A DECISION PROCESS MODEL FOR CLOSING THE STRUCTURAL STEEL MATERIALS LOOP IN CONSTRUCTION

By

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To my lovely wife Anita, who is a constant source of inspiration, support, love, and also to my wonderful children Nicole, Jason, Jamie, Julie, Lindsay, and Sam who have always supported me in my academic endeavors

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KEY TO ABBREVIATIONS

AEC	Architectural, Engineering, and Construction
AIA	American Institute of Architects
AISC	American Institute of Steel Construction
ASTM	American Society for Testing Materials
C&D	Construction and Demolition
CM	Construction manager
D_fD	Design for Deconstruction
E_c	Extraction Cost
E_e	Embodied Energy
EOR	Engineer of Record
EPA	Environmental Performance Assessment
G_j	Giga Joule
IBC	International Building Code
LCA	Life Cycle Analysis
LEED®	Leadership in Environmental and Energy Design
M_c	Manufacturing Cost
M_j	Mega Joule
NDT	Non-destructive testing
USGBC	United States Green Building Council

Abstract of Dissertation Presented to the Graduate School
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Requirements for the Degree of Doctor of Philosophy

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By

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When a structure is slated for demolition, there is a significant opportunity to maximize reuse of existing materials by deconstructing rather than demolishing the building. Because deconstruction is time intensive and time is money in construction, project stakeholders choose demolition over deconstruction and send construction and demolition (C&D) materials to a landfill. C&D waste can make up a large portion of the materials handled on a typical construction project. Project stakeholders overlook the potential of reusing these materials in a new facility, capturing and preserving the embodied energy invested in these materials.

At best, designers and constructors reuse a very narrow range of materials, "low hanging fruit," so to speak, such as concrete, wood, and masonry. This approach ignores the true tenets of sustainability. When C&D materials are not recycled and introduced back into the material supply chain, new resources must be mined, processed and manufactured and their embodied energy is lost and must be made up somewhere along the line contributing to the further depletion of the earths' non-renewable resources. Increased efforts in the sustainable reuse of

building materials will lead to substantive and tangible results such as reduction in environmental damage, reduction in greenhouse gases, conservation of landfill space, reduced demand for new materials, and decreased raw materials' mining.

Structural steel, a significant component in most building projects, has enormous potential for reuse in future building projects. Testing and recertification of steel members to ensure they meet the performance characteristic requirements is achievable with applications of specific testing measures available in academia and/or independent testing labs. Structural steel components recovered for reuse have enormous potential in the construction materials marketplace and the material supply stream without causing further damage to the environment through various reproduction processes.

CHAPTER 1
INTRODUCTION

Introduction

Expansion and development of the built environment is the foremost cause of depletion of our non-renewable natural resources. As a compromise we must continue to develop new ways to reuse materials consumed in the construction process or risk, at some point, an austere reduction in the availability of resources for use in the building industry. Exploitation of resources at the current rate of consumption, if un-checked, will jeopardize the ability of future generations to enjoy the same access we have enjoyed throughout history. The consumption tempo we are accustomed to is in direct opposition to one of the foundational concepts of sustainability; ‘responsible stewardship of our natural resources’. The Brundtland Commission Report of 1987 states the definition of sustainability as "meeting the needs of the present without compromising the ability of future generations to meet their own needs." Recycling of recovered steel components, the most common and accepted process to supply the structural steel demand in the construction industry is an appropriate start to a sustainable approach but reuse of structural steel will take us closer to a more sustainable result. Historically, the majority of the approaches to sustainability regarding how we view materials use have been in the realm of recycling, not reuse as illustrated in Figure 1-1. For the most part reuse of construction materials recovered from existing structures is a new concept with many inhibitors to its advancement. This is even truer with the idea of reusing structural steel components reclaimed from buildings being demolished. The purpose of this research project is to develop a systematic decision process model which will assist and enable construction industry professionals and owners in moving toward a more sustainable approach of materials consumption of structural steel reuse.

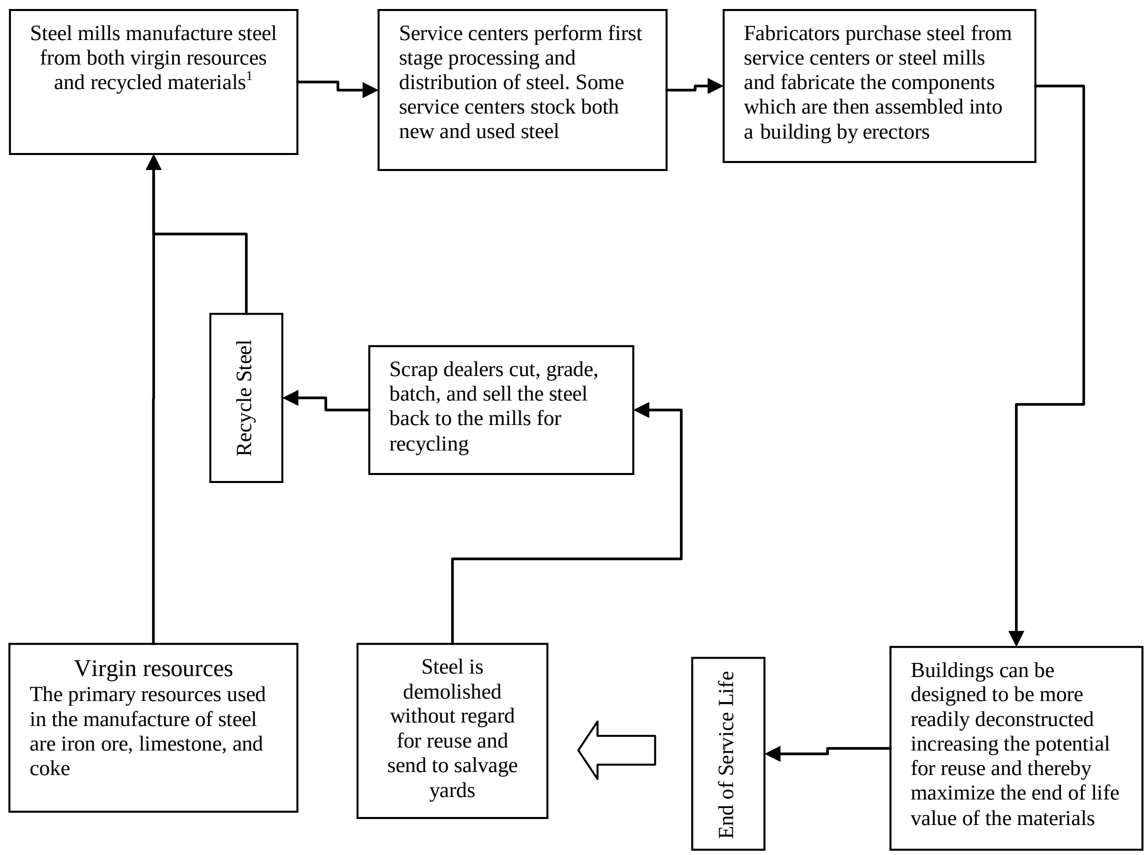


Figure 1-1. Current steel use process for construction

Although recycling does positively contribute to lessen the impact on the environment and does produce many tangible benefits for our society, its impact is not as far-reaching as the premise of reusing materials or products in their reclaimed or extracted state. Since buildings have a profound impact on our natural environment, materials reuse is the next logical step within the sustainable materials reuse hierarchy process to positively impact the detrimental effect that contemporary structures has on our resource consumption. Figure 1-2 illustrates the impacts of how we conceive use of materials in the sustainability hierarchy and the key correlation between economic benefits and sustainability benefits. Within this accepted hierarchy it is clear that reuse of structural steel components is more beneficial to society and the built environment than recycling or other forms of secondary use.

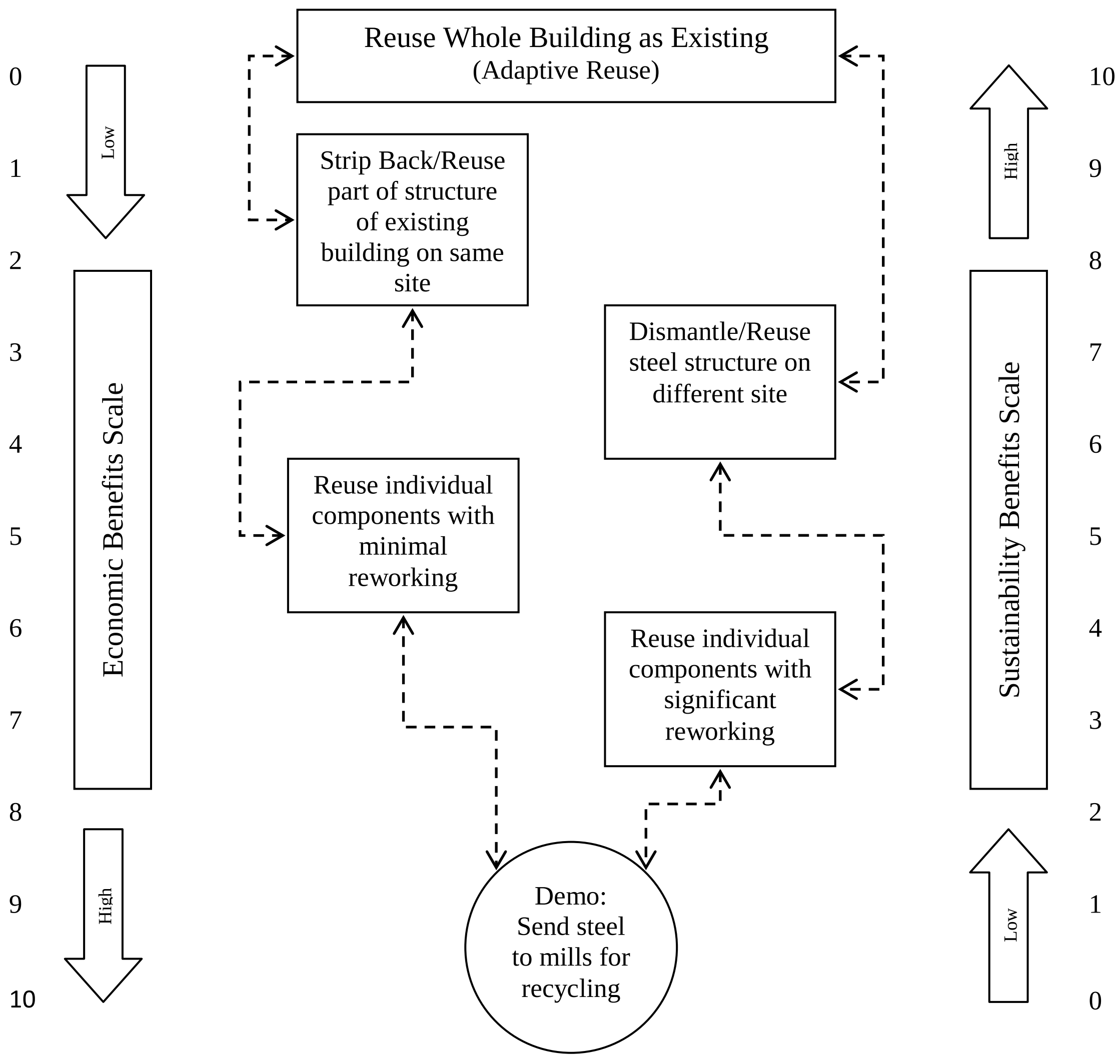


Figure 1-2. Sustainable steel reuse hierarchy

As Figure 1-2 illustrates there are varying levels of structural steel materials reuse that have either high economic and low sustainable benefits or high sustainability and low economic benefits; with other initiatives falling within those two extremes. In terms of the most impactive sustainability benefit, reuse of entire building (otherwise known as adaptive reuse) containing structural steel ascends to the top of hierarchy. The significant drawback is the economic benefit is substantially low due to very few changes to the structural system. Conversely, demolishing the structure and sending the steel into the recycling process produces the highest economic benefits but due to the increases in energy use and consumption along with negative impacts to the environment it contains the lowest sustainability benefits. Between these two extremes are viable and positive choices that have been implemented; (1) strip back and reuse part of existing building at the same location, (2) dismantle/reuse steel structure on different site, (3) dismantle/reuse steel structure on different site, (4) reuse individual components with minimal reworking, and (5) reuse individual components with significant reworking. Each of these five choices must be evaluated by the project team within the context of not only a cost/benefit analysis but also sustainability objectives. The challenge to the operators and builders of the built environment is to find the correct balance within the sustainable materials reuse hierarchy between economic and sustainable benefits.

Both material recycling and more importantly material reuse are part of a larger initiative known as *sustainability* or *sustainable construction*. This recent approach to expansion of the built environment has created a sensitivity and awareness of the affects our resource consumption is having on our natural systems and takes into account how present materials consumption will have on future generations in their ability to expand their built environment.

Building demolition and deconstruction, an intrinsic component of the expansion of the built environment, has been historically approached as *'getting rid of the old structure as quickly as possible to make room for the new'*. Until recently, this demolition and deconstruction process did not include, as part of its specific steps, measures to assure reuse of as many existing materials as possible. To date, the approach to material reuse has been one of *'picking the low-hanging fruit'* and not challenging ourselves to find ways to reuse the more complex materials and products.

The preponderance of materials we employ in new structures contain some potential reuse benefits as well as some level of embodied energy (E_e). Embodied energy is a well-defined and accepted way to measure the impact of materials commonly used in the construction process. Most of the efforts to date have focused on capturing embodied energies thru recycling initiatives. Traditionally not much has been done with material reuse within the context of structural steel components.

