Include multifunctional spaces in design;
- Maximize the use of interior partitions that are demountable, reusable and recyclable;
- Provide more than the minimum spatial areas and floor heights; and
- Use of adaptable floor plans, including large grids that can be subdivided.

The American Society of testing and Materials (ASTM) provided guidelines that architects and engineers are recommended to follow in order to design for adaptive reuse of a modern building [53] [54] [55]:

- Design spaces such that minimum disruption will be caused to occupants due to physical change;

- Design luminaries to facilitate of relocating within ceiling grid or when up-lighting is used;
- Design air diffusers on flexible ducts for easy relocating at minimum cost with minimum disruption to occupants;
- Design exhaust air ducts for special exhausts for easy reinstalling - space and capacity should be available in ceiling and duct shafts;
- Design sprinkler heads to facilitate easy relocating within ceiling grid;
- Design pre-wired horizontal distribution systems in ceilings or floors, with spare capacity and easy access to accommodate change of workplace layouts;
- Design for easy relocation of partition walls that causes minimum damage to flooring or ceiling systems; and
- Design partition walls to be easily removed and fully salvageable.

The previous strategies were a few of many others suggested by different researches to design a more adaptable building that would facilitate the rapid change of use and accommodates the needs of different users. Davidson et al wrote, “The identification of common technical design features and appearance in relation to building usage allows the development of a platform for mass customization. Cost, quality, and time certainly benefits would be gained from the improvements in procurement and construction consistency.” [56].

CHAPTER 5
DESIGN FOR DECONSTRUCTION

What is Design for Deconstruction

Designing for deconstruction is a concept that emerged in the 1990s. It borrows from the fields of design for disassembly, reuse, remanufacturing, and recycling in the consumer products industries [44]. The overall objective of designing for deconstruction is to reduce the environmental impacts such as pollution from the demolition of buildings, and to increase the stream of used and recycled building materials through designing for the recovery and the eventual reprocessing of building materials. The idea is to employ design practices that facilitate the recovery of materials with high capacity for recycling and reuse in order to selectively and systematically deconstruct buildings that would otherwise be completely or partially demolished at the end of their useful lives.

Since buildings, at the end of their useful lives, are most likely to be demolished allowing space for new construction, designing for deconstruction focuses on the recovery of recyclable and reusable materials with the intent of utilizing them in the construction or rehabilitation of other structures. Architects and engineers should identify in the design phase the different building elements, components, subcomponents, and materials that could potentially be recovered for reuse and recycling.

Why Design for Deconstruction

Designing for deconstruction requires architects and engineers to select materials that have a high capacity for reuse in subsequent projects and materials that are recyclable and reprocessed into new products whether or not in the construction industry thus ultimately closing the materials loop. The selection of materials by building designers should take into account the results from different environmental assessments such as embodied energy, closing the materials loop, and so on in order to identify the most environmentally friendly stream of construction materials.

According to Webster and Costello, “The act of preparing a deconstruction plan will force the building designers to put systematic thought into how the building will be dismantled at the end of its life. This process could lead to creative strategies that go beyond the quantifiable prescriptive requirements that would likely be included in a future credit.” [32].

Environmental Advantages

Designing for deconstruction is a tool for reducing the environmental burden by designing for the recovery of materials that have the capacity to be reused or recycled. As a result, designing for deconstruction facilitates the achievement of different environmentally cautious results such as closing the materials loop, reducing the embodied energy and emissions of CO_2 and finally minimizing the ecological footprint required for the life-cycle of the different building materials. According to a study done by BioRegional Development Group in the United Kingdom, the potential for salvaging and recycling building materials thus eliminating the need for new materials is enormous. The study suggests that reclaiming, reusing, or recycling materials can save up to 95% of their embodied energy [11].

Exhibit A

To illustrate, the study creates two models that include resource flow data and embodied CO_2 figures for a variety of building materials [11]. The first model promotes the environmental advantages via the reuse of building materials. The model aims at calculating the reduction in the embodied CO_2 using Potential Impact Reduction (PIR) factors associated with different reclaimed building material, and construction materials with the capacity for salvaging and reuse. The details are the following:

- The PIR is estimated at 11%

- 50% of slate can be reused
- 35% of brick can be reused
- 40% of all steel can be reused
- 30% of all metal products can be reused
- 33% of timber products can be reused

The study suggests that even though the percentages mentioned above are ambitious, they are feasible and potentially economic. The two obstacles that the study foresees is the lack of the proper extensive supply chains for the different high quality building materials with the capacity for reuse, and the current construction design practices that result in a slow switch from demolition to a dismantling approach. The results are illustrated in Figure 5-1.

Exhibit B

The second model aims at showing that increasing the recycling content in building materials chosen by architects and engineers potentially reduces the embodied CO_2. Similar to the first model, the reduction of the embodied CO_2 is calculated using different PIR factors. The model suggests the use of Ground Granulated Blastfurnace Slag (GGBS) and Pulverized-Fuel Ash (PFA) as a substitute for a proportion of the cement in concrete. GGBS is found to have an 80% reduction in embodied CO_2 compared to cement. The results are based on the following data:

- The PIR is estimated at 9.6%
- 20 million tones per year of additional recycled and secondary aggregates are suggested[1]
- 5.5 million tons of crushed glass sand is used instead of virgin sand[2]
- 10% additional use of GGBS and PFA instead of cement
- 20% increase in recycled aggregate content by using GGBS and PFA in ready made concrete, concrete blocks, and concrete roofing tiles

[1] This exceeds the Mineral Planning Guidance target for an increase of 12 million tons by 2006

[2] This requires all recycled glass to be used for this purpose

- 5% increase in recycled clay content
- 20% increase in timber recycled chip or sawdust content
- 50% increase in recycled content of plastic products

The results are illustrated in Figure 5-2.

PIR from increased use of reclaimed materials	Resource flow ("000 tonnes)	Embodied CO2 ('000 tonnes)	Increased reclaimed use ("000 tonnes)	PIR factor for reclaimed materials (%)	Embodied CO2 reduction ('000 tonnes)	% reduction
Crushed rock	126,568	2,772	0		0	0.0
Sand & gravel	82,539	1,808	0		0	0.0
Cement	11,072	13,504	0		0	0.0
Slate	78	1	39	0.95	0	0.0
Ready made concrete	53,494	10,862	0		0	0.0
Concrete blocks	34,644	7,256	3,464	0.95	689	9.0
Concrete roofing tiles	2,568	538	0		0	0.0
Fibre cement products	158	468	0		0	0.0
Bricks	7,409	4,408	2,470	0.90	1,323	17.2
Glass	3,349	3,786	0		0	0.0
Steel	2,500	5,333	1,000	0.95	2,026	26.4
Other metals	850	9,520	255	0.95	2,713	35.3
Timber	1,925	3,504	642	0.80	935	12.2
Plastics	550	4,934	0		0	0.0
Paints	410	1,353	0		0	0.0
		70,044			7,687	
					% reduction 11.0	

Figure 5-1. Results for Exhibit A [Adopted from **Lazarus, N.** Potential for Reducing the Environmental Impact of Construction Materials, 2005]

PIR from increased recycled content	Resource flow ("000 tonnes)	Embodied CO2 ('000 tonnes)	Increased recycled content ('000 tonnes)	PIR factor for recycled content (%)	Embodied CO2 reduction ('000 tonnes)	% reduction
Crushed rock	126,568	2,772	20,000	0.55	241	3.6
Sand & gravel	82,539	1,808	5,500	0.75	90	1.4
Cement	11,072	13,504	1,107	0.80	1,080	16.3
Slate	78	1	~	~	0	0.0
Ready made concrete	53,494	10,862	10,700	0.80	1,738	26.2
Concrete blocks	34,644	7,256	3,464	0.90	653	9.8
Concrete roofing tiles	2,568	538	257	0.90	48	0.7
Fibre cement products	158	468	16	0.90	43	0.6
Bricks	7,409	4,408	370	0.95	209	3.2
Glass	3,349	3,786	~	~	0	0.0
Steel	2,500	5,333	~	~	0	0.0
Other metals	850	9,520	~	~	0	0.0
Timber	1,925	3,504	385	0.80	560	8.4
Plastics	550	4,934	275	0.80	1,973	29.7
Paints	410	1,353	~	~	0	0.0
		70,044			6,637	
					% reduction 9.5	

Figure 5-2. Results for Exhibit B [Adopted from **Lazarus, N.** Potential for Reducing the Environmental Impact of Construction Materials, 2005]

Economic Benefits

Overview

Deconstruction requires an infrastructure of skilled contractors and laborers who are familiar in deconstructing buildings. Generally, the owners' major concerns that govern the decision to design for deconstruction or not is based on the following factors that typically occur at the end of the building's useful life [12]:

- The average cost landfill tipping fees
- The average cost of labor and equipment needed for the deconstruction process
- The ease of disassembly which in turn affects labor and equipment costs
- The value of materials designed for recovery
- Time required for deconstruction which also affects labor cost

Since buildings are ideally designed to stand the test of time, accurate predictions for any of the previous factors are nearly impossible. Therefore, architects and engineers should rely on archived economic data and on experts' opinions to estimate the costs of landfills, labor, equipment and even the value of materials at the end of the building's life cycle. For instance, records show that the national averages for landfill tipping can cost as much as $100 per ton in states such as Vermont or New York [12].

The labor and equipment costs for deconstructing a building can get expensive depending on the complexity and location on the project. However, since designing for deconstruction aims at maximizing the diversion of materials from landfills, this helps the owner or developer minimize the tipping fees which in return offsets to a great degree the labor and equipment costs associated with deconstructing the building. Also, having well trained deconstruction personnel and promoting safety on the job site further reduces the overall labor costs of deconstruction projects. Another appealing economic incentive for designing for deconstruction is the return on the value of salvaged building materials. This requires establishing a market for salvaged materials with values that are competitive with other alternatives.

According to Changes in Construction Materials Prices report in 2007, "In general, through 2003 most construction materials show very modest increases and many decreases in price, similar to the overall PPI[3] for finished goods, which fell 1.6% in 2001, rose 1.2% in 2002, and rose 4% in 2003. Beginning in 2004, however, numerous construction materials have had one or more periods of double-digit increases, whereas the CPI[4] continued to rise at a 2.5-5.6% annual rate." The report continues, "Contractors have reported increases in cement and rebar prices since January that are likely to drive up concrete prices." [45].

Needless to say that the resale value of materials designed for recovery at the end of the building's life cycle is crucial. Therefore, designers can promote designing for deconstruction by choosing materials that have high quality and will have a high dollar amount return when recovered in the future. The value of many recovered resources depends on the robustness of the local recovered materials markets, which varies a great deal historically.

Exhibit C

In the United Kingdom, BioRegional Reclaimed declared that it has a proposal to dismantle two unfinished steel-structure office buildings (see Figure 5-3) that were erected in the year 2001 [37]. The owner of the office building has two options. The first is to demolish the buildings and scrap the steel and the second is to deconstruct the buildings and sell the steel for reuse. BioRegional Reclaimed assessed both options based on two factors:

- Costs of deconstruction versus the costs of demolition
- The net economic values at the end of the project

At first glance, the demolition of the project was the easier route to take. The risks and the costs are low. The demolition process itself and the clearing of the site was estimated at 6 weeks.

[3] PPI stands for Producer Price Index

[4] CPI stands for Customer Price Index

On the other hand, deconstructing the projects was risky because the steel can be damaged during the dismantling process and there is always the chance of not being able to sell the recovered steel.

Figure 5-3. The Two Steel Based Projects [Adopted from **Lazarus, N.** *Potential for Reducing the Environmental Impact of Construction Materials*, 2005]

Also, dismantling the buildings was considerably more costly initially because it involved more factors such as shot blasting, haulage of steel, structural certification, handling, storage, and sales. Furthermore, the time scale to dismantle the buildings was estimated at 10 weeks and the stocks were estimated to be cleared over 52 weeks. Figure 5-4 below illustrates the details of the study.

Even though the demolition option is initially cost-effective and requires less time, the study concludes that in the long run, the owner’s capital return is higher when taking the dismantling option. The resale and the wastage scrap values of recovered steel are significantly higher than the scrap value of the demolished steel thus returning a much higher net profit. As a result, dismantling a building is more economically and environmentally beneficial in the long run.

Option 1 - Demolish for scrap

Demolition costs	£15,000
Scrap value	£35,000
Net value	£20,000
Timescale	Demolished and site cleared in 6 weeks
Risks	Very low

Option 2 - Dismantle for re-use

Dismantling costs	£55,000
Shotblasting costs	£34,000
Haulage	£6,000
Structural certification	£3,000
Handling, storage and sales	£30,000
	£128,000
Wastage scrap value	£10,000
Resale value	£150,000
	£160,000
Net value	£32,000
Timescale	Dismantled in 10 weeks Stocks gradually cleared over 52 weeks
Risks	Damage during dismantling Unable to resell
Eco-footprint savings	420ha years
Embodied CO2 savings	581 tonnes

Figure 5-4. Data for Exhibit C [Adopted from **Lazarus, N.** Potential for Reducing the Environmental Impact of Construction Materials, 2005]

Deconstruction Constraints

The ultimate goal for designing for deconstruction is to facilitate disassembly as an alternative to demolition of buildings at the end of their useful lives. Doing so generates a stream of used building materials and components that have the capacity for reuse and recycling thus the potential to be implemented in the next generation of building structures. However, the benefits of designing a building for deconstruction today will not be realized until the useful lives of the buildings designed for deconstruction have expired [46]. Figure 5-5 illustrates median ages of buildings in different industry sectors.

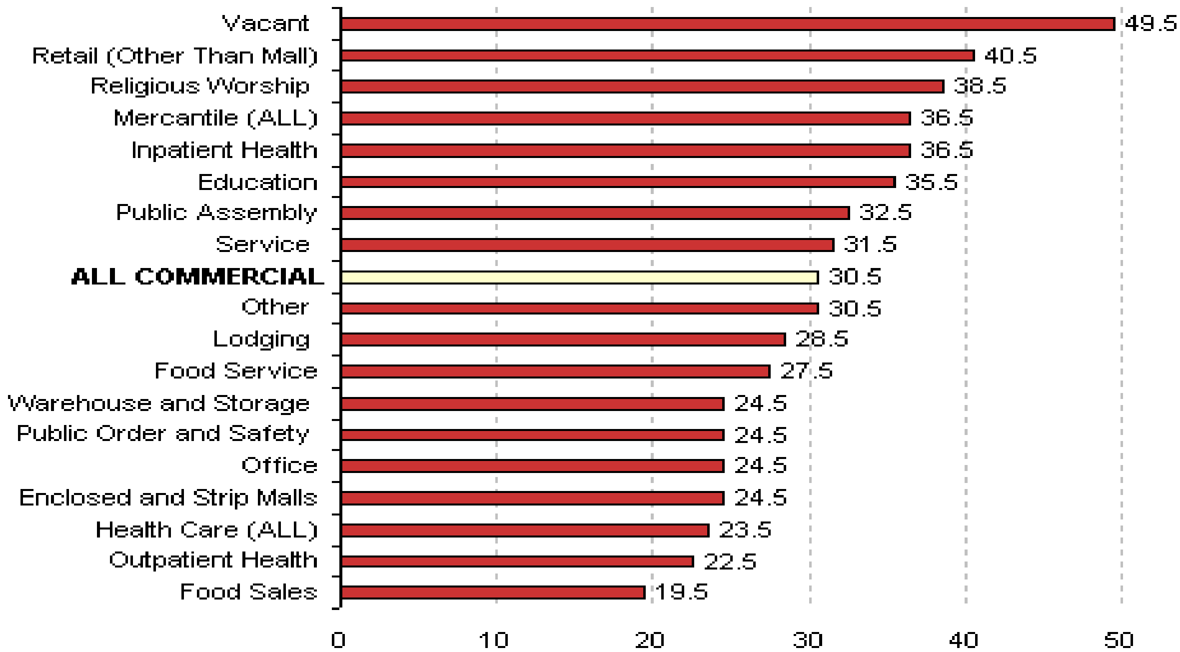


Figure 5-5. Median Age of Buildings in Years [Adopted from Energy Information Administration, *Commercial Building Energy Consumption Survey*, 1999]

There are a number of constraints facing designing for deconstruction in today's industry. Constraints include the lack of deconstruction professionals and time and cost effectiveness when designing for deconstruction. Nevertheless, there are two primary challenges that are considered chiefs among the design for deconstruction constraints:

- Lack of markets for used components – the strength of the used building materials market in a given area is directly related to the area's local attitude towards used building material and the population and location of the area [46]. In order to achieve any level of profitability, the deconstruction industry requires implementing a successful market for the salvaged building materials. However, the demands for used construction materials are directly and negatively influenced by the perception of low value of any salvaged building material and the sense of taking the risk of not using new building materials potentially leading to a structure that is not as strongly intact. According to Grothe and Neun, this negative perception in the construction industry is due to common misconceptions associated with used and recycled materials such as dimensional problems, inconsistency in supply, high risk, and poor quality [47]. All these factors negatively affect the rise of a profitable market for recovered materials and thus undermine the efforts to promote designing for deconstruction.

- Lack of standards for reused and recycled demolition materials – today's construction industry lacks guidelines and specifications for reused and recycled Construction and demolition materials. Different industry sectors remain cynical to the idea of implementing used and recycled materials in the construction of a new building due to the absence of quality assurance components, purchasing guidelines, and materials specifications. In addition to that, there is a shortage of scientific and engineered methods and model specifications of analyzing the quality, validity, and the capacity for recycling and reuse

In his research, Abdol Chini points out that, “The natural trend towards increased social and environmental responsibility, along with the maturation of the deconstruction industry, will aid in the effort to improve perception of reused and recycled building materials.” [46]. Chini suggests four aspects of the construction industry that, if addressed properly, will have a direct positive impact on eliminating any consumer doubts or concerns regarding implementing used and recycled components in new construction; as a result, promoting design for deconstruction as a more appealing business alternative and increasing the profitability of a market for reused and recycled materials. The following is a brief summary of the four aspects:

- Information Availability – over the past few years, information and data regarding used and recycled building materials have become readily available. Even though the knowledge of the general public regarding reused and recycled building materials is still low, the growth of the deconstruction industry will increase the number of resources and references available thus educating the different construction sectors on the different aspects of deconstruction and material reuse.

- Overcoming the Perception of Risk – as mentioned earlier, the construction industry has a concern regarding the stability and strength of used and recycled building materials. Therefore, according to Chini, “Used products must show they perform as well or better than virgin products. Component recertification process must be refined and standardized before this can occur.” [46].

- Economic Incentives – the best method to promote designing for deconstruction is to establish economic rewards and incentives that can be achieved via the reuse and recycling of resources and minimizing waste generation.

- Guidelines and Specifications – the National Demolition Association suggests that the federal government should establish a specifications and guidelines for each recovered material thus increasing the marketability and producing durable, economic, and high quality recycled materials. For instance, Webster mentions that currently there are no technical difficulties for recovering and even grading dimension lumber.

Design Mechanism

How it is done

Design for deconstruction offers opportunities for reusing and recycling large quantities of building materials. Architects and engineers should identify in the design the total weight and percentage by weight of the different building elements, components, subcomponents, and materials that could potentially be salvaged for reuse and recycling.

Similar to the construction process, deconstruction of a building potentially generates enormous quantities of solid waste materials that can be reused, or recycled. It is recommended that architects and engineers specify in the design plan the best practice methods to sort, separate, collect, and properly dispose deconstruction solid waste on-site or off-site. The disposal of solid waste should be one of the hierarchy end-of-use options mentioned previously. Depending on the type of building materials selected for construction, architects and engineers may choose recommend the best end-of-use option at the end of the building's life cycle for each of those materials.