Embodied energy (discussed in detail in Chapter Two) is defined as the energy consumed by all of the processes associated with the production of a building, from the acquisition of natural resources to product delivery to building decommissioning, i.e. cradle-to-grave (Elliot, 1997). This method of energy use assessment can be looked on as an objective way of analyzing the impact of materials use across the entire supply chain spectrum. Reused structural steel has significantly less embodied energy for a building material as compared to recycled steel (Chapter 2 further elaborates on the total E_e). This assessment includes the mining and manufacturing of materials and equipment, the transport of the materials, and the administrative functions necessary to support their use.

The importance of embodied energy and other environmental impacts does not become apparent until we examine the materials from a life cycle approach, usually known in the building industry as Life Cycle Assessment or LCA (Kibert, 2008). This unique approach, regarding how various products and materials affect our natural systems, could become the relevant and accepted standard procedure in the analysis and coordination of a building scheduled to be demolished or deconstructed. This research project will focus on structural steel components and how they might best be reused in the construction of new facilities within the built environment.

Recycled materials make up approximately 97% (SRI, 2008) of the structural steel used today in the construction industry. This recycling initiative has drastically reduced the impact of natural resource extraction but still consumes significantly more embodied energy than reuse of structural steel components. Structural steel reclamation and reuse is an alternate path toward achieving a higher level of sustainability in the construction process. Stakeholders from all elements of the design and construction process must contribute various levels of expertise and knowledge to find new and more efficient ways to extract and reuse structural steel components. This will take a coordinated and sustained effort from a wide range of disciplines and constituencies: architects who provide the overall design criteria; engineers who design the specific systems and specify the materials; owners who finance the projects; contractors who manage the construction process and build the facility; municipalities who review and approve each project; suppliers and vendors who provide the materials and products necessary; sub-contractors who provide specialized skills; and society as a whole who will provide the push and demand more accountability in the reuse of construction materials.

Contribution

This research project identifies, develops, and advocates a cost-effective and comprehensive methodology to identify, extract, and reuse structural steel components from buildings scheduled for demolition or deconstruction. The main components of this project more clearly define than has been in the past, the processes and procedures that will enable those responsible for expansion of the built environment to significantly increase material reuse in lieu of recycling; specifically in the area of structural steel components.

The aim of this research is not to diminish the importance of recycling efforts currently in use for structural steel but rather increase the awareness of reuse as a viable and more environmentally responsible option. Since steel reuse develops significantly less amounts of embodied energy via its reintroduction back into the material supply stream, it becomes a much more environmentally attractive option for the decision-makers when creating new facilities within the framework of the built environment growth.

An increasing number of firms are engaging in voluntary or mandatory end-of-life product management or materials reuse. Since developments in material or product reuse are driven by a mixture of environmental concerns and economic opportunities, the most promising corporate end-of-life strategies create both economic and environmental value (Geyer and Jackson, 2004). This research project will investigate and contribute to the development of a decision-making process which will enhance both the economic and environmental value of structural steel components targeted for demolition and recycling.

Problem Statement

Material reuse can be defined as extracting materials, products, or components from existing structures and reusing them in their extracted state or a state with very few modifications or alterations to their existing properties. Material use and selection as part of the design and construction process has historically has been motivated by price, availability, ease of use, and aesthetic appeal. In the past little thought has been given to how material use and selection affects our environment and resource supplies. Until recently the approach appears to be one of ignorance of the fact that many of our resources are non-renewable and dwindling at alarming rates. An analysis of our current approach presents three distinct problem statements that will be addressed and evaluated as part of this research:

- The vast majority of structural steel components removed from buildings that are demolished are inserted into the recycling process, much of it by overseas fabricators
- The current process significantly increases the embodied energy of the building material procurement and construction cycle
- There is not a clearly defined decision process in place within the building industry to advocate, coordinate, facilitate, and support structural steel reuse

To a great extent the concepts of sustainability has changed how we view materials use (and reuse), to what level of efficiency, and applying concepts of recycling and reuse in the material selection and procurement process. The problem arises that reuse of many types of materials can be cost-prohibitive and inefficient. Those two factors alone tend to scare away the decision-makers from further developing new ways to reuse a wide range of building materials. Reuse of structural steel components presents a number of challenges within the context of the aforementioned motivations.

Research Questions

The major research questions as listed below were developed as a result of preliminary investigation of the scope and extent of how structural steel components are reused in the building industry today.

Primary

- How can the building industry significantly increase the reuse of structural steel components in their extracted state or with very limited modifications (re-fabrication)?

Secondary

- How can the cost of steel component extraction and reuse be reduced to the point where it is more economically attractive to potential users?
- How does steel reuse compare with steel recycling within a specific set of comparison metrics such as cost, embodied energy, and material selection?
- What kind of testing criteria are necessary to re-certify steel components identified for reuse?
- What methods are available to extract structural steel components in a non-destructive manner?

Chapter Three, Methodology, further elaborates the process of how the research questions were arrived at within the context of the research objectives.

Research Objectives

The objectives of this research are broken down into two categories to better emphasize how the objectives will reinforce the comprehensive impact on material use and how they collaborate with the goals of sustainable construction.

Primary Objective

- To develop a decision process model which will enable construction industry participants to significantly increase reuse of structural steel components in their extracted state by virtue of a more coordinated and collaborative effort within the AEC industry

Secondary Objective

- To decrease the cost and resources needed to extract structural steel components

Benefits of the Research

True sustainable construction produces benefits in a number of different areas. The benefits of this research are far reaching and will touch many aspects of sustainability to include social, economic, and environmental.

Social benefits include the reduction in the number of abandoned or empty structures not being used (these are many times identified as Brownfield sites) by applying materials reuse initiatives to them in lieu of letting them stand idle or simply demolished. Economic benefits will provide more employment opportunities by developing a whole new line of technology and jobs in the field of steel extraction and reuse. Environmental benefits will lessen the overall embodied energy of the material supply stream for new facility, lessen the use of non-renewable resources, and lessen amount of building materials not presently scheduled for reuse. LEED® awards points for using 5% (1point) to 10% (2 points) salvaged or refurbished materials (by cost), relative to the total cost of materials for the project (see Appendix D).This credit encourages the use of existing materials, as energy is required to produce new materials regardless of whether they are extracted from recycled or virgin stock. Furthermore, the energy required to produce new steel has decreased 45% over the last 25 years, largely due to improvements in yield. Before, 100 tons of raw materials produced 60 tons of steel products, and now, the same 100 tons produces 90 tons of steel products (Modern Steel Construction, 2003). It is generally thought that the environmental benefits from reuse are greater than recycling since reuse requires little reprocessing. Reuse also preserves the value added when manufacturing the component and generally minimizes any environmental impacts from reprocessing. Whole buildings or individual components can be reused. For steel this is confirmed by a study in the UK by the Steel Construction Institute which suggests that reusing steel leads to significantly greater environmental benefits than steel recycling and correlates well with savings in greenhouse gas emissions.

Thus, from an environmental, and often economic, point of view it is desirable that as many components of a building as possible are extracted from the waste stream for reuse at the end of their useful life. Materials consumption; this benefit is listed separate although it is actually a amalgamation of economic and sustainable benefits --- it is also one of the most significant and verifiable benefits of steel reuse, i.e. the reduction of materials and energy consumption necessary to produce steel via the recycling process (See Figure 1-2) in support of the demand from the building industry

Research Methodology

The most significant component of this research is derived out its methodology and how it provides a practical and achievable decision model process to extract structural steel shapes from existing buildings, test them for strength properties, re-certify their use, and reintroduce them back into the material supply stream. Figure 1-3 shows the logical succession of steps proposed to identify the scope of the research and establish the necessary parameter conditions for the research.

The basic approach of the research will be to conduct surveys to collect specific data from a range of disciplines and constituencies, conduct interviews to verify and augment information collected via the survey documents, and conduct field work to develop case studies where potential structural steel component reuse occurs. This qualitative approach will support the investigation of the research questions, sufficiently address the problem statement, and support the achievement of the overall objectives of this research. The by-product of this methodology was a decision process model which addressed all of the concerns, barriers, and challenges associated with a novel idea of this magnitude.

The basic assumptions of this research, as elaborated in this section, are the driving force behind the structure of the methodology with the overall aim to develop the aforementioned decision process model to facilitate greater reuse of steel. The methodology will also appropriately address the many variables and factors that are currently preventing greater reuse of structural steel components in the building industry.

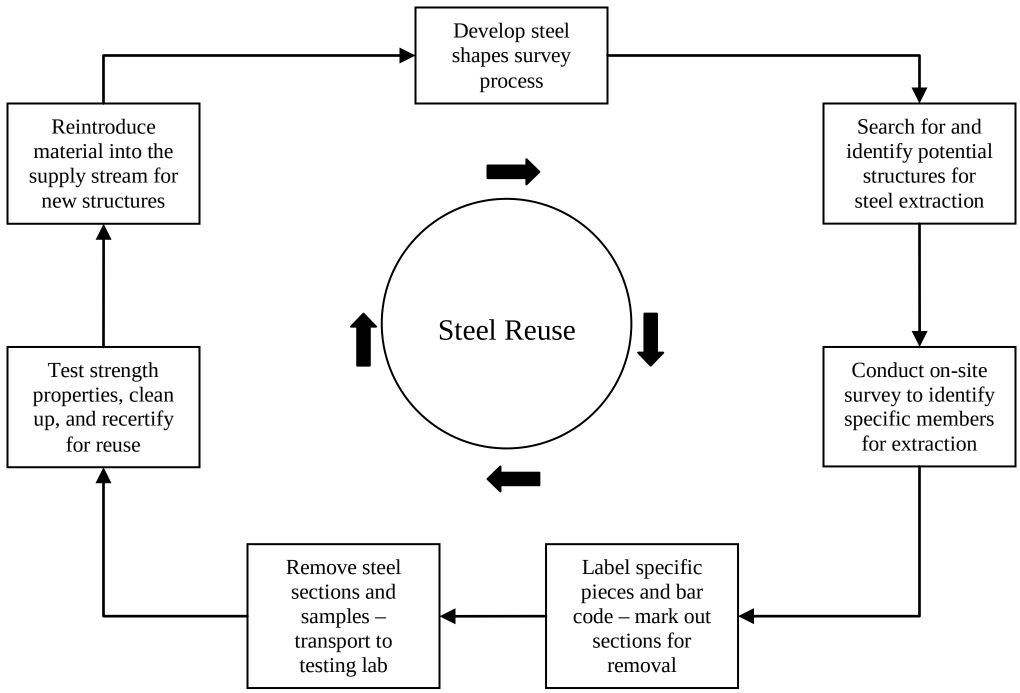


Figure 1-3. Structural steel extraction and reuse cycle

Dissertation Organization

The organizational layout and outline is explained in greater detail in the succeeding chapters. Chapter 1, Introduction presents the purpose of the research, the general scope and parameters of the research; concepts of sustainability; embodied energy and how it relates to reuse of structural steel products as well as the relevant research questions, assumptions and limitations, research objectives, brief description of proposed methodology, and benefits of the research. Chapter 2, Literature Review evaluates the current literature and research pertaining to structural steel reuse as well as critical related subject areas such as recycling, adaptive reuse, reclamation, and deconstruction.

Chapter 3, Methodology explains the design of the research, research objectives and questions, methodical steps applied, case studies used, retrieval and extraction methods, verification property testing, and material reuse introduction into the material supply stream.

Chapter 4, Results presents in detail the findings of the surveys and interviews (data collection) and an analysis of those findings. Chapter 5, Decision Process Model discusses the solutions to the research questions along derived from the findings and data collection. Chapter 6, Conclusions presents overall conclusions developed from the findings and discusses their relationship to the research questions and objectives. Chapter 7, Recommendations discusses possible recommendations for future research and the potential benefits of further study in this area of research.

Assumptions, Limitations, and Constraints

The assumptions that were identified as guiding factors to the research were are listed below. These assumptions were identified to clarify the scope of the research and set clear parameters such as to site access, types of steel for reuse, and testing considerations.

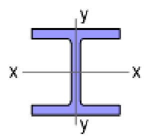
Assumptions

- Contractors would give access for sample sections and material assessments; this includes finding one dedicated contractor who was willing to fully participate and supply the necessary resources to conduct the field portion of the research
- Reuse of structural steel sections has be inhibited by cost, lack of process, and ease of procurement of alternatives such as recycled steel
- Structural steel retains its strength and durability in most installation applications (exceptions are elaborated upon in Chapter Four and Five)

Limitations and constraints

- Finding suitable contractors and projects in which sample field studies and reports could be generated – the access to the target projects could be limited by economic delays
- Code compliance for materials reuse – current code does not address steel reuse
- Lack of a well-established mechanism for exchange of steel components
- Only steel intended for permanent use in new structural steel frames was part of this research

- Technology available to remove steel components without damaging their structural properties and done in a cost-effective manner
- Research will be limited to the structural steel shapes as shown in Figure 1-4
- Possible low response rates for surveys
- Time availability of industry professional to sit for follow-up interviews



Wide flange rolled sections used for vertical columns or horizontal beams

Figure 1-4. Structural steel shape identified for extraction and reuse

Research Population

Projects which define the research population were selected based upon availability, access, appropriate types of steel components available for extraction, progress stage of demolition (or deconstruction), and size. These projects were then treated as case studies of which relevant information and materials were collected and extracted for the basic research. This population of projects was provided by several different construction management firms in the greater Milwaukee area.

Summary

The problems and challenges of increasing the reuse of structural steel is not an easy one to solve in the short term however new processes and initiatives such as those put forward in this research will enable the stakeholders of the built environment access to new information which will allow them to reuse more structural steel products going forward.