Buildings are complex structures that consist of a variety of materials and components having different life spans, unique methods of disassembly per material or component, and diverse economic worth if recovered correctly [28]. As a result, building designs and the choice of building materials are crucial to the success of the deconstruction process. It is also recommended that designers, architects, and engineers consider the following factors in their designs:

- The quantity of each type of material that the design requires
- The impact of each type of material used on the environment during the construction phase, the deconstruction phase, and its the end-of-use option
- The ease of salvaging with minimal amounts of damage for each type of material designed

- Whether the materials recovered has the potential to increase, retain, or decrease in value
- The life cycle of each type of material used

Managing Deconstruction Materials

Each construction project is unique and so should be each project's deconstruction waste management plan. However, the general rule of thumb is that a deconstruction waste management plan should include the following:

- Identification Plan – should be conducted towards the end of the design development to predict the types and quantities of the materials that are designed for recovery [48]. The identification plan must include the individual weight, in tons, for each building material in the design including but not limited to wood, metal, concrete, asphalt and so on, as well as the sum, in tons, of all quantities added together. The percentage of total waste diverted is calculated by dividing the total weight, in tons, of materials designed for recovery by the sum of the total quantities of materials used in the building. The result will be the total percentage of material recovered and diverted from landfills. Architects and engineers should design for the recovery of the maximum amount of building materials.
- Data Matrix – outlines the quantities of deconstruction materials that are designed for potential reuse or recycling. The matrix also gives architects and engineers the option of indentifying the appropriate procedures for handling and the processing facilities to be used. Currently, there are two favored common waste diversion strategies:
- Source Separation: sorting the recovered materials into specific material types with no or minimum amount of contamination on site.
- Commingled or Off-site Separation – collecting all material types into a mixed collection system and separating them into recyclable, reusable, or waste material types in an off-site facility.
- The previous strategies have proven to be the most common separation methods employed in the building demolition industry. However, architects and engineers might develop a better approach for handling materials during the deconstruction project depending on the project's deconstruction conditions and scenarios. The data matrix should include the following:
- Total Weight (in tons): architects and engineers should have a fairly accurate estimate of the total weight in tons of all the building materials, components, elements, and so on in the designed project.
- Total Weight of Reusable Materials Designed - includes the total weight in tons of all the materials with the potential for subsequent reuse on another project or facility. Such materials include but not limited to precast concrete panels or whole concrete blocks,

whole bricks and masonry blocks, and different building components such as plumbing fixtures, lights, doors, trim, windows, hardware, and architectural artifacts that can often be properly recovered and reused.

- Total Weight of Recyclable Materials Designed - includes the total weight in tons of building materials with the capacity for subsequent processing into new products. Such materials include but are not limited to broken and cast-in-place concrete, broken bricks and masonry units, aluminum, steel, asphaltic paving, wood, other metals, and glass.

- Waste – the total amount in tons of material that is included in the design project but can neither be salvaged for reuse or recycling thus has to end up in a landfill. The amount predicted for landfills should be minimal.

- Material handling methods –This step is optional. It indicate which separation method is recommended during the deconstruction project for materials salvaged for reuse, recycling, and materials left for landfills. As mentioned earlier, some of the suggested methods are:

- Source Separation or

- Commingled or off-site Separation or

- Different handling method developed by architects or engineers

- Percentage of Total Weight – includes the final estimates of the percentages of building materials designed for reuse, recycling, and landfills by dividing each of the total weights in steps 2, 3, and 4 by the total weight in step 1.

Design for Reuse

Deconstruction allows materials to be recovered with the least amount of damage or environmental contamination. In general, some of the categories of materials that have the highest potential for salvaging and recycling are the following [49]:

- Asphaltic concrete paving
- Concrete
- Concrete reinforcing steel
- Brick
- Concrete masonry units
- Wood studs
- Wood joists
- Plywood and oriented strand board
- Wood paneling
- Wood trim
- Structural and miscellaneous steel

- Carpet pad
- Demountable partitions
- Equipment
- Cabinets
- Plumbing fixtures
- Piping
- Support and hangers
- Valves Sprinklers
- Landscaping Materials

The challenge facing architects and engineers when designing for deconstruction is due to the fact that a building is usually designed to stand the test of time thus it is difficult to estimate the economic value of the materials designed for salvage and what kind of technology will be available for recovering the material at the end of the building's life cycle [4]. Nevertheless, it is possible to purposely design a building for a shorter lifespan, which is the case in many exhibition halls, to facilitate the disassembly process and accurately estimate the value of reused materials [6].

There are four major structural materials that dominate in the construction industry today: wood, steel, masonry, and concrete. It is highly likely that architects and engineers will select one or more of those four materials when designing a building. As a result, Webster and Costello suggest a number of designing guidelines that would potentially facilitate the deconstruction process and preserve the quality of recovered materials [4].

The guidelines aim at limiting or completely eliminating any damage to the materials used in systems dominantly constructed from one or more of those four major structural elements. It is recommended that building designers should thoroughly evaluate the complete life-cycle of a building and its environmental impacts on a case-by-case basis to determine the best design approach that increase the capacity for reuse of wood, steel, masonry and concrete.

Wood

- Damaging wood during the disassembly process is one of the major concerns. One solution would be to use screws and bolts at connections instead of nails since they are easier to remove. Another solution is to utilize the industry standard bolting patterns to lessen wood damage.

- Another concern is the decay and insect damage. A solution would be to use robust management techniques in order to reduce if not completely eliminate any insect damage or decay.

- Engineered I-joist wood is not recommended because of the intensive care needed to avoid damaging them compared to other wood products.

- Separate the structure from plumbing, electrical, and HVAC services as much as possible

- Label members with species and grades.

- To facilitate final deconstruction, designers should consider using panelized construction particularly at roofs. Panelized construction, for instance, allows complete panels to be reused in whole or to be easily removed and deconstructed to the ground.

- Adhesives should be avoided as much as possible such as when fastening floor sheathing to joists.

According to structural engineer Mark Webster, most of the old grown harvested salvaged timber does not end up in structures, but instead it's being up-cycled by sawing them for flooring and furniture [4]. Webster suggests that large timber members could be easily reused for structural applications, even though it is time consuming, if kept intact. However, large members are more difficult to recover if used as flooring or other finishes.

Steel

- Clamped friction connections and bolted connections should be considered. Even though bolted members require more patching during re-fabrication because of the bolt holes, they are easier to deconstruct and have a higher resistance to damages than welded-connections members.

- Develop systems using bolted or clamped fasteners and pre-cast elements as a substitute for conventional composite floor systems using welded studs and cast-in-place concrete. That also requires developing code-approved design procedures to minimize the fabrication modifications ultimately avoiding the re-fabrication of steel

- Use precast decks.
- Simplify the shapes and avoid short filler pieces to minimize the use of stiffeners and other welded accessories.
- Mark steel grades and shape destinations
- Look for other alternatives for spray-on fireproofing. Even though fire proofing does not contain asbestos anymore, it is not simple to remove from the steel framing. It also adds extra shipping weight and volume to shipping from the construction site to the fabrication facility.

In today's industry, steel is mostly separated from other materials and recycled. However, since salvaging is more cost effective and environmentally friendly than recycling, architects and engineers should keep in mind that steel is a strong candidate for reuse and thus improves the deconstruction cost equation.

Masonary

- Since there is no cost effective technology currently available to separate the mortar from the brick, it is strongly recommended that portland cement mortars should be avoided.
- As a substitute for portland cement mortars, lime mortars should be considered especially for historical renovations projects. Structural engineers agree that lime mortar has the adequate strength to be used in veneer and bearing wall applications. It is also softer than the brick and thus can be easily removed. However, its effectiveness in new construction, its durability, water-resistance, and maintenance are still under investigation.
- In hollow masonry construction, architects and engineers should consider using unbounded post-tension reinforcement as a substitute for ground reinforcement.
- An alternative to using mortar to secure brick masonry would be using mechanical fasteners. This design idea has been implemented by Italian architect Rezno Piano in his design for the IRCAM façade in Paris [50].

In today's construction, building codes, especially in seismically active regions, require masonry construction to be steel reinforced making it safer during earth quakes. Unfortunately, this practice makes it almost impossible to recover any of the constituent materials because the steel is completely embedded in the portland cement's grout. As a result, engineers agree that structural masonry constructed today is a poor choice for buildings designed for deconstruction.

Engineers also agree that there is a need today for innovative ideas that would ease the recovery of masonry.

Concrete

- Avoid cast-in-place concrete because it usually consists of one contiguous whole with no joints to separate. Cast-in-place concrete is heavy and difficult to move with minor damage to the structure, and it is often custom designed. Therefore, the future deconstruction engineer will lack the information on strength and serviceability to be able to properly reuse the member. A more common end-of-use practice for cast-in-place concrete is down-cycling.

- Consider using pre-cast concrete members wherever possible. Precast concrete offer greater reuse potential because it comes in standard sizes with standard amounts of reinforcement.

- Precast members should be fastened together with removable, durable, mechanical fasteners such as stainless steel. Such fasteners resist in-plane diaphragm forces and out-of-plane shear forces.

- Avoid cracking the members by allowing for thermal movement at the connections

- Topping slabs placed over precast floor members can be accounted for by developing new systems for connecting pre-cast plank and tees.

- Provide a smooth sub-floor by using removable materials such as plywood on sleepers.

- Label each member's concrete strength and member reinforcement

- Implement precast foundation walls, shallow precast footings, and precast slab-on-grades as much as possible because of their greater capacity of salvage.

- Avoid basements and below-grade construction because foundation walls and deep footings are not that likely to be recovered properly.

Design Principles

Design Guidelines

In order to maximize the benefits of designing for deconstruction, architects and engineers must fully understand the material life cycles for all the major components of the buildings. Designing for deconstruction requires architects and engineers at the design stage to estimate the types and quantities of materials needed, the relative ease or difficulty of salvage, and the relative value of the material after it is recovered [12].

According to Guy et al, the most appropriate time to address design principles for the deconstruction of the buildings is during the schematic design and at 35% design development [48]. Primarily architects, then engineers, have the highest influence and input on what deconstruction design strategies fit best for each project. Guy et al conducted a two part survey that included 12 industry professionals i.e. architects, engineers, construction managers, and specialty contractors. The purpose of the two-part survey was to find out which team member had a more valuable input to contribute to what deconstruction design principles and to determine when it is crucial in the different stages of the project to address each principle (see Figures 5-6 and 5-7).

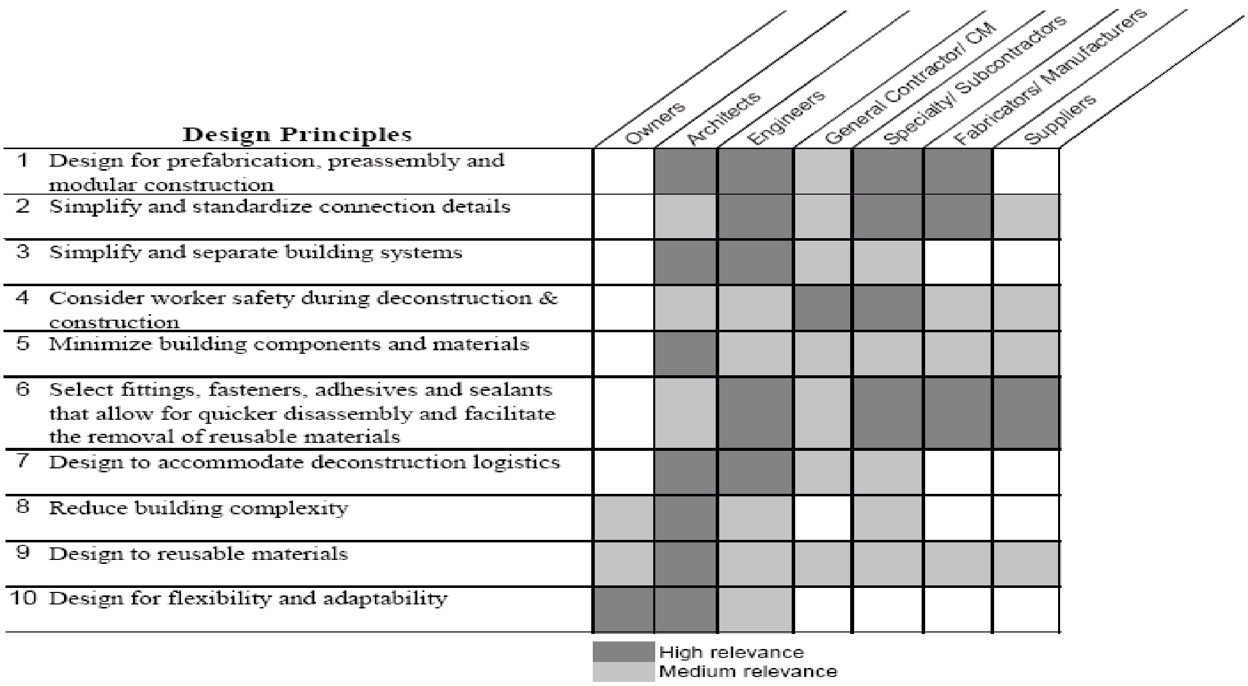


Figure 5-6. Application Matrix for Project Team Members [Adopted from Pulaski, M., Hweitt, C., Horman, M. & Guy, B. *Design for Deconstruction: Material Reuse and Constructability,* 2002]

	Design Principles	Program Development	Schematic Design	35% Design Development	70% Design Development	100% Design Development	Construction Documents	Construction
1	Design for prefabrication, preassembly and modular construction	Medium	High	Medium	Medium	Medium	Medium	
2	Simplify and standardize connection details			High	Medium	Medium	Medium	
3	Simplify and separate building systems	Medium	High	Medium				
4	Consider worker safety during deconstruction & construction			Medium	Medium	Medium	Medium	High
5	Minimize building components and materials	High	High	Medium	Medium	Medium	Medium	
6	Select fittings, fasteners, adhesives and sealants that allow for quicker disassembly and facilitate the removal of reusable materials				Medium	Medium	Medium	Medium
7	Design to accommodate deconstruction logistics	Medium	Medium	Medium	Medium			Medium
8	Reduce building complexity	High	High	Medium				
9	Design to reusable materials	Medium	Medium	High	Medium	Medium	Medium	
10	Design for flexibility and adaptability	High	High	Medium				

High relevance
Medium relevance

Figure 5-7. Application Matrix for Design Phases [Adopted from Pulaski, M., Hweitt, C., Horman, M. & Guy, B. *Design for Deconstruction: Material Reuse and Constructability*, 2002]

According to professional dismantler Daniel Costello, there are design practices that can greatly help facilitating the dismantling of a building while conserving the quality of the building materials [4]. Conversely, there are design practices that severely increase the difficulty to disassemble the building without damaging the building materials. Based on his experience in the dismantling business, Costello suggests the following:

- Keep building systems transparent, visible, and easy to identify
- Layout similar building systems and materials in regular and repeating patterns. Custom components usually have no use in any other buildings. An example would be the steel framing of the exterior envelope of the Bilbao Guggenheim Museum or the Stata Center at The Massachusetts Institute of Technology (MIT)
- Simplify building systems and interconnections and limit the number of different material types and component sizes. Complex building structures are usually hidden, different to understand, and challenging to deconstruct.

- Do not mix material grades. Materials with different properties have less value. According to Costello, “A building framed using multiple wood species or steel grades yields a potentially confusing array of materials that may not be as effectively reused as materials from a building constructed using a single material grade.” [4].

- Label different building materials. The identification of unlabeled materials is extremely difficult and may result in lumping better grades with lesser grades for simplicity purposes during the deconstruction process

General Design Concepts

Guy and Shell provide architects and engineers with the following list[1] of design concepts for facilitating deconstruction of buildings [44]:

- Compressed wheat-straw interior partition panels with integral paper facing are an example of self-supporting elements that can be disassembled as a unit and have the additional benefit of being a homogeneous and natural/recyclable material as a substitute for drywall and light wood 2”x 4” framing. Additional benefit of being a homogeneous and natural/recyclable material as a substitute for drywall and light wood 2”x 4”framing.

- Bolted roof trusses and offset tie-downs of roof to wall connectors that are attached at a point away from the actual point of contact of the roof structure to the wall. This would require an additional element such as a knee-brace to bridge between the two elements and increase the distance between the points of connection to roof and wall, but allows for ease of access to the connectors.

- Platform-type wall construction whereby the walls sit on top of the floor structure and does not extend through the horizontal plane of the floor structure and the floor above rests on top of the wall element. Separating the plane of the top and bottom of the wall from the plane of the floor structure facilitates mechanical separation and structural stability during the deconstruction process. Pre-cast concrete floor panels act in this manner.

- Light-weight materials, for instance, integral and modular elements, the combine finish, thermal and moisture protection, and structure, for roof structure, substructure and finishes to reduce the stresses on the lower portions of the building and reduce work at height and use of equipment. The impediments of height can be somewhat mitigated by integral worker stations and points of connection for equipment and handling. An example of this principle would be structurally insulated panels (SIP). Substituting a glued and heterogeneous SIP system for individual wood roofing members must be weighed against the potential for reuse and recycling of the panels.

---

[1] The list was adopted directly from **Bradly G. & Shell S.** *Design for Deconstruction and Material Reuse*, Proceedings of the CIB Task Group 39-Deconstruction Meeting, CIB Publication no. 272, 2002

- Simple consolidation of plumbing service points within a building has the benefit of reducing the length of lines, but also reduces the points of entanglement and conflict with other elements such as walls and ceilings/roofs.

- A separation of structure from enclosure will greatly facilitate adaptation and deconstruction, however it is important to remember regional climatic forces, whereby a building in a temperate climate will not be as penalized by a possible variety of enclosures and loose- fit as will a building in a high heating load climate.

- Hazardous materials such as asbestos and lead-based paint have been outlawed. The next generation of these materials will include fibrous insulations, chemical treatments for wood, and many other materials used as sealants, caulking, coatings, binders, and adhesives. All materials should be examined using a precautionary approach to eliminate possible toxicity or future regulatory constraints to their use and disposition.

- Nails and bolts have appropriate uses as per the type of connection and size of the members. A variety of nails in one building causes the requirement for multiple tools for removal. A mix of bolts, screws, nails requires constant shifting from one tool to the next. Fewer connectors and consolidation of the types and sizes of connectors will reduce the need for multiple tools and constant change from one tool to the next.

- Long spans and post and beam construction reduce interior structural elements and allow for structural stability when removing partitions and envelope elements.

- Doubling and tripling the functions that a component provides will help "dematerialize" the building in general and reduce the problem of layering of materials.

- Separating long-lived components from short-lived components will facilitate adaptation and reduce the complexity of deconstruction, whereby types of materials can be removed one at a time, facilitating the collection process for recycling.

- The requirement for access to connectors is a functional requirement that in turn dictates a building aesthetic. Access areas for maintenance are well-understood but little dealt with even in conventional design, due to the need to maximize habitable and income-producing square footage, and maintain a highly refined aesthetic. The design for deconstruction aesthetic is modeled in the "high-tech" architecture aesthetic.

- Elimination of caulking and sealants and high-tolerances in the connections can be offset by the ease of removing components for repair and replacement, and designing in durability, using mechanical instead of chemical-based water protection.

Webster and Costello write," Designing for deconstruction is an act of faith; faith that new materials will become scarcer and more expensive, faith that deconstruction will become commonplace, faith that the designed building will not be burnt to the ground by fire or flattened by a tornado. Who knows what the construction industry will be like in 50 or 100 years?" [4]. Nevertheless, the goal is to make designing for deconstruction mainstream and a trend in building design practices. One day, building owners who designed their buildings for deconstruction might look back with great appreciation towards architects and engineers who took the extra step beyond the conventional designs that usually end building lives as expensive liabilities, but instead employed design practices and building resources that facilitated the recovery of materials for profitable future reuse.

CHAPTER 6
RECOMMENDATIONS

Adding onto LEED-NC

Despite their major contributions to the environment from reducing pollution impacts to increasing resource and economic efficiency in the adaptation and eventual disassembly of buildings, designing for deconstruction and adaptive reuse are not currently offered as a multi-part credit or even a stand-alone credit in LEED-NC.

There are two major obstacles that stand in the way of making designing for deconstruction and adaptive reuse attainable credits in LEED-NC:

- Gaining the popular support to institute design for deconstruction and adaptive reuse as such attainable credits
- Finding a way to quantify design for deconstruction and adaptive reuse

Gaining popular support for designing for deconstruction and adaptive requires a new mind-set for designers, architects and even owners. It is a common practice in the construction industry not to pay much attention to the end-of-life, much less the after-life, in current building designs. Ultimately, the demand for including design for deconstruction and adaptive reuse as LEED-NC credits requires an infrastructure of contractors skilled in deconstructing and reconfiguring a building, competitive costs for deconstruction and recovered materials with other alternatives, and establishing a solid market for recovered materials. Therefore, design for deconstruction and adaptive reuse will be more successful in routine building development, such as low- to mid-rise commercial development and housing, which accounts for most construction. These buildings are the most likely to have regular and repeating floor plans, simple construction, and relatively short life-spans.