CHAPTER 2
LITERATURE REVIEW

Introduction

Structural steel, a material widely utilized in the building industry for many decades, is commonly used as a building product due to unique characteristics it contributes as part of the overall construction process such as ease/speed of erection, availability, strength, flexibility, durability, and cost. The major advantage of steel is its high strength relative to the strengths of other common structural materials: wood, masonry, and concrete (Rokach, 1991). Framing systems utilizing structural steel are recycled, recyclable, and potentially reusable. Steel, as a building material, is the most recycled product used in the construction process with nearly 100% of structural steel plates and beams recycled, (CISC, 2007) setting the pace for the design professional in the pursuit of sustainable construction. Steel, by nature, is the only type of structural member that can be easily reprocessed with minimal investment. Even without special activities that facilitate demolition work, steel members can be reused after minimal reprocessing procedures such as cutting, drilling, and welding (Fujita & Iwata, 2008). Reuse of structural steel components provides benefits in three distinct ways not currently realized by today's design and construction process; environmental, economical, and social. Environmentally the benefits are realized in three separate ways; (1) the significant reduction in embodied energy consumption by virtue of reuse, (2) the significant reduction of harmful by products released into our ecosystems by current steel recycling and production processes, and (3) significant reduction in the use and depletion of non-renewable natural resources.

Not to diminish the efforts and results of recycling steel, but it still does not appropriately address the increase in embodied energy via the recycling process. When looking at the embodied energy of any material or product introduced into the design and construction process we must start at the initial creation phase and conduct an analysis of all phases of the life cycle of that material to determine its true impact on the environment. In its virgin or recycled state, in terms of embodied energy, structural steel does not favorably compare to other structural materials available to designers and constructors (See Table 2-1). Reuse of structural steel fully addresses the issue of finding ways to process and manufacture building products and components via processes that use significantly less energy over many cycles of use.

Table 2-1. Embodied energy of common structural materials[1]

	Embodied Energy	
Type of Material	MJ/kg	MJ/m^3
Cement	5.6	3,200
Concrete Masonry Units	0.94	2,350
Timber (kiln dried)	1.6	880
Glue-laminated timber	4.6	2,530
Framing lumber	2.5	1,380
Pre-cast tilt-up concrete panels	2.0	2,780
Clay bricks	2.5	5,170
Steel (recycled)	8.9	77,210
Steel (virgin)	32.0	251,200
Steel (recycled, imported)	35.0	274,570
Steel (reused)[2]	2.9	23,000
Stone (local)	0.79	2,030

Notes to Table:

1. Source (Architecture, 2030)
2. Approximate value (calculated value discussed in Chapter 5)

As Table 2-1 indicates embodied energy of structural steel via the current production processes is very high as compared to other structural building materials. The proposition of steel reuse adequately addresses significant reductions in embodied energy, contrary to that of recycling. Economically the benefits are realized through a process which eliminates the necessity of sending scrap steel bound for recycling overseas to be processed into new structural steel components. New industries and jobs would be created by the reuse process. Dismantling and reuse of structural steel components creates more employment and training opportunities for low-skilled workers than demolition. This brings jobs and career opportunities into the community, which in turn stimulates local economies (Chini, 2003). Furthermore, the skills learned in disassembling and deconstructing a building can be applied in other facets of the construction process thereby potentially creating additional areas of employment and jobs.

The social benefits are much less tangible and more difficult to assess and quantify. One of the obvious ones is the potential of adding new jobs where unemployment is high. Recovering steel for reuse can many times have as a source structure abandoned buildings in economically stressed areas. Brownfield sites many times will be located in high unemployment areas and these types of building can be a lucrative source for steel to be reused. The economic benefits on some levels tie directly into the social benefits. From those an economic benefit would be derived due to new types of industries and construction processes.

Background Material

An exhaustive literature search was conducted which explored a wide array of sources relevant to the research objectives and questions. Concepts such as sustainability, deconstruction, and recycling, embodied energy, adaptive reuse, and reclamation were investigated and analyzed as to how they affect the structural steel reuse process and the role reuse plays in the overall design and construction process. Many of these processes, sustainable unto themselves, are closely related and in some cases intrinsically connected to the reuse process. In this light they must be discussed to some level of detail to form the basis of reuse as a sustainable process which will produce a wide range of benefits to society. To effectively demonstrate the crucial link between reuse of structural steel and other aspects of sustainable construction a significant amount of background material must be discussed to fully understand how important this research is in the context of not only environmental impacts but also overall benefits to the construction industry itself.

Construction waste is inherently a resource lost in the building process and thereby an unrealized profit. More and more construction firms understand the economic benefits derived from recycling, and even more so reuse. The potential benefits that can be achieved are proportionate to the efficient use of materials, energy, and other resources commonly used in the construction process. Any processes that adds value via reuse to what has been traditionally known as materials targeted for recycling can lead to significant financial benefits as well. The increasing appeal for reuse of common construction materials such as structural steel is driven in part by the LEED® green building rating system as well as a general societal awareness of environmental concerns. Engineers and architects are looking to incorporate reused materials and components where possible, and viable on an ever-increasing scale.

Structural Steel Reuse Sample Projects

The literature search revealed a relatively small number of structural steel reuse sample projects (or sample projects) directly related to the research topic. The selection criteria for including the projects in this chapter were as follows: (1) some element of reuse (as illustrated in the hierarchy in Figure 1-2) of structural steel in the building project, (2) an accepted approach to sustainability such as the LEED® rating system, and/or (3) a very closely associated sustainable discipline such as recycling or adaptive reuse. Throughout North America, hundreds of used building material stores sell materials for construction and renovation projects. Materials (such as used lumber and bricks) and other items (such as doors and windows) are salvaged mostly from remodeling projects, pre-demolition salvage, and the growing practice of deconstruction—the selective disassembly of buildings to reuse and recycle parts (EPA, 2008). For the most part this is not the case for structural steel sections recovered from buildings. The literature search and review exposed very limited applications of structural steel reuse which significantly relate to the main focus of this research. The following steel reuse sample projects (CISC, 2007) illustrate examples of the limited extent of structural steel reuse in the industry today. A brief summary has been provided at the end of each case study description.

<u>Sample Project #1: The Eaton building in Montreal</u> (CISC, 2007)

Date of reused steel: 1920's – 1950's

In 2002, the Eaton building in Montreal was refurbished it into a new and elegant complex. Although part of the structure was gutted to create an ovoid atrium, much of the structure was reused. Most of the steel, which dates from several eras, ranging from the 20's to the 50's, could be reused – as concluded by the engineering firm Pasquin St-Jean which had coupons of the steel tested for its yield strength, and carbon content. It turns out that the low yield strength of that period could be compensated by the fact that many of the members were oversized, a common practice for that period. Even the columns could be reused. Although the steel had higher carbon content than the new steel, it was still possible to weld onto it. The top floor was reinforced, as its structure was the former roof. The roof was refurbished as a floor, necessitating extra joists between the existing ones. As far as the rest of the building is concerned, a major portion of the complexity was due to problems with interfaces between different parts of the building built at different periods, and the new parts, complicated by non-typical geometries. The team explained that they would have all benefited from more extensive visual assessments and testing earlier in this fast-track project.

Case Summary – This is a good example of adaptive reuse of an existing building; the highest form of reuse in terms of sustainability as illustrated in Figure 1-1. The fact that more extensive *visual assessment and testing earlier in the project would have produced a greater benefit is critically linked to one of the steps in the decision model process outlined in Chapter 4.*

Sample Project #2: Baie St-Paul's New Town Hall (CISC, 2007)

Date of reused steel: 1960's

Anne Carrier Architects were retained by the City of Baie St-Paul for their New Town Hall. In 2003, the architects created the required signature space from an old industrial building built in the 1960's. With the exception of one corner of the building, which once endured a fire, all of the steel was reused. Several coupons tested from different locations revealed that the yield strength employed at the time of construction could be taken for calculating the resistance of the members based on current standards, and that welding would not be a problem. There appeared to be several sources of steel – one of which originated in Britain – which prompted the engineer to test in different locations. Much of the steel is left exposed inside, including the roof joists, and traces of the past were deliberately left untouched on many of the columns.

Case Summary – This is another example of adaptive reuse where existing steel has met the engineering standards for the new structure (this is linked to one of the assumptions stated in Chapter One).

Sample Project #3: University of Toronto Student Centre (CISC, 2007)

Date of reused steel: 1970s

In 2003, Dunlop Architects were asked by University of Toronto students, who are members of the building committee, to provide a building that reflected a sustainable approach for their new Student Center. In fact, the students did not understand why such an approach was not adopted by default for all buildings under construction today. Dunlop Architects and Halsall Engineers came up with the idea that part of the material could come from existing sources.

Halsall, who is presently working on demolishing part of the ROM building, proposed reusing ROM girders for the new Student Centre. Since Halsall had done that part of the ROM building in the late 1970s, they had all the necessary archives for demonstrating the material quality of the steel to be reused – therefore no testing was required. The most significant project challenge however, was for the architect to find the right official from the ROM building to speak to the right University of Toronto official, for accepting the (donated) steel. This administrative aspect had to be factored into the project scheduling of this reuse. The reused steel amounted to approximately 18 tons of saved steel.

Case Summary – This is an excellent example of reclaiming structural steel sections from one project and reusing them as part of the structural system in a new project. This case study is very close in scope and intent of aim of this research project.

<u>Sample Project #4: Chapiteau des Arts du Cirque </u>(CISC, 2007)

Dates of reused steel: several

In 2003, Le Cirque du Soleil retained the proposal by Schème, and Jodoin, Lamarre, Pratte & Associates, in part for their sustainable development concept for the design of the Chapiteau des Arts du Cirque. The intention to integrate reused steel was part of the green building view of the project. Some promising options seemed possible with steel available from two fabricators. For different reasons, one of which was timing, the structural engineer Martoni Cyr et Associés found the required steel elsewhere, at Panzini Demolition.

Case Summary: In this project, the engineers only needed a chemical test to verify the weld-ability of the steel, relying on the lower allowable yield stress for unidentified steel as permitted in the steel construction standard. One of the recovered beams still had rivets. Interestingly, the reused beams of the Chapiteau are left exposed, and in their original state, reflecting the *historical character of the steel beam and thereby sensitizing visitors to material reuse. For example, one of the exposed beams came from one of the Old Angus shops in Montreal and was left "as is". The reused steel for this project was purchased through a new acquiring process, as this was a relatively 'non-standard' order.*

Sample Project #5: Bel-Air in Montreal (CISC, 2007)

Date of reused steel: 1950's

The new government building in the revitalized west end of the city is an example of how the deconstruction of an old building can provide materials for a new project at the same location. In addition to the strategy to minimize the environmental impact of materials by reclaiming and reusing materials wherever possible, the project incorporates a range of other innovative green features such as natural ventilation, day lighting systems, geothermal heat sources, radiant floor heating systems, solar heating, and water management systems. The combined effect of these strategies is expected to qualify the project for a gold LEED® green building rating and provide energy savings of more than 40 per cent, compared to energy requirements of conventional construction methods.

Many of the original building components and materials were salvaged and reused (in this and other projects) or recycled, and new materials were carefully screened and selected with impact on the environment in mind. Materials from the old buildings reused in the new project included steel joists, steel cladding, bricks, and crushed concrete (as backfill). This case study focuses on the issues arising during the deconstruction, design, and construction process that particularly relate to the reuse of steel components.

The site consisted of a series of industrial buildings dating from 1851, with various more recent additions. Previously, it had been used for a variety of heavy industries, including a foundry, but in more recent times the buildings served as storage space. An old drawing from a newspaper indicates that these buildings were the first in Montreal to use saw-tooth north-facing lighting in the roof. However, the buildings were altered considerably over many years and the original roof structure had been replaced. It was estimated that the existing steel roof structure dated from the 1950s.

By the late 1990s, the site was run down and contaminated. Public Works and Government Services Canada (PWGSC), who owned the site, wanted to redevelop it to help revitalize the neighborhood around the St. Henri district of Montreal. They proposed a facility to house various government departments, including the Royal Canadian Mounted Police, the Canada Customs and Revenue Agency, Human Resources Development Canada, and the Department of National Defense's Naval Reserve. In total, over 15,000 m^2 of floor area was created for warehousing, office space, and other specialized uses. Sharing facilities such as meeting rooms, storage space, and heating and lighting systems allows the tenants to benefit from the economies of scale and save unnecessary building costs.

PWGSC also wanted to use the project to demonstrate a green building approach and showcase a range of green strategies, including reuse of the buildings or components and recycling of materials that were already on the site. The idea for reusing materials was strongly embedded in the client's request for proposals from architects as part of an overall green strategy aimed to achieve a LEED® green building rating of gold.

The site was seriously contaminated with heavy oils, slag, and other industrial pollutants from its previous use as a foundry, and required considerable remediation. This entailed removing large amounts of contaminated soil, which in turn meant that most of the old buildings on site had to be removed. Originally, the architects had hoped to keep at least some of the existing buildings and find new uses for them, thereby reducing demolition waste and avoiding consumption of new resources. Keeping the buildings would also have facilitated storage of reclaimed materials during construction and assisted in programming of the new construction process. However, as the soil remediation progressed, it became clear that it would not be economical to maintain the structural integrity of the old buildings while removing substantial amounts of contaminated soil. Although attempts were made to keep some of the buildings, or parts of buildings, eventually doing so proved to be uneconomical, and gradually more and more of the buildings were demolished.

This piecemeal process of removing buildings affected the layout and shape of the new building, as the first strategic design decisions were made when it was still expected that some of the original buildings would be reused. As it became clear that little would remain, there was no time to reconsider the whole design, rather, the scheme had to be extended to accommodate the newly demolished areas of the site.