Even though certain aspects of design for deconstruction and adaptive reuse may be quantifiable, further discussions are needed as to whether the measures are sufficient to earn a

LEED-NC credit. Designing for deconstruction suggests the use of maximum amount of reusable, reprocessed, and recyclable materials while minimizing the building complexity. On the other hand, designing for adaptive reuse requires designing for flexibility of the majority of the building's components as and the interior non-structural elements.

Aesthetic conventions and economic factors that influence the building use and materials values over long periods of time are nearly impossible to predict. However, architects and engineers control the specific uses of materials in a building design, the connection between the individual materials and components, the inter-relationships between building elements, and the design of spaces as well as the whole-building structure. As a result, architects and engineers can make an educated estimate at the design stage that quantifies and models the efficiency performance after the reconfiguration of the building for a different use or the cost effectiveness of the building materials and components with the capacity for reuse, remanufacturing, and recycling at the end of the building's useful life.

New LEED-NC Credits.

Building elements are defined as major building parts e.g. roofs, vertical structures, walls, floors, or foundations. Building components are defined as the next level of non-structural building parts such as interior walls, doors, floor coverings and ceiling systems. Sub-components are a breakdown of components into their smaller pieces such as the duct systems of heating and cooling systems, the hardware for a door unit, or the sash of a window unit. Finally, materials are defined as the constituent materials from which all other elements, components, and sub-components are made, such as plastics, metals, wood, and masonry.

Deconstruction facilitates the salvaging process in order to reuse or recycle the reclaimed building components, sub-components, and materials, thus minimizing the need for virgin materials in subsequent projects. Adaptability maximizes the preserved building elements and components during a renovation project, thus exposes the building to minor structural changes and improves its operating performance.

Ultimately, the intent of the Materials and Resources category in the LEED-NC rating system is for architects, engineers and even owners to sustainably manage the lifecycle of the building's different materials, elements, and components. Sustainable management of all resource flows associated with a building should be addressed in the design, operation, renovation, and finally the deconstruction phase.

Therefore, the Materials & Resources (MR) category would appear to be the logical place to include points for deconstruction and adaptive reuse.

This study proposes two additional credits in the Material and Resources category that exclusively address design for adaptive reuse and design for deconstruction in LEED-NC, awarding a maximum of six points distributed equally among both categories towards a LEED-NC certification. The Materials and Resources category has seven existing LEED credits thus the proposed credits will be MR Credit 8 – Design for Deconstruction and MR Credit 9 – Design for Adaptive Reuse.

The proposed credits require designers, architects, and engineers to establish a plan that capitalizes on construction design practices that facilitate the deconstruction or the adaptability of a building and utilize the use of the hierarchy of the end-of-use options for buildings, elements, components, subcomponents, and materials respectively. Ideally, the design process should act as an independent level of information that specifies exactly what the types of materials and components are used in the construction process and adopt construction strategies that architects and engineers believe best facilitate the deconstruction and adaptability processes.

LEED-NC and Design for Deconstruction

According to the hierarchy of methods of material recovery, the architects and engineers should select construction materials depending on their economic and environmental benefits. The focus should be on maintaining the materials quality and value with time, thus reducing the embodied energy needed to reprocess new construction materials and minimizing the extraction of new and raw materials for new building.

Webster and Costello suggest that the proposed LEED credit should include a stand-alone credit for the design for reuse of building materials [4]. They recommend the credit uses a minimum percentage, by weight, of reusable building components as a base line to earn a point in the proposed credit. Structural engineers and building dismantlers strongly emphasize that future design for deconstruction credit should require the preparation of a deconstruction plan. Chris Morgan and Fionn Stevenson from the Scottish Ecological Design Association (SEDA) suggest that the design for deconstruction plan should include a statement of deconstruction strategies related to the building, a list of building elements and their expected service life and end-of-life options, and finally instructions on how to deconstruct the building elements [58].

This study recommends that the proposed Materials and Resources Credit 8 contains of a weight factor (W.F.) for each end-of use option, an achieved product (A.P.), the percentages of materials with the capacity for reuse, up-cycle, recycle, and down-cycle, and finally, the points associated with the total sum of the achieved products. The percentages of materials are based on the materials weight (in tons) in relation to the weight of the entire building. The achieved product is a result of multiplying the weight factor of each end-of-use option by the weight percentage of materials associated with that option.

This study strongly recommends that architects and engineers target a building design that contains a minimum of 10% by weight of the building materials with the capacity for salvaging and reuse, a minimum of 15% of the building materials with the possibility for up-cycling, a minimum of 20% of materials with the ability for re-cycling, and a minimum of 45% of materials with the potential for down-cycling at the end of the building's useful life. The intent of MR Credit 8 is ultimately to divert at least 90% or more of deconstruction materials based on total weight from disposal in landfills. The five end-of-use options for building materials and the weight factor associated with each option are illustrated in Table 6-1 below:

Table 6-1. End-of-Use Options and Their Weight Factors

End-Of-Use Option	Weight Factor (W.F.)
Reuse	8
Up-cycle	6
Re-cycle	4
Down-cycle	2
Landfill	0

The weight factors were chosen based on the environmental and economic benefits of the hierarchy of end-of-use options. The reuse of materials is ranked first among the end-of-use options thus earning the highest weight factor. Reuse allows the building materials to retain their current economic values, reduces significantly the embodied energy required to recycle, and minimizes the need to extract and mold virgin materials thus reducing carbon footprint and cutting into resource use.

Up-cycling is ranked second because it transforms disposable materials into new materials of greater use and economic value. Up-cycling reinvests in the environment via reduction of waste and minimizing the need for new materials. However, there are certain levels of environment impacts associated with the up-cycling process e.g. embodied energy. Also, there is a limited stream of construction materials that can under-take the up-cycling process and manage to increase in quality and economic value.

Re-cycling is ranked third. It is the process of sorting, cleansing, treating and reconstituting solid waste and other discarded materials for the purpose of using the altered form and retaining the materials economic value. Down-cycling is ranked fourth because of the materials' reduction in quality, viability, and economic value after undergoing the down-cycling process. It has high levels of environment impacts; however it has the widest range of available resources of construction materials. Finally, disposing the material in landfills is ranked last on the hierarchy of the end-of-use options because of its significant effects on the environment and no capital return. Table 6-2 below illustrates the amounts of LEED-NC obtainable points associated with the achieved product.

Table 6-2. Achieved Product and LEED-NC Points

Achieved Product (A.P.)	LEED Points
A.P. < 1.5	No points
1.5 ≤ A.P. < 2	1 point
2 ≤ A.P. < 2.5	2 points
2.5 ≤ A.P.	3 points

MR Credit 8: Design for Deconstruction

The following is a detailed description of what MR Credit 8 entails.

MR Credit 8: Design for Deconstruction

1 – 3 Points

Intent

Establish a sustainable deconstruction plan by employing design strategies that facilitate the ease of disassembly of buildings with the capacity for material reuse or recycling thus reducing the demand for raw materials, minimizing waste, and reducing environmental impacts resulting from the extraction and processing of new materials

Requirements

Maximize the achieved product (A.P.) via the ease of disassembly of different building systems, modular construction, minimizing materials use and selecting building materials with the capacity for subsequent reuse or the potential for recycling and reprocessing at the end of the building's useful life

Achieved Product (A.P.)	**LEED Points**
A.P. < 1.5	No points
1.5 ≤ A.P. < 2	1 point
2 ≤ A.P. < 2.5	2 points
2.5 ≤ A.P.	3 points

Potential Technologies and Strategies

Include components that are field connected using easily removable mechanical fasteners. Avoid using materials that are connected using field-installed adhesives or welds unless they may be easily removable to permit material reuse. Avoid nails by using screws and bolts especially in wood frame connections. Minimize the use of cast-in-place concrete and grouted, reinforced masonry and masonry laid in portland cement mortars.

SUBMITTALS

- Deconstruction Strategy Statements – details the anticipated disassembly process and includes a thorough description of the different strategies that architects and engineers devised to ease the disassembly of the material and the end of the building's life cycle.
- A list of Building's Elements, Components, and Materials – includes the specifications of the elements, components, and materials used in constructing the building in addition to their expected service life, weight, end of life options e.g. reuse, recycle, or landfill, and a recommended handling strategy when salvaged during the deconstruction process.
- A Set of the Deconstruction Blueprints and Drawings – for facilitating the deconstruction process by including all the design and specification information necessary. Information may include key structural properties, locations of wiring systems, and photographs of connections use in construction of the building and so on. Ideally the blueprints should be digital, made readily available, and kept up to date.

Calculations

$$\text{\% of materials recovered} = \frac{\text{Total weight of materials designed for recovery (tons)}}{\text{Total weight of the project (tons)}} \times 100\%$$

$$\% \text{ of materials reused} = \frac{\text{Total weight of materials designed for reuse (tons)}}{\text{Total weight of the project (tons)}} \text{x}100\%$$

$$\% \text{ of materials up-cycled} = \frac{\text{Total weight of materials designed for up-cycling (tons)}}{\text{Total weight of the project (tons)}} \text{x}100\%$$

$$\% \text{ of materials re-cycled} = \frac{\text{Total weight of materials designed for recycling (tons)}}{\text{Total weight of the project (tons)}} \text{x}100\%$$

$$\% \text{ of materials down-cycled} = \frac{\text{Total weight of materials designed for down-cycling (tons)}}{\text{Total weight of the project (tons)}} \text{x}100\%$$

$$\% \text{ of wasted materials} = \frac{\text{Total weight of materials ending up in a landfill (tons)}}{\text{Total weight of the project (tons)}} \text{x}100$$

CASE STUDY: The Three-Building Comparison

To better understand how MR Credit 8 is structured, three buildings, each with a different structural system, were analyzed [12].The first building, Global Ecology Research Center has a steel structural system. The second building, CSUMB Library, has a cast-in-place concrete structural system. The third building, Chartwell School, has a wood structural system. Refer to Figure 6-1 for pictures of the three buildings. The selected projects were all designed for deconstruction. They had readily available data and documentation which reflected their particular materials specifications and deconstruction strategies. The major materials in each project and their weights were identified using the project's documentations as a guide.

Figure 6-1. Ecology Research Center, CSUMB Library, and Chartwell School Respectively [Adopted from Shell, S., Gutierrez, O., & Fisher, L. *Design for Deconstruction The Chartwell School Case Study*, http://www.lifecyclebuilding.org/files/DFD.pdf, December 2006]

The Mechanical, electrical, and plumbing equipment, furniture, fixtures, and other materials that usually occur in smaller quantities were omitted from the analysis to keep the data gathering task manageable. The weights of the materials included were then graphed as a percentage of the total materials in each project to give a visual representation of the material breakdown (see Figure 6-2).

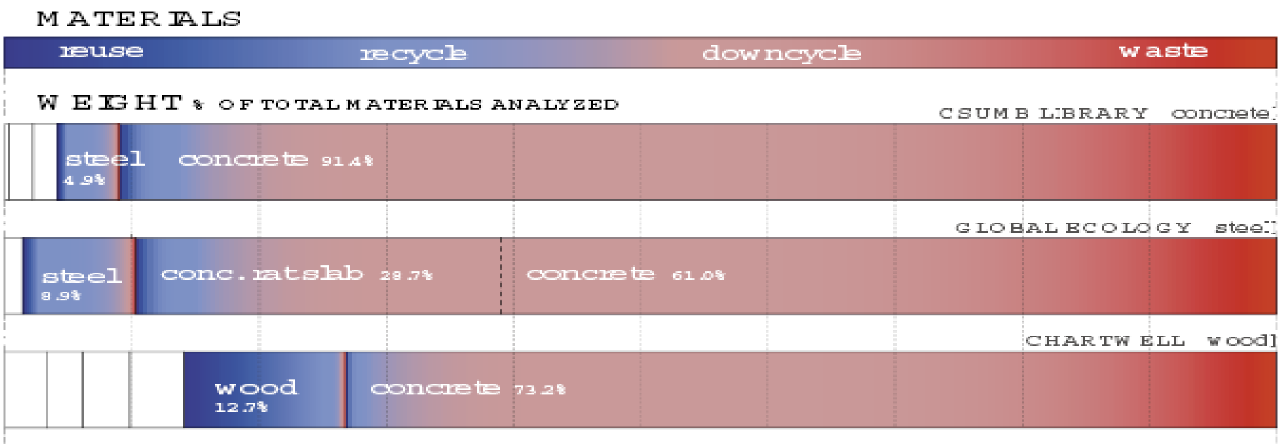


Figure 6-2. Weight of the Materials [Adopted from Shell, S., Gutierrez, O., & Fisher, L. *Design for Deconstruction The Chartwell School Case Study*, http://www.lifecyclebuilding.org/files/DFD.pdf, December 2006]

As indicated by the bar at the top of the graph in Figure 6-4, the gradation of colors indicates what weight percentage of these materials can be salvaged for reuse, recycle, down-cycle, or have no potential use at the end of the buildings' useful life thus is considered a waste and will potentially end up in a landfill.

The percentages were based on commonly proposed end-of-use options for different building materials. For example, cast-in-place concrete can usually be down-cycled by crushing it at the end of the building's useful life and reusing it as engineered fill, road base, and occasionally as aggregate for new concrete. Steel and wood on the other hand, can be mostly re-cycled but very little can be salvaged and reused in its existing form. Evidently, Concrete dominates the total materials used on the basis of weight.

Table 6-3 below illustrates the weight percentages of each of the major building materials in the three projects and their end-of-use option.

Table 6-3. Summary of Materials Recovered Weight Percentages

		Reuse	Up-cycle	Re-cycle	Down-cycle
Ecology Research Center	Steel	0.90%		7%	0.90%
	Concrete				45.75%
	Concrete slab	0.90%		6%	22.80%
	Wood				
CSUMB Library	Steel	0.90%		3%	0.90%
	Concrete	1.20%		6%	69%
	Concrete slab				
	Wood				
Chartwell School	Steel				
	Concrete			5.12%	57.10%
	Concrete slab				
	Wood	2.54%		10.03%	0.13%

Project 1 – Global Ecology Research Center - The building's designers were so confident with their results that they decided to abstain from a LEED-NC rating, as it would add to the cost of the development. Nevertheless, the building has performed so well, that it was named one of the top ten green buildings of the year 2007.

It is evident that this building satisfies multiple deconstruction design guidelines and strategies. The building designers addressed the life cycle of the different building materials in their design. For the purpose of this study, had the designers of the Global Ecology Research Center applied for a LEED-NC rating that adopts the proposed category for designing for deconstruction, the building would most likely have earned LEED points in MR Credit 8. Table 6-4 displays the results.

Table 6-4. MR Credit 8 Points for Global Ecology Research Center

	Percentages	W.F.	A.P.
Reuse	1.80%	8	0.144
Up-cycle	0%	6	0
Re-cycle	13%	4	0.52
Down-cycle	68.55%	2	1.371
Landfill	15%	0	0
		Total A.P.	2.035

Total LEED points earned in MR Credit 8:	**2**

Project 2 - CSUMB Library - The California State University Monetary Bay library is a $64 million, 136,000-sq-ft facility. According to Thomas Blessing, "If the university wants to pursue LEED certification, we could probably make at least silver based on our energy-efficiency elements. Just our under-floor air distribution system alone will surpass Title 25 requirements by 30%." [51].

Table 6-5 below suggests how many extra points the CSUMB library can potentially earn with the addition of the proposed MR Credit 8 to LEED-NC's current rating system.

Table 6-5. MR Credit 8 Points for CSUMB Library

	Percentages	W.F.	A.P.
Reuse	2.10%	8	0.168
Up-cycle	0%	6	0
Re-cycle	9%	4	0.36
Down-cycle	69.90%	2	1.38
Landfill	15%	0	0
		Total A.P.	1.908

Total LEED points earned in MR Credit 8:	**1**

Project 3 - Chartwell School - According to the US EPA, "One goal in designing for deconstruction is to reduce the lifecycle impacts of construction through materials reuse. Understanding the various material lifecycles is a helpful decision-making tool in this process, and one that was employed in the construction of the Chartwell School. The material lifecycles for all major components of the project were taken into consideration in the project's design. Project managers estimated the quantities of embodied carbon dioxide (CO2) emissions for many of the materials, considered the relative ease or difficulty of salvage, and explored the post-recovery value of that material. This analysis helped focus efforts toward wood structural and finish components, which have the greatest potential reuse value when balanced against their CO^2 footprints." [52]. Table 6-6 illustrates how the proposed LEED-NC MR Credit 8 can apply to the Chartwell School and the extra points that the design can potentially earn.

Table 6-6. MR Credit 8 Points for Chartwell School

	Percentages	W.F.	A.P.
Reuse	2.54%	8	0.2
Up-cycle	0%	6	0
Re-cycle	15%	4	0.6
Down-cycle	57.23%	2	1.14
Landfill	11%	0	0
		Total A.P.	1.94

Total LEED points earned in MR Credit 8:	**1**

LEED-NC and Design Adaptive Reuse

The first step in evaluating the adaptability in an architectural design is by determining whether the architects and engineers have made a mindful effort to incorporate as many adaptability principles and guidelines as possible in the design. As mentioned previously, the adaptability principles and guidelines are design strategies that address a building's ability to adapt to major reconfigurations and modifications while experiencing minor structural and infrastructural impacts.

In order for the project to earn the point associated with this credit, the recovery of a minimum of 75% to 95% of building elements and 50% of the interior non-structural components are recommended by this study. The preceding percentages are determined by the architects and engineers at the design stage based on the square footage of the components designed for retaining and the total square footage of the area containing those components. For instance, interior non-structural components reuse is determined by dividing the total proposed area (sq. ft.) of retained interior non-structural components by the total area (sq. ft.) of the entire interior, nonstructural components included in the completed design.

The same formula applies towards determining the percentages of the retained building elements. In short, architects and engineers should design a flexible building that has the ability to adapt more than 75% of its exterior shell and a minimum of 50% of its interior non-structural components during its life cycle to major renovations leading to a new building use with minor changes to the structural integrity of the building.

Also, the different adaptability design strategies that architects and engineers implement should be consistent with the American Society of Testing and Materials' guidelines provided in their E1692-95a, E1679-95, and E1334-95 international designation standard practice. Refer to Chapter 4 of this study for a list of some of the adaptability design practices recommended by the ASTM.

MR Credit 9: Design for Adaptive Reuse

The following is a detailed description of what MR Credit 9 entails.

MR Credit 9: Design for Adaptive Reuse

1 - 3 points

Intent

Coordinate designs for building interior modules and building structural system that permit reconfigurations of space layout increasing the longevity of buildings, improving its operating performance, and allowing for spatial flexibility for future reuse.

Requirements

MR Credit 9.1 – ADAPTIVE REUSE: Maintain 75% of Building elements

1 point

Design for maintaining 75% of building elements based on surface area such as existing walls, floors, and roofs in the structure and envelope

MR Credit 9.2 – ADAPTIVE REUSE: Maintain 95% of Building elements

1point

Design for maintaining an additional 20% (95% total based on surface area) of building elements such as existing walls, floors, and roofs in the structure and envelope.

MR Credit 9.3 – ADAPTIVE REUSE: Maintain 50% of Building's Interior

1 point

Design for reusing 50% based on surface area of the interior non-structural components of the building.

Potential Technologies and Strategies

Design the building for flexibility by choosing a structural system that allows spaces to be reconfigured such as simple consolidation of MEP service points within the building reducing the length of lines and the points of entanglement and conflict with other elements. Consider also designing access pathways for changes to building utilities and infrastructure. Adopt the "open-space" concept when designing offices with modular wall panel systems.

Submittals

At the design stage, submit:

- Reconfiguration strategy statements - Architects and engineers shall provide statements presenting detailed strategies as to how and to what extend the building's structural and spatial adaptability is provided.

- A list of building’s elements, components, and materials - includes the specifications of the elements, components, and materials used in constructing the building in addition to their expected service life and a proposed handling strategy during the building’s rehabilitation process.

- A set of the reconfiguration blueprints and drawings – Architects and engineers shall include building plans and detailed specifications. The blueprints and drawings shall elaborate specific design strategies justifying the intended outcome. Ideally the blueprints should be digital, made readily available, and kept up to date.