At an early stage, the client appointed AEdifica, a Montreal architectural practice, to oversee the deconstruction process and identify materials that could be reused, either on site or elsewhere. A contractor specializing in deconstruction (as opposed to demolition) was hired to take down the existing building and find ways of reusing as many components as possible and recycling the rest of the material, where possible. Most of the material was reused off site in other projects around Montreal, or was sent for recycling. A full materials audit was carried out, tracing which materials were available and where they were disposed of. AEdifica estimates that the overall cost of the deconstruction process was no higher than the cost of traditional demolition, when the revenue resulting from the reused materials is considered. However, timing is critical. The deconstruction process requires more time for careful handling of reusable materials and this must be built into the project schedule. Also, deconstruction requires space for storage of the reclaimed materials, ideally on site, but if necessary, elsewhere, and while new uses are being found for them.

Approximately 325 open-web steel roof joists were identified as suitable for reuse. In addition, a considerable amount of steel cladding, some brick, some timber, and electrical and mechanical equipment such as elevator components could be reused. Other materials such as wiring, pipes, wood beams, and other steel sections were suitable for recycling, and concrete was crushed to use as fill during the shoring process or for site engineering works.

An architectural consortium was appointed for the design of the new buildings, including architects with local expertise and others with a green building track record. The architects developed initial conceptual ideas for the site, organizing the structural system around the parking bay and warehouse racking grid requirements. They then inspected the materials and components available from the deconstruction of the existing building to assess their potential for reuse in the new building, and the designs were revised to suit the available materials. Access to information at the appropriate time in the design process was found to be crucial. Initially, information about the components from old drawings and specifications was not available to the designers. Thus, the precise dimensions of the components that might be reused were not known to the design team when the critical structural spacing decisions were being made. This meant that the designs had to be based on estimates; the architects had to maintain as much flexibility as possible in the design to accommodate a range of sizes, which complicated matters. Old drawings can save time and facilitate the design process, as well as increasing opportunities for reuse. In this case, the architects found relevant information which initially was thought to have been lost at the Public Works Canada archive, and which helped them to identify the structural characteristics of components.

The open-web steel joists were deemed useful for the new roof structure. However, to establish their structural integrity and suitability, X-ray imaging and chemical analysis had to be carried out, at a cost of approximately $20,000. This showed that they were suitable for the new building, provided they were used at closer centers than modern joists. Initially, 100 joists were put aside for use on this project, with the remainder being disposed of for other reuse projects or for steel recycling. Ultimately, some 65 joists were reused.

The designers also identified the potential for reuse of steel cladding for internal finishes in some of the larger warehouse spaces, and the old brick, although unsuitable for use externally, was appropriate for internal wall surfaces. The project was divided into three contractual phases:

- Deconstruction
- Site remediation, shoring, and other ground works
- New construction

This led to some coordination problems and issues with contractors not accepting responsibility for dealing appropriately with the materials being reclaimed. Unfortunately, the deconstruction process caused damage to some of the steel joists, which made them unsuitable for reuse. There was also a shortage of suitable storage space on site during construction. This caused the joists to be moved several times around the site, from one external storage area to another, and eventually to be placed in a storage yard off site. This multiple handling, and the time delay between deconstruction and reuse (over two years), led to damage to about 15 per cent of the steel joists and resulted in additional costs.

Eventually, the open-web steel joists were sent to a steel fabricator for sorting and minor re-fabrication. This was necessary, as it was found that there was some variation in their length.

Although some were adapted in length in the workshop, there were still problems that required adjustment of the joist seats on site. The joists were also cleaned and repainted prior to installation on site. The steel cladding required trimming of damaged areas and repainting prior to installation in the new building.

The increasing awareness of the value of old buildings, both for adaptive reuse and for the value of reusable components within them, led PWGSC to set out a green strategy which included reusing construction materials right at the start of the project, even before demolition was considered. This established strong guidelines for the conservation and reuse of the materials already available on the site. The deconstruction of the old buildings on the site and integration of various materials from those buildings into the new project provide many lessons for the reuse of structural steel and other components, including:

- Deconstruction of a building, rather than demolition, is economically viable but managing the materials with the necessary care requires added time, and this must be built into the schedule

- The role of the client is crucial in any deconstruction and reuse strategy. The client needs to accept that there are some additional risks involved and more time is needed for the reclaiming and reuse of material

- Deconstruction requires space for storage of the reclaimed materials, either on site or elsewhere, before new uses can be found for them, and they can be removed

- Because of the nature of the connections of the components, steel is particularly suited to deconstruction and steel components can be readily reused. Other materials can offer additional problems due to the nature of connections and the characteristics of the materials

- The availability of information at the appropriate time in the design process is important. Information about sizes of available reclaimed components needs to be available to designers in the early stages of design to facilitate appropriate design decisions

- The availability of drawings and specifications of the building from which the steel components are reclaimed can save time and facilitate the design process, as well as increasing reuse opportunities

Case Summary: The reuse of steel at 740 rue Bel-Air demonstrates the relevance of a comprehensive materials strategy in a project aiming to significantly reduce the environmental impact of a new building, thereby achieving a high LEED green building rating. The success of the project opens the way for more projects to adopt similar strategies, based on the lessons that have been identified above.

<u>Sample Project #6: Angus Technopole Building</u> (CISC, 2007)

Date of Reused Steel: 1900 to 1950

A former locomotive assembly plant in the heart of Montréal, Québec, previously used by the Canadian Pacific Railway (CPR), was converted into light industrial workshops and office spaces for community-focused businesses. The Angus Technopôle facility, designated the Innovation Centre of Montréal by the Québec government, provides a wonderful example of heritage steel and brick architecture. The facility was to be demolished, but thanks to the vision of the architects at Aedifica, it was converted into a unique facility featuring wonderful spaces and showcasing the historic steel structure.

Green strategies deployed in the conversion of the locomotive shop included reuse of the existing steel skeleton, exposing the open-web riveted structural members, and the use of existing exterior brick walls as screen walls. It is estimated that over 85 percent of all materials on site, including the majority of the steel, are from the old structure. Also, interior furnishings and fittings were reused and the aesthetic features of the building were retained.

The purpose of the Angus Technopôle building is to serve the urban community by establishing and promoting a working environment for community-focused companies that can support each other and provide employment and services to the neighborhood. The sense of community is actively fostered within the facility and among local residents, who are informed of activities at the building through public meetings and publications. The companies occupying the building are themselves involved in servicing, manufacturing, and research and development, besides providing employment for neighborhood. Over 500 people have already been employed at the site. By reusing the large Brownfield site and renewing the historic landmark building in the urban core of the city, it is the community's intention to revitalize the social economy of the neighborhood and provide 2,000 people with employment by 2008, as well as demonstrating sustainability in an industrial context.

The old industrial complex on the site at 2600 William-Tremblay Street in Montreal included 6.5 hectares of railway yards that are gradually being redeveloped into a business park. In addition, the site included huge steel and brick sheds containing extensive open spaces without columns, which accommodated the locomotives that were built there. The buildings were originally over 400 m (1,300 ft) long, built in phases over the first half of the twentieth century. The CPR activities on this site provided primary employment in the area, and the buildings also had a history as the focal point of the community. By the 1990s, however, they were no longer in use and were decaying.

The original intention of the client was to remove the old factory buildings and replace them with modern light industrial facilities. Some of the buildings were demolished in preparation for new construction. However, the architects for the Technopôle building realized the unique nature of the structures and their heritage value, and with grassroots support from the community, managed to persuade the client to save part of the buildings.

The first phase of the project, completed in September 1999, involved the conversion of about one third of the original building into the Technôpole Innovation Centre consisting of 12,500 m² of floor space, divided into units ranging from 350 m² to 1,500 m². These are occupied by offices and research spaces on the upper level and light industrial units on the ground floor, arranged around a central interior street flooded with natural light from above. The success of this first phase influenced the second and led to the conversion of another part of the old locomotive factory into a supermarket with an area of about 7,400 m^2, completed in the spring of 2001.

The architects and engineers made a strategic decision to maintain as much of the existing steel and brick structure as possible in their original state, with minimum intervention. During the first phase, some sections of the building, which is almost 200 m long and over 50 m wide, had to be removed to create parking and loading areas. But even where roofs were removed, walls often remained as external screens. Where possible, the industrial heritage of the building has been highlighted, so huge riveted steel structures such as overhead rails and lifting cranes are exposed in the central circulation area and made into major features of the building.

The old industrial steel structure afforded the architects considerable flexibility in accommodating the new building's uses. New lightweight steel-frame additions were integrated within the huge spaces of the old building to house the office and workshop spaces. The new structures were designed to minimize their impact, both structurally and visually, on the old frame. Thus, there is minimal connection between old and new, and they are clearly differentiated, although the new structure does provide some strengthening and lateral bracing to the old frame. The old components maintain the aesthetic of the building's industrial heritage, featuring heavy steel sections riveted together to form large beams, girders, and lattice columns. In contrast, the new structure is lightweight and refined, with minimal dimensions of components.

The new structure had to be designed to minimize the use of new supports, so the designers developed a system for using the smallest possible number of new support columns and keeping them away from the existing structure. Furthermore, new foundations had to be strictly limited, to avoid undermining the old building and disturbing the poor soil below the ground slab. Thus, the existing ground slab was kept, and a new cover of concrete poured on it. This proved to be of economic benefit, since it saved excavation and disposal costs. Lateral bracing was also added by the introduction of several vertical circulation cores along the central circulation zone, away from the existing structure.

As part of the strategy for maximum reuse, the architects recommended that various steel and other components which were removed from the building should be reused on site. Some components were used in landscaping and to demarcate parking areas for cars, although this practice was not entirely successful, as it caused problems for snow clearance. Even the steel rails from the locomotive shop were reused as bollards and other architectural features, although only after a method was found to straighten them.

The original building consisted of huge spaces to house the industrial activity of its designated use. With the introduction of the new structure, the building now accommodates a series of small workshops and office spaces that can expand and adapt to the changing needs of the tenants. The flexible steel structure allows the addition of mezzanines and additional floors, if required. At the higher level, the roof structure is so deep that it is possible to add floor levels within the structural bays, with links between each bay through the old steel roof trusses. This can create unique spaces and views and allows the building to change and evolve with time.

The reuse of the building was accompanied by energy-saving measures selected to efficiently ventilate, cool, and integrate natural lighting into the various spaces. Day lighting levels are improved by the flexibility of the structure, allowing appropriate glazing to be integrated, and the central street is used to both provide lighting and as a ventilation flue. The envelope was significantly upgraded with roof insulation and superior insulation for all new outside walls, and fenestration with low-emissivity glass. The open design allows free cooling on summer nights by its integration of operable, louvered windows and air extractors with skylights, reducing the need for air conditioning. The building was chosen as one of Canada’s representatives in the international Green Building Challenge in 2000. As part of this process, a green assessment was carried out using the Green Building Assessment Tool (GB Tool) green rating system. The project scored well, particularly for materials use and site amenity.

Although this is an unusual project featuring a very large, and unique, industrial building, the work demonstrates the opportunities that are available for creative reuse of old steel-frame structures, even in very specific circumstances. The designers have used the aesthetic and structural features of the existing steel structure to create a building with distinctive spaces and flexible uses.

The following key aspects of the process have been identified:

- It is possible to keep industrial heritage buildings in place and find new uses for them while creating unique spaces with a high demand for tenancy
- Reuse of much of the old building means that a large proportion of the materials for the new project come from what is already on site -- in this case, an estimated 85per cent of materials were already on site
- New steel structures can be used to provide additional support and bracing, while remaining aesthetically separate from the heritage steel
- A motivated and inspired project team is essential when innovative ideas are proposed
- The process is helped if the client understands the benefits of sustainable design and sets an agenda early on for developing strategies for material reuse

Case Summary: The reuse of steel in this building contributed significantly to improving its environmental performance, and offers a model for other projects where heritage buildings are involved.

Sample Project #7: Beddington Zero Energy Development (CISC, 2007)

Date of Reused Steel: Unknown

The BedZED development located in South London, England, is a mixed-use housing and workspace project that integrates sustainable design practices into many aspects of its design and construction process. Completed in September, 2002, the scheme consists of 82 residential dwellings, 18 live/work spaces and further work-only spaces, together comprising 8,500 m^2 of floor space. The scheme uses a load-bearing masonry structure, but with some structural steel elements, particularly in the workspace areas. It illustrates how reclaimed steel (and other reclaimed materials) from local sources can be readily integrated into a development of this kind, significantly reducing embodied energy, other environmental impacts and costs. This case study focuses on how suitable reclaimed structural steel from local sources was identified and used in the buildings, and what lessons are relevant for other projects.

The project was initiated by Bill Dunster Architects and the Bioregional Development Group, a locally-based environmental charity which develops local products to meet local needs. Their aim was to prove that a large-scale mixed-use development could address a wide range of sustainability issues, including the reuse of building materials and the incorporation of fossil-fuel saving strategies, while also being cost-effective. Ultimately, as the name suggests, the intention was to create a zero fossil-energy development producing no net carbon emissions. Funded by the Peabody Trust, a social housing group, and with support from the local authorities, the project was built on the site of a disused sewage treatment plant in Beddington, South London.

The design team adopted a range of strategies to address the environmental impact of the buildings. The scheme has a high building density, showing the importance of using land resources to the fullest. Energy use is reduced through passive design strategies such as building orientation, high performance triple-glazing, thermal mass and high levels of insulation. Energy is supplied by photo-voltaic cells and a combined heat and power (CHP) plant using local tree cuttings as a fuel source. Building materials such as locally sourced, untreated oak cladding and local brick were used as exterior wall cladding. Timber was locally sourced for floorboards and weatherboarding, and reclaimed from other sources for interior partition studwork. The use of reclaimed building materials in place of new is one of the most effective ways the construction industry can reduce its environmental impact and become more sustainable. Altogether, 3,404 tons of reclaimed and recycled materials were used, accounting for about 15% of the total materials in the project. Most of the materials came from sources within 50 km (35 miles) of the site, reducing transport movements and the associated environmental problems

Although the main construction is load-bearing masonry, over 100 tons of structural steel was also required. Early in the design process, the design team identified the potential for using reclaimed steel in the project. The steel components were used mainly in the workspace areas of the development, where 1,600 m² of floor space is divided into 23 units. Ninety-five per cent of the steel used in these workspaces came from reclaimed sources.

Using reclaimed steel was important to the design team to minimize the environmental impacts of using new steel. However, as Bill Dunster, the architect, recalled in a lecture given in June, 2002, *"We had terrible problems persuading people it was a sensible idea to use reclaimed steel. Once they got the hang of it and we got our quality assurance systems up and running it ended up with no problem whatsoever."*

There are not many large stores of good quality reclaimed steel for structural purposes readily available in the UK. At BedZED, the design team, and in particular the construction managers, Gardiner and Theobold, searched local salvage yards and demolition companies within a 50 km radius of the site for appropriate structural steel sections. Three potential sources, at Croydon, Limpsfield and Brighton, were identified, and these were inspected by the structural engineers to establish quality and suitability. The structural steel girders from the redevelopment of Brighton Train Station were found to be in good condition, suitable for reuse, and most appropriate. These supplied about 80% of the steel requirements for the project. The remainder of the 98 tons of reclaimed steel used came from two other local sources. The steel was stored by the salvage contractor until it was required.

In subsequent projects, Bioregional have found that salvage yards, demolition companies, and even transport companies are often willing to store reclaimed steel for significant periods until the steel is required. They have also noted that a construction management contract, rather than a traditional tendered contract, gives more incentive for the construction managers to embrace project aims, such as using reclaimed materials. In projects where traditional tendered contracts were used they found it more difficult to engage the contractors in the reuse process unless the requirements are clearly laid out in the tender documents.

The only structural steel sections that did not use reclaimed steel were the curved beams required for the arched link bridges. Time and program pressures, and the local section bender being unwilling to pass the sections through the bending machine, created difficulty finding a reclaimed source for this procedure. However, there appears to be no technical reason why reclaimed steel could not be passed through a steel bender in the future. The use of reclaimed steel had little impact on the design. The design team expected that the design would have to be adjusted to suit the available reclaimed steel, but in fact little accommodation was necessary. Prior to identification of the reclaimed steel, approximate section sizes had been specified by the structural engineers. The connection details were also designed to accommodate a range of sizes, allowing for more flexible sourcing. Any reclaimed material has to satisfy the requirements of client and building code officials. The structural engineers, Ellis & Moore, inspected the reclaimed sections before purchase, and established their date of manufacture and their condition in terms of rust or scaling, the number of connections used previously, and suitability for re-fabrication. Since these were common, standard sections, they were able to use information about the performance of historical sections available in the UK to establish the structural characteristics of the steel. From this they were able to satisfy all concerned about the structural integrity of the steel.

The steel was sent to Joy Steel for the small amounts of re-fabrication that were required. The only significant difference during fabrication from using new steel was that in some cases extra sandblasting was required to clean the steel before finishes were applied. The steel sections were re-painted prior to delivery to site and showed few signs of their previous use other than extra bolt holes and welding marks

As a result of their involvement in BedZED, the environmental charity Bioregional Development Group decided to establish a new company, Bioregional Reclaimed, as a trading subsidiary specializing in supply of reclaimed building materials for construction projects. Their aim is to take demolition, salvage or scrap materials and find uses for them. They offer advice to architects and their clients on the potential for reclaimed materials and disposal of materials on construction projects, and can provide a quantified assessment of the potential reduction in environmental impact from using reclaimed materials. They also source and supply reclaimed materials to order.

A major component of their work is sourcing reclaimed steel. Generally, they focus on smaller projects requiring 10 to 20 tons of steel, but have handled larger projects of 60 tons or more. They are typically able to purchase reclaimed steel at about $850 per ton and sell at $1300 per ton, which is less than the cost of new steel in the UK. Bioregional have also observed that some demolition contractors are now aware of the potential for reclaimed materials and are beginning to present themselves as suppliers to green minded designers. Experience of using reclaimed steel at BedZED and other projects undertaken by Bioregional Reclaimed has identified the following important guidelines:

- Real commitment to the idea of reuse is required from the design team and contractor at an early stage
- It is beneficial if decisions on using reclaimed materials are made early in the design process, allowing more time to identify steel sources
- An indication of approximate sizes and lengths of steel sections early in the design process helps to find sources for the reclaimed steel at an early stage
- Flexibility in the design approach helps by allowing available steel sizes to be accommodated
- The use of common steel sizes in the design helps, as these are more likely to be available as reclaimed
- Long spans can be a problem as less reclaimed steel of this type is available
- Storage of steel may be an issue if it is identified early in the process. However, experience suggests that salvage yards or even transport companies are often willing to store steel for significant periods
- The type of contract used for the construction is important. A management contractor may be more willing to embrace the project aims of reusing materials than a traditionally tendered contractor

- If a conventional main contractor is used, the requirement for reclaimed materials must be specified in a water-tight way or else the contractor may be unwilling to make the effort required and may well try to wriggle out of this once the project is underway

Case Summary: The reused steel in this project helped the designers to meet the goals of minimizing environmental impact in a cost effective way. The project also demonstrates how such a strategy can be readily adopted. Bioregional Reclaimed are now applying the lessons learned at BedZED to various other projects.

<u>Sample Project #8: BMW Sales and Service Centre</u> (CISC, 2007)

Date of Reused Steel: 1960's

BMW is an internationally renowned car manufacturer based in Germany that prides itself on offering top quality products and services to discerning customers. As a leading innovator in the automotive industry, the company also has a commitment to environmental standards and what it calls "sustainable production". After the Rio Summit in 1992, the company implemented strict environmental guidelines. Since then BMW has been certified under the ISO 14001 environmental management accreditation scheme.

BMW's new flagship store in downtown Toronto opened in the autumn of 2003, located on a highly visible site by the Don Valley Parkway (a major traffic artery) and the Don River. The mandate to the design team was to create nearly 4,000 m^2 of new showroom and retail facilities, including a "lifestyle boutique" for BMW owners and enthusiasts, with a further 6,000 m^2 of space devoted to a service centre. The building is spread across six floors and features the reuse of an existing steel structure, considerably adapted for its new purpose. As an example of how an existing steel frame can be considerably altered for a new use, the BMW Sales and Service Centre illustrate the adaptability of steel structures. This case study focuses on the design issues that arose from the decision to reuse the existing steel structure, and the resulting benefits.

One of the most important features of the site for BMW was its location close to the downtown area and its visibility from the Don Valley Parkway. The site was occupied by an existing 1960's steel framed factory building (extended in the 1970's), and was classified as a "Brownfield site" requiring extensive remediation. It is also adjacent to the Don River, which is an environmentally sensitive area, and the building is located in the river's flood plain. Any new construction on the site would have to comply with stringent setback regulations established by the Toronto & Region Conservation Authority. This would have pushed a new building further away from the Parkway, making it impossible to retain the same visibility as the existing structure. Thus, it made sense to keep the existing structural frame so that the new building would not have to meet current setback standards, and adapt it with structural alterations, additions and a whole new exterior and interior.

Because of the narrow site, the existing building consisted of a one-bay steel frame structure with hollow precast concrete panels spanning about 4.8 m (16 feet) between the frames. This single-bay structural system proved convenient for the new use, as it permitted a column free space. The existing building was stripped back to its steel skeleton and hollow core precast concrete slabs, which were mostly kept. One floor was partly removed to create double-height space for more dramatic effect and various other interior alterations were made. A one-storey addition was also added on the south side to house the service department. The steel frame was flexible enough to accommodate these various changes and additions. The exterior was retrofitted along the north, south and east facades with curtain walling comprising mainly of blue-tinted glass. The rest of the building was clad with pre-cast concrete panels. Six car "display windows" were provided on the 4th and 5th floors which were glazed in clear lead-free glass for high visibility and minimum visual distortion. This highly visible display has been compared to a vending machine – almost as if one can simply go up to the building, deposit money, and a car will roll out the front door. At night a 9 m x 18 m backlit vinyl billboard, lit from within, attracts attention to the building.

At the beginning of the project it was determined that the existing structure, though sound, would need strengthening to meet the current building codes. A major part of the structural retrofit was to upgrade the frame to comply with current seismic requirements. Since three sides of the building were to be clad in glass, cross bracing was not an acceptable alternative for the seismic retrofit. However, the adaptability of the steel frame allowed strengthening to transform it into a moment resisting frame. New moment connections between beams and columns were constructed from large plate steel 25 mm to 40 mm (1” to 1 ½”) thick, and 900 mm (36”) wide. These were necessary to provide lateral stability for the structure. These plates were continuously welded around the existing columns. Steel plates, wide flange beams, and t-sections were used to strengthen beams and columns to increase their moment capacity resulting from seismic loads. Additional strengthening of columns was required in the double storey area. The roof was also strengthened to resist the weight of mechanical equipment and snow accumulation.

The BMW Sales and Service Centre offered the opportunity for an existing steel structure to be adapted and reused in-situ for a new building. Although a considerable amount of new steel was required for strengthening and other structural alterations, significant cost, time, and environmental benefits resulted from reuse. Considerable primary resources were saved by using the existing steel frame, eliminating the environmentally damaging and resource intensive process of frame and foundation construction. Reuse also resulted in a faster principal construction period, reducing local disruption.

Availability of drawings for the original building from the 1960s, and for the two storey addition from the 1970s, made it possible to identify accurately the structural properties of the steel. However, incomplete documentation for the addition necessitated a complete analysis of the existing structure. Visual inspection was required to confirm the actual quality of the steel and in addition the properties of the steel were confirmed by tensile tests. The steel was found to be in good condition, since it had not been exposed to the elements nor subjected to corrosion, and it was approved for reuse.

Despite the considerable degree of innovation and the high quality of construction, the project was completed in just over 2 years. This included inevitable delays as some strengthening work took place during severe winter weather - welding in subzero temperatures usually requires preheating and is not permitted below -15° C air temperature or when it snows. The steel found in the building conformed to the specifications indicated on the original drawings, with known properties. All in all the reuse of the steel structure resulted in very few complications.
Sustainable buildings must address issues of environment, cost, and social responsibility. The BMW Sales and Service Centre illustrate how an adaptive reuse of an existing steel-framed building can generate significant benefits. It illustrates the potential for reuse of whole steel structures to create new buildings and uses. This points the way for adaptive reuse of other buildings, reducing the demand for new resources and potentially reducing costs. It demonstrates the following:

- An existing structure, adapted and reused, may allow a more appropriate use of some sites compared to new buildings which may be restricted by current local requirements
- Available information from existing buildings helps considerably to facilitate the reuse process
- A steel structure can be adapted, (removing portions of floors), strengthened, enlarged, and its life extended, with relative ease

- Steel frames can be readily and cost-effectively strengthened to meet today's code requirements
- The reuse of an existing steel structure can lead to reduced project costs compared to building a new structure
- A new architectural aesthetic can be readily applied to an old steel structure creating an exciting building.

Case Summary: The innovation and design of the BMW Sales and Service Centre have garnered praise and acclaim from the architecture, design, and local communities, and successfully demonstrate a way forward for adaptive reuse of existing structures.

<u>Sample Project #9: Mountain Equipment Co-op Ottawa, Ontario</u> (CISC, 2007)

Date of Reused Steel: Unknown

The Mountain Equipment Co-op (MEC) store in Ottawa is a two-storey, 2,500 m² retail facility located on a shopping street close to downtown. Completed in June 2000, the store sells a variety of outdoor sports equipment and clothing and forms part of a chain of similar retail stores, many of which, like this one, address issues of sustainability in building practices. The project is an example of how a building structure can be taken down and key components reused in creating another building on the same site, significantly reducing the need for new materials, and potentially leading to environmental and cost benefits. This case study focuses on how the design team developed the new design to suit the requirements of the structural steel available from the old building on the site.

The MEC is a well-established retail company operating as a membership co-operative, supplying quality outdoor equipment in Canada for over 30 years. It operates retail facilities in 10 locations across Canada, from Vancouver to Halifax. The MEC prides itself on a reputation as a "green' company and has set an example to other commercial retailers about how to integrate environmental considerations into their activities. The MEC offers products designed to high standards for function, environmental impact, and long-lasting performance, with little to no packaging waste. They have applied a similar approach to their stores which follow rigorous green design principles. Some of the features found in their recently constructed buildings are: green roofs, composting toilets, day lighting systems, recycled or reused materials, radiant flooring, efficient heating and cooling techniques, and other energy-saving measures.

MEC is a particularly strong believer in reusing materials in construction, and reclaimed steel components are featured in several recently completed MEC stores, including those in Toronto, Ottawa, Montreal and Winnipeg. The Ottawa store is a notable early example of this philosophy of reuse. When MEC acquired the site, it was occupied by a 40-year-old two-storey former grocery store. Seventy-five per cent of this existing building, including the steel structure, was incorporated into the new building. Materials were chosen based on durability, recycled content, energy efficiency, life cycle costs, low embodied energy, low toxicity, and potential for reuse. The innovative approach to the design process allowed integration of systems and ideas for building sustainability at an early stage, which, in turn, led to a more efficient final product. In addition, the management of waste during construction led to significant reductions of waste going to landfill, and various strategies were adopted to conserve operating energy in the building. The MEC's design philosophy has never been strictly about appearance and budget; rather, it focuses on creating the most environmentally and socially sensitive structures possible. The Ottawa store was designed to meet C2000 low-energy design standards, and is one of the greenest retail buildings in the world, winning numerous accolades and awards.