Calculations

% of interior components designed for adaptive reuse =

$$\frac{\text{Area of interior components designed for adaptive reuse (sf)}}{\text{Total area of interior components (sf)}} \times 100\%$$

% of structural envelope designed for adaptive reuse =

$$\frac{\text{Area of structural envelope designed for adaptive reuse (sf)}}{\text{Total area of structural envelope (sf)}} \times 100\%$$

Reference Standard

- ASTM International Designation E1692-95a Stand   ard Classification for Serviceability of an Office for Change and Churn by Occupants

- ASTM International Designation E1679-95 Standard Practice for Setting the Requirements for the Serviceability of a Building or Building-Related Facility

- ASTM International Designation E1334-95 Standard Practice for Setting the Requirements for the Serviceability of a Building or Building-Related Facility

Information Documentation

General Problem

One of the predicaments for designing for deconstruction and designing for adaptive reuse is the documentation of information. There is no way of knowing what the future of the buildings that are currently being designed might be. Architects, engineers, and even owners can not predict whether the building will have one life cycle, multiple lifecycles, or when a complete dismantling of the structure will be required decades from now.

The building can be designed in a way that facilitates its future needs from renovation, reconfiguration, or even complete deconstruction and recovery of its materials. However, conveying the design information to be retrieved in the future is one of the key challenges that render to the success of designing for deconstruction and adaptive reuse. Future structural engineers and dismantlers need to know the detailed specifications of the building's design.

Ideally, after the building is constructed, the owner receives a conformed set of the building's architectural drawings. The problem is that over the building's lifecycle, it is highly likely to go through renovations, repair, and additions. Therefore, the architectural drawings that the owner receives will be referenced on more than one occasion which exposes them to levels of damage or they might even just get lost in the shuffle.

Even though architectural firm usually keep records of the designs they make in their office or other storage areas, a lot of these firms do not last as long as the buildings they design. As a result, future building owners might not even know who the architect that designed the building was. In addition to that, every renovation or addition to the building must also be documented for future use and that causes fluctuations in the quality, consistency, and thoroughness of these records. So the main question remains: How can we retain all this information in a form that is accessible decades from now?

BIM and LEED-NC Documentation

A solution proposed by this study is to institute a standard digital library such as Building Information Modeling (BIM) and REVIT Architecture, where all the designs can be stored, maintained, updated, and made accessible. USGBC requires many projects pursuing a LEED-NC certification to submit architectural drawings to support their credit qualification. Also, many LEED-NC points require calculating areas, volumes, or costs of buildings assemblies or materials for credit. Based on the proposed MR Credits 8 and 9, obtaining the LEED-NC points for those credits require calculating areas, weight, and percentages of materials with the capacity for recovery. It also requires categorizing different building materials based on their capacity for different end-of-use options, and finally demonstrating that the project incorporates the required percentages of materials and components with the ability for reuse, up-cycle, re-cycle, and down-cycle. .

According to AUTODESK, “A LEED requirement documented in REVIT building information model is far less likely to fall out of synch or be overlooked (and inadvertently violated) during project design than a requirement documented in a conventional CAD or object-CAD based application.” [59].

This study suggests that different information related to the deconstruction or reconfiguration of the building should be embedded directly in a schedule in the building information model. It should be maintained and updated dynamically with any new decisions as the project progresses through the design and the construction phases. That schedule should include:

- Different materials quantities and weights,
- End-of use options for these materials,
- The surface area of different structural elements and non-structural components,
- Percentages of the materials, components, and elements based on weight or area,
- Suggested deconstruction and disassembly strategies associated with the different materials, components, and elements

In conclusion, when a building needs to be demolished or renovated decades from now, parameters such as material quantities, weights, areas, end-of-use options and so on need to be retrieved easily and accurately. Building Information Modeling (BIM) and REVIT Architecture are excellent tools that help in the preservation of architectural and structural building information. Its proven ability to deliver cost-effective sustainable designs gives the firms the assurance they need to pursue an aggressive LEED-NC ranking for their projects and market their sustainable services competitively [59].

CHAPTER 7
CONCLUSION

The planet earth is home to about 6.76 billion human beings today. In the next thirty years, that number is expected to rise to reach about 9 billion human beings in the year 2040. Each new born will require his share of food, water, and shelter throughout his life time. This in return will only mean much more human congestions and increasing rates of consumption of the planet's natural resources to meet the needs and demands of the growing footprint of the global population. All of that creates much greater strains on the planet's capacity to absorb waste and generate natural resources.

The United States is home to 5% of the earth's population. However, it is a source for 30% of the population's waste. The average American creates 4.5 pounds of garbage a day. That amount has doubled from 30 years ago and is expected to rise in the future. The average house size in the U.S. has doubled since the 1970's and with that, the building material consumption and waste rates have also increased. The trend in the construction industry today is to focus on the building's lifecycle from the design, construction, renovation, to the demolition stage. When the building reaches the end of its useful life, it is completely and partially demolished. A miniature percentage of the demolition debris is recycled. However, the overwhelming percentage of the demolition waste ends up in a landfill.

To demolish the building and landfill the waste is considered a simple, and in some cases a cheap, end-of-use option. Therefore, the construction industry has not been interested in investing time and money on employing design practices that yield a different alternative at the end of the building's life. Nevertheless, the damage that current construction and demolition practices are inflicting on the environment has become unacceptable. The environmental degradation, natural resources depletion, and waste quantities have reached alarming levels. The extended chain of responsibility and the separation of responsibilities for manufacturing materials, design, construction, operation, maintenance, and eventual adaptation or disposal, have resulted in a breakdown of feedback loops among the parties involved in creating and operating the built environment [6]. As a result, current economic and environmental realities dictate minimizing the amount of building waste materials that end up in landfills thus significantly reducing and ultimately eliminating the need to have landfills. Instead, buildings should be preserved, renovated, or reused. And if none of these options is feasible, then building materials should be recovered for reuse or recycling.

The attention in the construction industry has recently shifted to focusing on finding design solutions that facilitate the reuse of a building or the salvaging of its materials. The fate of the building or its materials should not be addressed at the end of the building's useful life. Their fate should be thoroughly thought of during the designs stage. Designing for adaptive reuse or deconstruction are two design concepts that target the building's after-life. When designing a building for deconstruction or adaptive reuse, architects and engineers, even owners and investors, are taking the ecologically cautious approach. Designing for adaptive reuse allows the building to have multiple uses and to accommodate different occupants' needs, without affecting its structural integrity or presenting the need for demolition and new construction. Designing for deconstruction preserves the building materials quality during the disassembly process and enables their extraction for reuse or recycle.

Aside from their environmental advantages, designing for adaptive reuse and deconstruction add short term economic and possibly environmental costs to the project, but on a bigger scale of the lifecycle of the project, the long term benefits of utilizing those two concepts outweigh any initial costs.

The USGBC should recognize the magnitude of these outcomes and capitalize on them by offering two separate credits, for a total of six points, for designing for adaptive reuse and deconstruction in the Material and Resources category in its LEED-NC assessment system.

The future of this planet will certainly be different. It is up to its inhabitants to decide whether the planet can survive their growing needs or whether the human race will be the reason for its own self-destruction. The current depletion rate of the natural resources will certainly change in the future. That is not because the human needs for resources decreased, or that the people decided to behave differently. The reason will be that the planet is no longer capable of generating enough resources to accommodate the human demands and thus there will be less and less resources to harvest. The construction industry and its consumption and disposal rates will certainly play a role in deciding the fate of the planet and ultimately the human beings. Designing for adaptive reuse and deconstruction might not be the solution that will save the earth. However, they are definitely a step forward in the right direction and therefore are well worth exploring, recognizing, and rewarding.

APPENDIX
GREEN BUILDING ASSESMENT SYSTEMS

BREEAM (United Kingdom)

Building Research Establishment Environmental Assessment Method **(**BREEM) is considered the oldest building assessment and was easily the most successful until the advent of LEED. It was established by the Building Research Establishment (BRE) in the United Kingdom in 1988. BREEAM is also used in Canada and several European and Asian countries.

The original purpose for BREEAM was to help transform the construction of office buildings into high performance standards. BREEAM covers mainly offices, homes, and industrial units. It contains different assessment methods for each type of buildings:

- BREEAM Office version 2002
- BREEAM /New Industrial Units
- BREEAM EcoHomes
- BREEAM Retail version 2003

The BREEAM credits are awarded according to the building performance. BREEAM provides an overall score that is computed by adding together the credits for the different environmental weightings. The BREEAM rating is scaled between Pass, Good, Very Good, or Excellent. BREEAM assesses the performance of the building in the following areas [24]:

- Management
- Energy Use
- Health and Well-Being
- Pollution
- Transport
- Land Use
- Ecology
- Materials
- Water

CASBEE (Japan)

Comprehensive Assessment System for Building Environmental Efficiency (CASBEE) is a building assessment system designed specifically for Japan and the Japanese culture, social, and political conditions. CASBEE consists of multiple assessment tools for the different phases of the building being evaluated from the planning phase, design, completion, operation, to the renovation phase [24]:

- Tool-0 Pre-design Assessment Tool – For use by owners and planners to identify the project context, select the proper site, and determine the basic impact of the project
- Tool-1 Design for the environment Tool – A simple check system for designers and engineers to use during the design phase
- Tool-2 Eco-Labeling Tool – Use to rate the building after construction and to determine the basic property of the labeled building in the property market
- Tool-3 Sustainable Operation and Renovation Tool – Contains information for owners and managers on improving their building's performance during its operation

CASBEE is based on Building Environmental Efficiency (BEE) which is an attempt to describe the eco-efficiency of a building [24]. Eco-efficiency, according to the World Business Council on Sustainable Development (WBCSD), is maximizing the economic value while minimizing the environmental impacts.

The BEE rating is a number ranging from 0.5 to 3 corresponding to the building's class. The class of the building ranges from class S (highest for BEE of 3.0 or higher), class A (BEE of 1.5 to 3.0), B+ (BEE of 1.0 to 1.5), B- (BEE of 0.5 to 1.0) to C (BEE less that 0.5).

GREEN STAR (Australia)

Green Star was developed in Australia to target offices and office buildings in the Australian building market. It includes different rating tools for different building cycles e.g. design, construction, interiors, and operation. Green Star targets a variety of building classes from offices, retail stores, industrial, residential, etc. Green Star is built on existing building assessment system such as the British BREEAM system and The U.S. LEED system. Nevertheless, Green Star has established environmental measurement criteria with specific relevance to the Australian marketplace environment. Green Star Office Design version 1.0 covers the following categories [24]:

- Management (12 points)
- Indoor environmental quality (27 points)
- Energy (24 points)
- Transportation (11 points)
- Water (12 points)
- Materials (20 points)
- Land use and ecology (8 points)
- Emissions (13 points)
- Innovation (5 points)

There are a maximum of 132 points achievable for Green Star Office Design. The assessment system awards a certain number of *stars* that indicate the level of building performance. Six stars is the highest rating level where it recognizes and reward international leadership. Five stars recognize and reward Australian leadership. Finally, four stars indicate best practices in environmental leadership.

LIST OF REFERENCES

1 **Caldicott, H.** *If You Love this Planet: A Plan to Heal the Earth.*, New York, 1992

2 **Balachandran, S.** *Anticipating and responding to deconstruction through building design*, 2002

3 **Chiras, D.** *Lessons from Nature: Learning to Live Sustainably on the Earth. Washington, DC: Island Press*, 1992

4 **Webster, M. & Costello, D.** *Designing Structural Systems for Deconstruction: How to Extend a New Building's Useful Life and Prevent it from Going to Waste When the End Finally Comes,* Greenbuild Conference, Atlanta, GA, 2005

5 **Frisman, P.** Building Deconstruction, R-0911, 2004

6 Annex 31. Energy-Related Environmental Impact of Buildings, *Assessing the Adaptability of Buildings. International Energy Agency*, November 2001

7 **Kibert, C.** *Sustainable Construction: Green Building Design and Delivery*, 2nd edition, 2008, page 258

8 **STURGES J. L.** *Construction Materials Selection and Sustainability,* Leeds Metropolitan University, UK, http://buildnet.csir.co.za/cdcproc/docs/1st/sturges_jl1.pdf, June 2002

9 **Repa, E.W**. *NSWMA's 2005 Tip Fee Survey, http://wastec.isproductions.net/webmodules/webarticles/articlefiles/46Tipping%20Fee%20Bulletin%202005.pdf*, 2005

10 **Lazarus, N.** Construction Energy Materials Report: Toolkit for Carbon Neutral Developments – Part 1 http://www.bioregional.com/Materials%20report%20web%20cut%20final%20draft.pdf, February 2003

11 **Lazarus, N.** *Potential for Reducing the Environmental Impact of Construction Materials*, 2005

12 Shell, S., Gutierrez, O., & Fisher, L. *Design for Deconstruction The Chartwell School Case Study*, http://www.lifecyclebuilding.org/files/DFD.pdf, December 2006

13 **Crowther, P.** *Design for Disassembly: An Architectural Strategy for Sustainability*, 2002

14 **Macozma, D.** *Understanding the Concept of Flexibility in Design for Deconstruction*, CIB Publication no. 272, Germany, 2002

15 **Chini, A. R.** *General Issues of Construction Materials Recycling in the USA*, 2007

16 **McDonough W. & Braungart M**. *Cradle to Cradle: Remaking the Way We Make Things*, 2002

17 U.S. Green Building Council, An Introduction to the U.S. Green Building Council and the LEED Green Building Rating System, Copyright 2005 http://*greencampus.sxu.edu/ppt/intro_building_council.ppt* , October 2005

18 CMRA Master Specification for C&D Recycling, *Construction and Demolition Materials Recycling Requirements,* www.ciwmb.ca.gov/conDemo/specs/01151.doc, 2004

19 **Kibert, C.** *Sustainable Construction: Green Building Design and Delivery*, 2nd edition, 2008, p. 247

20 **Podkul, C**. Green Globes certification rises as alternative to LEED, *http://www.bizjournals.com/philadelphia/stories/2007/08/20/focus5.html*, August 2007

21 **Schendler, A. & Udall, R.** *LEED is Broken; Let's Fix It*, 2005

22 U.S. EPA Office of Air and Radiation, *Report to Congress on Indoor Air Quality, Volume II: Assessment and Control of Indoor Air Pollution,* 1989

23 **Katz, A**. National Studies Show Green Building as Key Part of America's Economic Future *Green Building Creates Green Jobs that Save Energy and Money, http://www.usgbc.org/Docs/News/National%20Studies%20Show%20Green%20Building%20as%20Key%20Part%20of%20America%20(2).pdf*, January 2009

24 **Kibert, C.** *Sustainable Construction: Green Building Design and Delivery*, 2nd edition, 2008, pp. 55-77

25 McGraw-Hill Construction, Greening of Corporate America, *SmartMarket Report*, 2007

26 **Kibert, C.** *Sustainable Construction: Green Building Design and Delivery*, 2nd edition, 2008, p. 58

27 Lifecycle Building Challenge, *TriPod: A Plug and Play Housing System*, *http://judging.lifecyclebuilding.org/entries/view/63*, 2008

28 **Smith, T.M., Fischlein, M., Suh, S. & Huelman, P.** *Green Building Rating Systems*: *A Comparison of the LEED AND Green Globes Systems in the US*, September 2006

29 **Davidson, N., Gibb, A.G., Austin, S.A., Goodier, C.I. & Warner, P.** *The Multispace Adaptable Building Concept and its Extension into Mass Customisation,* July 2006

30 The Sustainable Property Appraisal Project, *The Sustainability Factors http://www.sustainableproperty.ac.uk/sustainability-factors.htm*, October 2004

31 **Stella M. C.** *The Adaptive Reuse of Buildings: Remembrance or Oblivion*. http://www.international.icomos.org/victoriafalls2003/papers/B1-2%20 %20Casal%20%2B%20photos.pdf, November 2004

32 **Grammenous F. & Russel P**. *CMHC Building Adaptability: A View from the Future, 1997*

33 CIB International Conference, *Smart and Sustainable Built Environments*, http://www.chalmers.se/arch/SV/aktuellt/kalendarium/from-problem-to promise/downloadFile/attachment/SASBE2009_folder.pdf?nocache=1208413613.09, 2009

34 Existing Site Structures (DRAFT), *Sustainable Design Guidelines Reference Manual*, WTC Redevelopment Projects, SEQ-7, March 2004

35 **Bullen, P. A.** *Adaptive reuse & sustainability of commercial buildings*, Facilities 25(1/2):20-31, 2007

36 **Larrson, N. K**. *Sustainable Development and Open Building*, Presentation to CIB TG26, Brighton, UK, 1999

37 Environmental Research Group, School of Architecture, UBC, *Life Cycle Energy Use in Office Buildings*, 1994

38 M. Gordon Engineering, *Demolition Energy Analysis of Office Building Structural Systems*, 1997

39 **Wilkinson, S. & Reed, R.** *The Business Case for Incorporating Sustainability in Office Buildings: The Adaptive Reuse of Existing Buildings*, 14th Annual Pacific Real Estate Conference, Malaysia, 2008

40 **Ball, R. M.** *Re use potential and vacant industrial premises: revisiting the regeneration issue in Stoke on Trent*, Journal of Property Research 19(2): 93-110, 2002

41 **Pokrant, G.** *The Profit Statement*, Reznick Group, Spring 2006

42 Brand S., *How Buildings Learn: What Happens After They're Built*, 1994

43 **Duffy F. & Henney, A.** *The Changing City*, Bulstrode Press, London, 1989

44 **Bradly G. & Shell S.** *Design for Deconstruction and Material Reuse*, Proceedings of the CIB Task Group 39-Deconstruction Meeting, CIB Publication no. 272, 2002

45 **Simonson, K**. *Changes in Construction Materials Prices, 2001-2007*, http://www.transportation.org/meetings/2007washbrief/Changes%20in%20Construction%20 Materials%20Prices%202001-2007.pdf, March 2007

46 **Chini, A. R.** *Barriers to Deconstruction and Materials Reuse*,2003

47 **Grothe, M. & Neun, D.**, *A Report on the Feasibility of Construction: An Investigation of Deconstruction Activity in Four Cities*, http://www.huduser.org/Publications/PDF/deconstruct.pdf, 2002

48 **Pulaski, M., Hweitt, C., Horman, M. & Guy, B.** *Design for Deconstruction: Material Reuse and Constructability,* 2002

49 CDM, *Demolition Waste Management Plan Specification: Guide for Engineers*, 2004

50 **Mathews, K**. *Renzo Piano***,** http://www.greatbuildings.com/architects/Renzo_Piano.html, 2008

51 **Carlsen, R**. *California Construction: New library at CSUMB fills crucial need,* http://california.construction.com/features/archive/0708_feature4.asp, *August 2007*

52 The United States Environmental Protection Agency, *Lifecycle Construction Resource Guide*, http://www.lifecyclebuilding.org/files/Lifecycle%20Construction%20Resource%20Guide.pdf, March 2008

53 ASTM International. Designation E1692-95a Standard Classification for Serviceability of an Office for Change and Churn by Occupants, 2005

54 ASTM International. Designation E1679-95 Standard Practice for Setting the Requirements for the Serviceability of a Building or Building-Related Facility, 2005

55 ASTM International. Designation E1334-95 Standard Practice for Rating the Serviceability of a Building or Building-Related Facility, 2005

56 **Arge, K.** *Adaptable Office Buildings: theory and practice*, 2005, pp. 119-127

57 Energy Information Administration, *Commercial Building Energy Consumption Survey,* 1999

58 **Morgan, C. & Stevenson, F.** *Design for Deconstruction: SEDA Design Guidelines for Scotland* No 1, http://www.seda2.org/dfd/dfd.pdf, 2005

59 United States Green Building Council, *Building Momentum, National Trends and Prospects for High-Performance Green Buildings*, April 2002

60 **Coto, J.T**. *Building Systems Commissioning*, www.sustainablemri.com/ppt/**LEED**%20NC%20v2.2%20-%20Jorge%20-%20MBO%20-%20SMRI.ppt, 2002

61 Green Building Initiative, *Green Globes Rating / Certification: Recognize and Market Achievements in Environmental Sustainability*, http://www.thegbi.org/green-globes-tools/ratings-and-certifications.asp, 2009

BIOGRAPHICAL SKETCH

Tarek M. Saleh was born on November 11^{th}, 1983 in Saida, the southern capital of Lebanon. He has attended the National Evangelical Institute for Girls and Boys, one of the most prestigious schools in southern Lebanon. Upon finishing his high school studies, Mr. Saleh moved to the United States to start his college education. He completed his Bachelor of Science in electrical engineering at the University of Florida in the spring of 2007. Afterwards, he took the next career building step by getting accepted to the M.E. Sr. School of Building Construction graduate program at the University of Florida where he earned a Master of Science in building construction in the spring of 2009.