The Ottawa project was innovative in both construction and design. The design team consisted of the owner, the architects, the structural engineers, the mechanical and electrical engineers, the landscape architect, the construction managers, and a C2000 consultant who facilitated the team design process. From the very beginning, and through every stage, the design team worked collaboratively. In addition to the expertise of their particular roles, the various consultants also contributed to the overall design development. This led to the early integration of building systems, including mechanical, electrical, and structural systems, which produced a more cost-effective and energy-efficient building. From rough sketch to final design, the entire process took approximately two months.

The process was organized into a series of nine meetings lasting up to two days each, with gaps of one to two weeks between them for preparation. Performance targets for the building were set by the Mountain Equipment Co-op, based on their research about green building, and included reducing the environmental impact of building materials. Other goals related to the performance of the building were dictated by the design team's aim to achieve a gold rating using the LEED® green building rating system. Selection of materials for the project was driven by the goal of using the maximum possible amount of salvaged, rather than new, materials. Thus, much of the existing building was reused. A further goal to obtain a minimum of 80% of all materials from within 500 km of the site was also achieved. The challenge posed by the site and existing structure was how to functionally integrate the components of the former grocery store into the new building to best serve its particular purpose. Both a single-storey and a two-storey design were considered. A single-storey option would allow full reuse of the existing building, but would necessitate the purchase of an adjacent property to expand the existing 1,000m^2 footprint to the more appropriate and larger square plan desired. A two-storey option would fit onto the existing site, but would necessitate the deconstruction of the existing building, with the components being reused.

At this point, preliminary energy modeling was carried out, and the GB Tool applied to the two options. The two-storey building option was favored for its greater energy efficiency and more suitable layout for the retail space. Costs for both options were found to be virtually the same. The existing structure was carefully disassembled in order to reuse the available steel components in the new building. No significant problems were encountered during the disassembly and reassembly processes. The steel components were labeled and taken off site, as there was no room for stockpiling, and, in any case, required modifications could be made in the shop, rather than at the site. Since the original roof deck was welded, its removal led to damage beyond repair. It could not be reused in the new building, and was sent for recycling as raw steel. The original open-web steel joists were not damaged, as they were handled with care during dismantling of the deck.

The steel columns, beams and open-web steel joists were used in the original building to support a roof with a snow load typical for Ottawa, but would not be suitable for a 5kPa retail floor load. Thus, the reclaimed steel was used for the roof structure above the second floor of the store, superimposed on top of a new structure which supported the second-floor slab. Fifty per cent of the total roof joists in the new building were reused steel, supplemented with new steel joists and a new deck. The final dimensions of the building were 37m frontage along Richmond Road and 34m along the parking lot side of the building.

The structural spans being worked with in the new building were relatively large, at 12m to 15m, but were based on the dimensions used to support the roof of the existing structure. This meant that the load requirements for the new roof were virtually unchanged, though joist spacing was tightened in some locations to accommodate the roof projections or rooftop equipment. The new structure supporting the first-floor slab, consisting of large salvaged Douglas-fir columns and beams, was chosen to create a timber-framed ground floor that also satisfied aesthetic requirements, with low embodied energy and high salvaged content. These timber components had to be sized, inspected, and graded to fit with the steel structure use on the second-floor. This structure created a two-storey form that provided a retail space for the building that would accommodate the interior climbing wall feature, wall displays, and a two-storey atrium space.

Reusing structural steel requires establishing with confidence the structural characteristics of the reclaimed steel components. In this case, the original specifications and drawings for the existing structure were available to the design team and contractor. They were used to label all the steel as it was dismantled. All the steel members were inspected for damage and assessed by the structural engineer to confirm their structural capacities. They were then used in the new building in such a way that they supported similar loads to their previous use. This was acceptable for building code compliance. Many of the steel columns and wide-flange beams were bolted together, and the open-web steel joists used on the roof were mostly welded. The fact that connections in the new structure are bolted will facilitate its disassembly at the end of its life. There was some resistance from three of the four contractors bidding for the project, because of the unfamiliar challenge of using reclaimed steel and this was reflected in a natural inclination to bid higher. Fortunately, the lowest bidder on the project was also very keen to undertake the work and very much interested in the concept of reusing steel, so this was the bid accepted. To assist the tendering contractors, an open house was held, where materials were viewed by demolition contractors and others prior to tender. Materials that were not reused or recycled in the new building were sold later at an on-site sale.

This project illustrates how a determined client and design team can incorporate significant quantities of reusable construction materials into a major structure, thus reducing its environmental impact. The building used 56% recycled or reused content by weight, working within time, distance, and cost constraints. MEC has since used a similar approach for several other stores, with successful results.

The reused steel in the second-floor structure was architecturally expressed as an open structure, clearly showing the reused components involved and demonstrating the possibility of reclaiming this material for a new use.

The following aspects of the process have been identified as key:

- A motivated and inspired client and project team are essential
- The process is helped if the client understands the benefits of sustainable design and sets an agenda early on for developing strategies for reuse of materials
- Identifying the structural characteristics of the salvaged steel is aided if original documentation is available and if the age of the steel is known
- Some contractors may be nervous about tendering for unusual projects of this kind. There is a need to educate contractors and work with them to ensure that full cost benefits can be realized
- Steel reuse is easier if the components can be reused for a purpose similar to their original one
- When incorporating steel from an existing building in a new project, using similar structural layouts and maintaining original span sizes in the new design makes reuse easier
- An integrated design process makes the integration of reclaimed components far more easily achievable
- Bolting steel facilitates eventual dismantling

Case Summary: The reuse of steel in this building contributed significantly to meeting demanding environmental goals, and offers a model for other projects. The reuse of materials in buildings is site- specific and time-dependent, requiring acceptance of adapting the design and construction process and availability of reclaimed materials, both of which, hopefully, will *increase as salvaging components from demolition sites and other buildings becomes more routine within the construction industry.*

Sample Project #10: Parkwood Residences, Oshawa (CISC, 2007)

Date of Reused Steel: 1970

Parkwood Residences is a good example of the reuse of the entire steel frame of an existing building for a new purpose. The building envelope and other components of an abandoned office complex are being removed, leaving the steel structure, which is being adapted and extended, including the addition of new floors, to create a unique new residential development. This project won an Ontario Economic Development Award in 2004 for the revitalization of a downtown area, "recognizing excellence in marketing and product development." This case study focuses on the design and construction issues that arose during the process of adapting the steel frame, and the benefits that resulted.

The project is located at 44 and 50 Bond Street West in an old urban neighborhood in Oshawa, Ontario. The entire scheme encompasses 8,900 m^2 (96,000 sq ft) of floor area and consists of 120 residential units, ranging from 45 m^2 (485 sq ft) one-bedroom units to 115 m^2 (1,240 sq ft) two-bedroom units, with associated car parking. The redevelopment of the existing buildings on the site by Atria Development Corporation is the first new condominium development in the area for 20 years and is contributing to the revitalization of this downtown area of Oshawa. The scheme will be completed in 2006.

The two existing buildings on the site were government owned offices built in 1970. They had been previously tenanted by the Regional and Provincial Courts and other government agencies, but had been abandoned for the last ten years. As a result, they were suffering from neglect, broken windows, and other vandalism, so that they had become neighborhood eyesores.

The municipal authorities were keen to rejuvenate the area and Atria Development Corporation, a development company experienced in converting urban industrial buildings into residential lofts, identified the potential of these buildings. Working with Core Architects, who have experience in adaptive reuse projects, they developed a proposal for conversion of the buildings to residential use.

Many such neglected steel-frame buildings, no longer suitable for their intended use, have the potential to be adapted for new functions that can help in the regeneration of their neighborhoods and can provide valuable new floor space economically. In this case, the structure was suitable for conversion into an interesting residential development, with high quality spaces featuring lofty floor to ceiling heights. The steel structure was flexible enough to allow the necessary changes to be made to accommodate the new use. The costs of alteration compared favorably to new build. The developers predicted a cost saving from 10 percent to 15 percent resulting from reuse of the existing frame, including the remedial measures necessary to ensure the suitability of the frame for its new use.

Due to the nature of this tight urban site, demolition of the existing buildings would have been awkward and expensive. This led Core Architects to consider several possibilities for redevelopment, including reusing the existing steel structure which had the flexibility to provide an adequate frame for residential units. It was decided to strip the buildings back completely to their steel frames and floor slabs and to rebuild. The site at 44 Bond Street had previously held a 10 storey office tower that was also used as a regional courthouse, with parking. The basement is being replaced by storage for residents, and the rest of the building is being converted entirely into residential accommodation with only minor changes required to the structure, which allows for a variety of residential configurations. Due to changes in level it was difficult to integrate retail space at ground floor level, so ground floor spaces are being used for residential amenities. The former 4-storey office building at 50 Bond Street is being converted into a residential building of 6 stories but requires additional changes. Parking is being relocated to the ground and second floors. The structural bay width provides an efficient layout for the car parking area and generous aisle space. There will be enough parking on the first two floors of 50 Bond Street for both buildings. However, the existing overall width of 50 Bond Street was too large to allow a double-loaded corridor access or sufficient day-light for the residential spaces. So, two bays are being removed, one from the north and one from the south side at the 3rd and 4th floor levels. This will reduce the depth of the building, making it more suitable for residential layouts and allowing terraces and balconies to be added. Finally, the structural over-capacity of the steel will allow 2 new floors to be added on top of 50 Bond Street, increasing it to 6 stories.

Both buildings consist of a steel frame structure with composite steel deck floors and a floor to floor height of approximately 3.5 m. This allows for generous ceiling heights of 2.7 m in the new residential units. Typical structural bay sizes are approximately 8.5 m by 8.0 m, allowing for 3 parking spaces within each structural bay. The structure consists of wide flange beams and columns with bolted connections for primary members, and open web steel joists for the secondary members. The depths of the primary structural beams at 44 Bond Street are 410 mm and at 50 Bond Street are 460 mm. Both buildings have secondary open web steel joist depths of 310 mm and column sizes ranging from 250 mm to 300 mm.

Initially, the design team used old survey drawings from the time the building was constructed. These, however, proved inaccurate and not consistent with existing construction, leading to some incorrect design decisions. Also, original drawings were available only for 50

Bond Street. A new survey was required to ensure that accurate data were used. A general lesson from such projects is that transformation of old buildings for new uses requires audits to establish structural and physical integrity and to check configuration, column spacing, and plumbness against the drawings. It is dangerous to rely on old drawings which may not be accurate. In this case, after the interior and exterior finishes were stripped back from the structure, including removal of the fire proofing, the existing structural steel was inspected by the structural engineer and declared to be in good condition and suitable for reuse. All of the steel beams and composite steel floor decks could be kept. In addition, it was found that, owing to the lower floor loadings in residential buildings, the existing office structure at 50 Bond Street could accommodate two additional floors for residential use.

To check the integrity of the foundations, three different columns were chosen and the footings were excavated to verify footing depth and conditions in accordance with the base building drawings. The foundations and weight of the soil were found to be in good condition. However, since 50 Bond Street is to have two new floors added, the foundations of eight columns are to be strengthened to deal with the additional loads. This requires excavation around the column pad footing and addition of a wider concrete pad. Such work needs to be carefully planned, as access for machinery in an existing building is limited, and smaller equipment may have to be used. It will also affect the programming of the work.

In order to satisfy current requirements for progressive collapse and seismic resistance, the original structure at 44 Bond Street has to undergo some minor alterations to be suitable for use as a residential building. These measures include stiffening the column to beam junctions to become moment connections, stiffening of some members by welding additional steel plate stiffeners in appropriate locations, and the addition of stiffening across the bottom cord of the open web steel joists. This is all being carried out on site with little difficulty. Since code requirements for residential floor loadings are lower than the office floor loadings used in the design of the original buildings, reinforcing the floors is not generally necessary. However, where the first and second floors of 50 Bond Street are being converted to car parking, an additional 150 mm of in-situ reinforced concrete has been specified to strengthen the floor for the additional loads. Concrete is also being added around the columns in the parking areas to provide fireproofing.

The two new levels that are being added to 50 Bond Street consist of a new steel structure replicating the bay sizes of the structure below. Since the old roof slab is now to be a residential floor, the old slab has been removed; including the metal deck and open web joists, and a stronger composite floor slab is being added that can accommodate the higher floor loads. This building also requires additional lateral support in the east and west direction. This is provided by the integration of new concrete shear walls. When converting existing buildings into residential accommodation, architects must address fire protection of the structure and maintaining fire separation between dwellings as one of the key issues. For both buildings, the original spray-applied fireproofing was found to be in good condition, but had to be removed to allow for the various adaptations. It is being replaced with new fireproofing and encased in drywall, giving a two hour fire rating. In tumescent paints were considered but rejected as too expensive. The high floor-to-ceiling heights of the old offices leave plenty of space within a drop ceiling to accommodate the sprayed steel. A smaller floor-to-floor height would have made the drop ceiling more difficult to integrate.

The high floor-to-floor height also allows plenty of room to accommodate the mechanical systems for the residences in the ceiling void and still leave a generous 2.7 m room height, adding interest to the residential spaces. Each unit is designed with its own air conditioning, gas heating, and hot water system, and these can be easily accommodated throughout the structure with some modifications. Services such as pipes and electrical wires are integrated within the drop ceiling and through cored holes in the concrete floors. However, the new glazed facade of the building requires spandrel panels to cover the drop ceiling zone behind. Vertical circulation is provided in existing elevator and stair shafts. One existing elevator shaft is no longer required and is being removed. The floor openings can be easily filled with a new floor slab. The existing elevator does not go down to the basement and so a ramp has been designed to allow easy access. Some modifications are required to the existing escape stairs in 44 Bond Street to reroute from the second floor to the ground floor and maintain a protected stair route.

Although Atria Development Corporation has past experience of converting older buildings into lofts, Parkwood Residences is the first reuse of an exclusively steel frame building. It offers the opportunity to create a unique building, appealing to live in for its history and interesting characteristics, such as ceiling heights. Learning experiences from this project will inform Atria's approach to future projects for building reuse.

The following key issues that affect steel reuse have been identified from this project:

- In tight urban sites, avoiding demolition offers a variety of benefits that can be readily realized in many steel frame buildings
- Reuse rather than new build does not necessarily require compromise on the number of units provided on the site
- Flexible design approaches help to maximize the benefits of existing structures. It is important for the design to remain open to changes during construction and to accept that decisions and details may need to be reviewed on site, as issues arise to a greater extent than with new build
- Integration of parking into the existing structural grid should be reviewed by a traffic consultant if bay size is not optimal

- Good quality data on the existing structure is essential. It is dangerous to rely on old drawings; these need to be checked with on-site measurements. An understanding of the construction practices of the time of the original construction is also helpful
- Steel frames can be readily strengthened and adapted at low cost
- Fireproofing can be difficult to integrate and requires careful consideration
- Cost comparisons with new build can be favorable. This project generated a saving of about 12.5 percent from reusing the structure. Reusing existing elevators with some modifications provided considerable cost savings, as they are expensive elements to integrate into a building

Case Summary: As more people and commercial businesses are attracted to the area, the success of the reuse of the existing government buildings on Bond Street West will grow. The example set by this scheme illustrates how major adaptive transformation of existing run-down commercial buildings into new residential uses can help revitalize neighborhoods and lead to further social and economic improvements.

<u>Sample Project #11: Roy Stubbs Elementary School</u> (CISC, 2007)

Date of Reused Steel: 1991

The Roy Stibbs School, an elementary school facility in West Coquitlam, British Columbia, serving School District No.43, is an example of the reuse of a large portion of a whole structure in a new location. After a fire, the school buildings had to be rebuilt very quickly to meet community needs. Another school in the northern BC community of Cassiar was no longer required and had been taken down. The steel structure from this building was reused to speed up the construction process at the Roy Stibbs School. The work consisted of 2,470 m^2 new construction and 975 m^2 renovation, and was completed in less than a year. This case study focuses on the issues that arose during the design and construction process, particularly relating to the reuse of steel components and the seismic upgrades that were necessary.

In 1991, the British Columbia government financed and built a secondary school in Cassiar, an asbestos mining town just south of the Yukon border in northern British Columbia. Less than a year later, the mine was closed due to financial difficulties related to changing mining methods. As residents left in search of job opportunities, the town emptied and the school was shut down. So in 1992, not wanting to waste a brand new school, the provincial government, through School District No. 60 Peace River North, hired Norson Construction to deconstruct the building. The entire school was disassembled for reuse. Efforts were made to salvage everything: open web steel joists, steel studs, t-bars, ceiling lights, doors, hardware, fixtures, windows, exterior cladding and all mechanical systems. The open web steel joists were torched off the supporting beams (they had been welded to the beams), and the remainder of the structure was unbolted and then loaded for transport to Fort St. John. Norson Construction used some of the steel and other components for the construction of Robert Ogilvie Elementary School in Fort St. John. However, the contractor noted that the deconstruction, transportation and then reconstruction, which necessitated multiple handling, or "touching three times," raised the cost of the reused steel so that it was comparable to the cost of new steel. Other non-structural components were incorporated into the construction of a new K-12 school in Hudson Hope, also built by Norson Construction for School District 60, with Killick, Metz, Brown, and Rose as the architects. After losing its classroom wing to a fire in December, 1993, the Roy Stibbs School in West Coquitlam needed to be rebuilt quickly. The fire left the staff and students without a school. They were forced to load onto buses everyday and commute outside their community to another school in Burnaby. The routine was difficult and it became very important for the community to rebuild the Roy Stibbs School as quickly as possible. Killick, Metz, Brown, Rose Architects were appointed to design the new building. They had also been the architects of the Cassiar Secondary School and were aware that the material from that school had been dismantled and the steel was stored in Fort. St. John. When it was apparent that Roy Stibbs School reconstruction would require a tight schedule, the architect, in discussion with the construction manager, Task Construction Management, suggested the reuse of steel from the Cassiar School. Once this decision was made, the new school building was designed to maximize reuse of the available steel. The Cassiar School was a central two storey building, with a single storey on either side housing the gymnasium and shop. It was decided that the two storey main part would be reused at Coquitlam.

Representatives from the Roy Stibbs School project flew to Fort St. John to properly identify and determine the viability of the structural steel that had been stockpiled. The site inspection report identified the steel as "*stored neatly outdoors …. Most was visible although some was buried in snow. Missing and located in Hudson Hope are the OWSJ* [open web steel joists] *for the upper floor and roof over the central corridor. Steel is generally in good condition*." The structural characteristics of the steel were determined from the original construction documents, and shop drawings of the Cassiar School and the components were prepared for transportation. It is estimated that over 75% of steel for the Roy Stibbs School came from Cassiar.

The original structure for the Cassiar School was designed for greater snow loads than required for Coquitlam but it was designed for much smaller seismic forces than required at the new location. After the decision was made to reuse the steel the structural layout for the new building adopted the same structural grid as used in Cassiar. The interior layout was adopted to suit the elementary school's functional requirements. This maximized the potential for reuse of the components, although there were some components that had to be redesigned to meet the new seismic loading requirements. Some of the joists had to have their chords repaired as they were damaged during dismantling and transportation.

On arrival in Coquitlam, the steel was inspected and damage from deconstruction and transportation was identified by an independent material testing consultant. A total of 466 open web steel joists were reused, most in the condition in which they arrived, needing only to be cleaned and touched up with primer. Others were later modified on site to work with the new structure. The cost of joist modification on site was $8,700. Some of the open web steel joists had bent and burnt-through chords and joist seats that required grinding where the flange was cut or gouged. The flanges of beams which supported the joists required filling and grinding at joist seat locations. Some bracing members were damaged at attachment to gussets. Fire proofing was mostly removed and the primer paint was in good condition except at welds. Upgrading of seismic characteristics with the addition of bracing plates was needed on the reused steel to accommodate the higher seismic zoning of Coquitlam. Dormers in the original Roy Stibbs School that were not damaged by the fire were reworked into the new building. New steel was used for braced bays, all bridging, the upper dormer roof, isolated beams and columns on all levels, and perimeter angles.

The major design issue that arose from the reuse of structural steel was the change in seismic requirements from zone 3 in Cassiar to zone 4 in Coquitlam. The Cassiar School was designed for approximately 50% of the seismic load requirements in Coquitlam. A new foundation was designed with crawl space grade beam walls along braced bays to provide resistance to overturning. Bracing had to be redesigned, not only to accommodate significantly greater earthquake forces but to suit the new layout. This resulted in fewer interior braced bays impacting the diaphragm design and connections between slab and beams. Fortunately, the

Cassiar School was designed for a snow load that was 2.5 times the snow load requirement of buildings in Coquitlam and so no additional problems were created by snow loading.
The total cost of structural steel was $353,266. The cost of transporting steel from Fort St. John to Coquitlam was $27,812. The cost of embedded steel was $7,960. The cost of seismic upgrade to reused steel was $78,674.

According to the structural engineer for the project, one of the “greatest challenges” with reusing structural steel at the Roy Stibbs School site was scheduling. With such a short project timeline, organizing the reuse of structural steel created many scheduling difficulties. However, this challenge was obviously overcome. The BC Minister of Education at the time declared the project “the fastest built school in the history of the province” since it was built in less than 7 months, and the school was completed less than a year after being destroyed by fire. This might not have been possible without reuse of an existing structure. The stockpile of steel ready for reuse was also an important factor in the successful reuse of structural steel in this project. It is often difficult to arrange for a timely delivery when the steel is being deconstructed from an ongoing demolition project.

The relatively easy alteration of the steel structure from one seismic zone to another demonstrates that steel can be readily adapted for new uses. The deconstruction, salvage, and reuse of structural steel from the Cassiar School are a successful example of how the components of existing buildings can become valuable resources for other projects. It also demonstrates how it may be possible to establish more closed loops in the Canadian construction industry and should be looked to for future possibilities in sustainable steel construction.

Case Summary: Roy Stibbs School was built prior to the introduction of the LEED™ green building rating system as a design tool in the Canadian construction industry (CaGBC, *2004). Many of the contemporary reasons for reuse, such as those supported through LEED® may not have been the driving force to reuse steel in this project. However, from a sustainable construction perspective, LEED® would have supported the reuse of structural steel in this project. LEED® includes two credits which can be achieved from the reuse of materials: Resource Reuse and Innovative Design. Resource Reuse ("Materials & Resources", credit 3) aims to extend the life cycle of building components by specifying salvaged or refurbished components. Innovative Design ("Innovation & Design Process", credit 1) aims to support green building design initiatives not included in the existing rating scheme. The reuse of steel can contribute to these LEED® credits, although it may need to be part of a larger strategy of materials reuse.*

<u>Sample Project #12: University of Toronto Scarborough Campus Student Centre</u> (CISC, 2007)

Date of Reused Steel:

The University of Toronto Scarborough Campus (UTSC) Student Centre is a new, three-storey, 4,700 m2 facility located along the entrance to the main campus. Completed in October 2004, the building is home to a range of student services, organizations and clubs as well as campus amenities.

Of the approximately 300 tons of structural steel in the Student Centre, 16 tons came from another building. The steel was deconstructed from the old Terrace Gallery of Royal Ontario Museum (ROM) and reused in the student office wing of the new Student Centre. This case study will track the processes that facilitated the reuse of structural steel components in the building from initiation of a reuse strategy and accessing a source of salvaged steel through deconstruction, fabrication, and erection of the reused steel. It is important to highlight the successful aspects of steel reuse during the building process and to recognize the strong commitment of the client and design team to overcoming challenges which arose throughout the design process.

At the start of the project, the client assembled a User Plan Committee to develop a building program emphasizing long-term sustainable goals that would best serve current and future students of the university. When the project entered the schematic design stage, the User Plan Committee became the Implementation Committee, ensuring that the stated objectives were realized in the project. The design team embraced the sustainability goals developed by the client and looked to the LEED® Green Building Rating System as a guide for their green agenda. A sustainable design charrette involving consultant and client representatives was organized to evaluate the site's development potential, architectural design opportunities, and possible environmental approaches. From this emerged a strategy for the possible reuse of materials, with particular opportunities identified for structural wood decking and structural steel, and efforts were made to source those materials.

Demolition companies were contacted to help identify possible sources of reusable steel. Sourcing components directly from a demolition in progress and tracking down available components in salvage yards emerged as two options. With no suitable demolition projects identified, the search turned to existing stockpiles of reusable steel. Unfortunately, the quantities of available steel components found in the salvage yards did not meet the project's needs (insufficient quantity of suitable members) and the process was abandoned. However, early on in the project, the wing under demolition at the ROM was identified as a possible source of crushed concrete for reuse as backfill and concrete aggregates in the Student Centre. Further investigation showed that while the ROM structure was largely of concrete there were also two penthouses with one-storey deep, long-span trusses built of wide-flange steel components potentially reusable in the UTSC project.

There was general support from the ROM and its designers for the steel to be reused, as long as the process did not interfere with their construction schedule. The University of Toronto was asked to cover the extra costs of deconstruction and transportation of the steel components. Establishing the structural characteristics of the reclaimed steel was easy, since the ROM still had original structural drawings of the building being demolished. The task was further simplified because the Student Centre's engineering consultants were also the design engineers for the original ROM addition being demolished and therefore already had archive copies of the drawings in their office.

The steel was salvaged from the ROM by the demolition contractor with little difficulty. The truss had to be separated from the two composite floors which it supported. During deconstruction, the steel was torch-cut, not sheared, to retain the largest useful length of steel possible and to reduce the risk of damage. The deconstruction contract included cutting the steel components to length and their delivery to the fabricator, up to 45 km from the site.

Initial concerns of the design team included the economic and environmental costs associated with transporting the salvaged steel. To minimise cost and environmental impact, the steel components went directly from the demolition site to the fabricator for cleaning, refabrication and painting. The surface finish of the reclaimed steel was similar to that of the new steel, but existing features (holes, clip angles) were left visible, so that the history of the reused steel would remain visible. The components had not been fireproofed, and reached the fabricator in reasonably clean condition. Shear stud projections and other leftover attachments were removed. According to the fabricator, the cleaning process required little additional work compared to new steel. However, a lack of advance knowledge of the steel's condition had made it difficult for the fabricator to accurately prepare a bid for the fabrication work. This, however, did not impede the project in any way.

Time constraints did create some problems, as delivery of the reclaimed steel to the fabricator was delayed due to problems at the ROM demolition site. This put into question the reuse process and necessitated the consideration of an alternate strategy for purchase. In the end, the steel did arrive in time for fabrication and delivery to site for assembly.

After fabrication, the reused steel components arriving on site for construction were treated no differently than new steel components and created no difficulties during erection. The steel was fabricated with bolt connections, offering a single mechanism for construction and enabling unbolting for future deconstruction and reuse.

The extremely tight schedule afforded no time for dealing with unforeseen circumstances. For successful incorporation of the salvaged steel components the design process had to remain flexible. Once the ROM demolition was identified as an appropriate source of reusable steel, the relationship between schedules of the two projects became crucial. Unfortunately, there was very little opportunity to synchronize timelines in order to make the steel reuse easier. The structural engineers began an iterative process of determining where and how the steel could best be integrated. It was decided that the amount of reclaimed steel available could not meet the structural needs of the entire project but would be sufficient for the student office wing, creating a focus on, and showcase of material reuse. Although reuse of steel was limited to one part of the building, the design team later realized that a greater amount of salvaged steel could have been incorporated into the building, with the exception of the large complex cantilevers that required specific sizing early on in the design.

The one-storey truss in the ROM had been built from wide-flange steel sections. These were reused as both columns and beams. The available sizes dictated the design of the structure, which resulted in deeper beams and some over-design; consequently, the structural framing was redesigned; the beams were rotated 90 degrees, allowing ductwork to fit properly within the designed ceiling depth. The steel was exposed, with visible scars (stiffeners, gussets, holes), but cleaned with a finish matching the new steel. The final aesthetic subtly shows the material's history; although the Architects expressed mild disappointment that the steel's past use was not more evident.

The cost of deconstruction and delivery of the salvaged steel to the fabricator was between \$4,000 and \$5,000. The extra cost of fabrication, namely, to grind off the shear studs, was \$6,000 to \$7,000. Comparing these amounts to the \$12,000 to \$15,000 that new steel would have cost indicates that the overall cost impact of reusing steel was neutral. However, as understanding of the reuse process in the industry improves, more opportunities will be identified and the cost of facilitating reuse will decrease.

The LEED® Green Building Rating System was used as a guide to the development and implementation of the project's sustainability agenda. The project is currently registered with the Canada Green Building Council and the architects anticipate that it will achieve a silver level of certification. LEED® includes two credits which can be achieved by the reuse of materials: *Resource Reuse* and *Innovative Design*. *Resource Reuse* ("Materials & Resources", credit 3) aims to extend the useful life of building components by specifying salvaged or refurbished components. *Innovative Design* ("Innovation & Design Process", credit 1) aims to support green building design initiatives not included in the existing rating scheme.

The cost of reclaimed steel accounted for only a small proportion of the total cost of building materials used in the project as availability of reusable materials was limited. Therefore, the building does not meet the 5% minimum required for the *Resource Reuse* credit. However, the architects are seeking a credit for *Innovative Design* because of the educational value of demonstrating successful reuse of steel.

The strategy for long-term sustainability developed by the design team and client at the start of the project was a major factor in its success. This highlights the importance of providing the client with information on the benefits of sustainable design and setting an agenda early on for developing strategies for material reuse. Although there are challenges in facilitating the reuse of structural steel, the following key lessons, learned in the process of designing and constructing the UTSC Student Centre, can help future projects:

- A strong commitment on the part of the client and the project team is fundamental
- The design should allow for the possibility of various depths of structural member, since it may be necessary to make adjustments depending on the availability of reclaimed steel and the servicing system used. This can be achieved by designing a flexible structural zone, within which various structural solutions can be accommodated
- Timing is critical if steel is being obtained from demolition projects that are in progress. Ideally, the reclaimed steel should be available two to three months (depending on the quantity required) before it is needed in the new project. Success is more likely if the two projects, deconstruction and construction, are carefully coordinated. Acquiring the steel ahead of time and storing it until it is needed could eliminate the timing issue
- Identifying the structural characteristics of the salvaged steel is easier if it is from a project for which original documentation is available
- Fabrication pricing can be difficult if the condition of the reclaimed steel surface is not well known. An accurate description of the salvaged steel, with images, or an opportunity to inspect it would improve the accuracy of the fabrication bid
- Quality control during deconstruction of steel is important in order to avoid damage which could make the steel unusable

- There needs to be better connection between demand for reclaimed steel and its supply. It would be useful to have access to a schedule of demolition projects, each with a brief project description

Case Summary: The reuse of structural steel in the UTSC Student Centre was a success and contributed to the client's agenda of long term sustainability. The process of facilitating reuse offers many useful lessons for the future projects that aim to reuse steel.

<u>Sample Project #13: Retail Reconstruction – Ottawa, Ontario</u> (CISC, 2007)

Date of Reused Steel:

This project followed an integrated design process that saw the contractor involved early on in the process. As part of the project team, the contractor was required to complete a detailed survey and inventory of the various types and quantities of materials found within the existing structure. After careful review by the project team the decision was made to reuse the structural steel from the existing building as a second story structure on the new facility. To facilitate this process, the contractor carefully labeled, disassembled, and stored the steel beams and columns identified for reuse until the time came for installation. The materials were tested by a qualified inspector to ensure their structural integrity. For this project the structural steel components that were reuse were wide-flange beams and columns and open-web steel joists. By reusing the steel components the project realized an approximate savings of $9,000 and a time savings of six weeks. The amount of steel that was reused was approximately 15% of the total materials by volume reused or recycled from this project.

Case Summary: This case study is a good example of reusing structural steel components extracted from their first use.

Many other projects were identified in the literature search that had some minimal components of structural steel reuse however they did not meet the minimal standard of reuse application as outlined in the limitations of this research. The most common form of reuse was for horizontal and vertical forming and shoring of concrete systems, a strictly temporary application not consistent with the intent of this research.

History of Structural Steel Production

For structural steel, a material with very high embodied energy, knowledge of the history of structural steel technology is necessary to place its' reuse into proper context. The history of structural steel dates back to the late 1800's where it was first introduced into the construction process (Burn, 1961). At that time, due to its untested nature as a structural system, professionals in the building industry did not envision just how prevalent it would be incorporated into the vast majority of new structures in one capacity or another that make up the built environment. It did not take long for constructors of the built environment to realize the enormous potential of using steel as the structural frame for new buildings. Many factors contributed to the rapid rise in its use to include availability, ease of erection, low cost, adaptability to designs, and constructability. Throughout the twentieth century steel increased in use exponentially, almost without hindrance or control (Warren, 2001). Eventually, non-renewable natural resources necessary for the production of new steel started to dry up or become unduly expensive to extract from the earth. In addition to the availability of iron ore, pressures to start recycling steel and produce building materials that have less negative impact on the environment have become commonplace and in some cases demanded by society. Soon manufacturers realize they could produce new steel using almost all recycled scrap cheaper and more efficiently than the use of iron ore as the main material resource. At this point recycled steel scrap is the main source in the production of structural steel components in the building industry (MSC, 2008).

Sustainability

Recent expansion of the built environment has created an awareness of how man is impacting our ecosystems by depleting, at an ever increasing and alarming rate, our non-renewable resources. These natural resources are the material components needed to create and build new structures. What has become increasingly clear is the supply of many of the needed resources is very limited and if their use is continued at present rates depletion could soon lead to extinction.

Sustainability has become the driving force behind a new manner in which we design and construct the built environment. Needs of both present and future generations must be based on two fundamental concepts: (1) the fair and just intergenerational allocation and use of natural resources, and (2) the preservation of biological systems function across time (Kibert, 1999). There are many definitions of sustainability that must be evaluated in order to fully understand how structural steel reuse is linked to each of them:

- Meeting the needs of present without compromising the ability of future generations to meet their needs (Kibert, 2008)
- Understanding the interconnections among economy, society, and environment (Sustainable Measures, 2008)
- The belief, begun by modern environmentalists and social justice advocates, that all of society must work together to preserve the earth's resources and ecosystems

The concept of increasing reuse of structural steel components extracted from existing structures coincides with the aforementioned concepts. This unique approach allows us to continue expansion based on social demands and needs while significantly lessening the impact of our natural systems and resources; especially the non-renewable type.

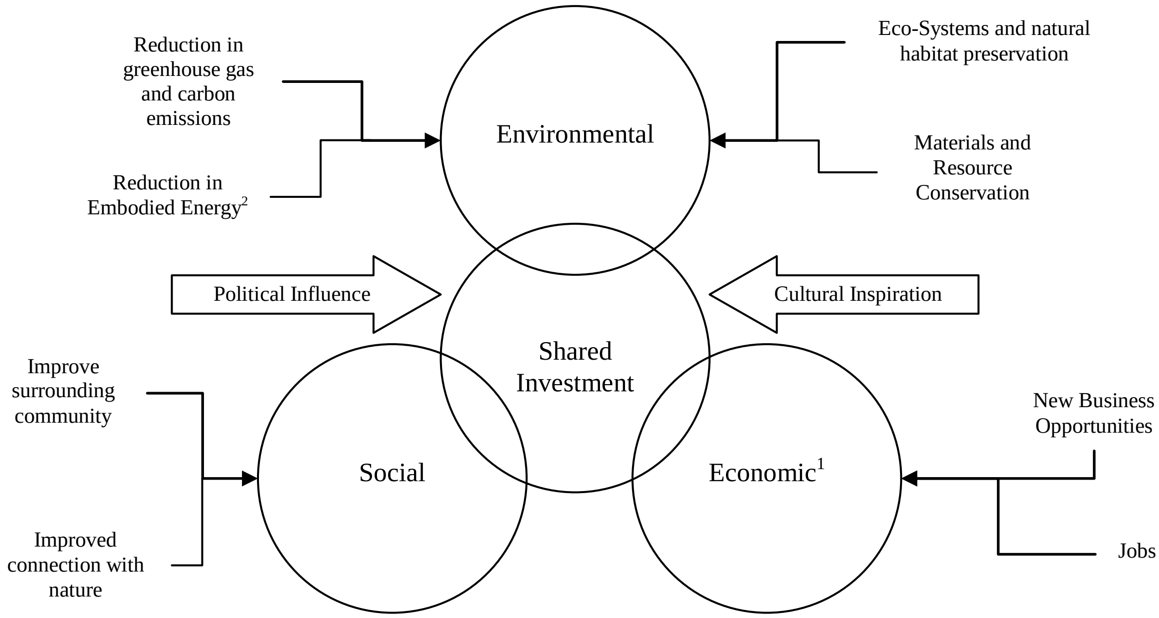


Figure 2-1. Sustainable linkage to the world

Notes to Figure

1. Does not include economic benefits for green buildings
2. Lower embodied energy leads to reductions in use of fossil fuels

To generalize, simplify, and gain agreement as to what sustainability is, the definition can be summarized as a system that delivers services without exhausting resources over time and uses all resources efficiently in an environmental, social, and economic sense (Celik, 2006).

Embodied Energy

All materials consume energy in their production, transportation, and installation. The impact these processes have on our environment and resource depletion is not readily apparent. A more technical way of evaluating a material is to consider its embodied energy, or the energy needed to produce a building product. The high amounts of embodied energy necessary to produce recycled steel products or import recycled steel products from outside the country in lieu of reusing steel makes it easily understandable why the building industry should pursue steel reuse vigorously to become more sustainable in this aspect of construction. In theory, steel sections could have multiple uses beyond its first use thereby significantly reducing the amount of embodied energy needed to support the demand for structural steel (see Figure 2-4). Since positive environmental impacts are one of the most important benefits of structural steel reuse, it is critical to understand the role of embodied energy plays in not only the analysis of reused steel potential but also the comparison with new steel on the basis of energy usage.

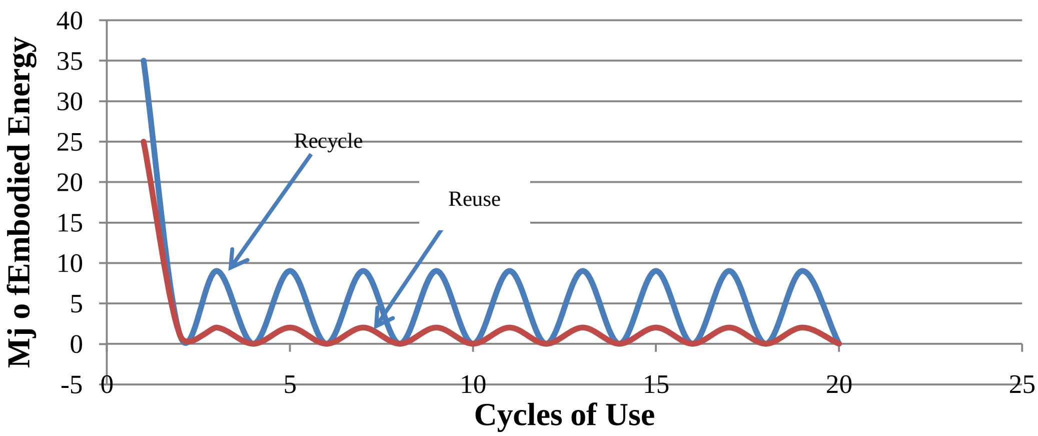


Figure 2-2. Embodied energy comparison

<u>Note to Figure</u>

1. Total Mj is approximated to illustrate the differences between recycled and reused

Defining Embodied Energy

Traditionally considered, embodied is an accounting methodology which aims to find the sum total of the energy necessary - from the raw material extraction, to transport, manufacturing, assembly, installation as well as the capital and other costs of a specific material - to produce a service or product and finally its disassembly, deconstruction and/or decomposition (Oikos, 2008). Any definition of embodied energy must consider the quantity of energy required by all of the activities associated with production cycles, including the relative amounts of energy consumed in all activities upstream to the acquisition of resources and the portion of energy used in making equipment and in other supporting functions i.e. direct energy plus indirect energy.

Different methodologies produce different understandings of the scale and scope of application and the type of energy embodied. Some methodologies are interested in accounting for the energy embodied in terms of oil that supports economic processes. Other types of methodologies are concerned to account for the energy embodied in terms of sunlight that supports ecological processes. And others like systems ecology are concerned about the support of the ecological-economic process as a whole. Embodied energy as a concept used in systems ecology seeks to measure the "true" energy cost of an item, and has extended this to the concept of "true" value. Methodologies such as emergy (Kibert, 2006) have also sought to link embodied energy with fundamental concepts, such as capacitance for example, in physical, electronic and chemical sciences.

Embodied Energy Comparison

In choosing between alternative building materials or products on the basis of embodied energy, not only the initial materials should be considered but also the materials consumed over the life of the building during maintenance, repair and replacement. As buildings are becoming more energy efficient in their operation, the embodied energy is approaching half the lifetime energy consumption (Sustainable ABC). When decision-makers are making material selections in the design process the most common approach considers the cycle of embodied energy consumption only up to and including initial installation. In terms of this research project the embodied energy comparison is focused on recycled steel vs. reused steel with the cycle ending at installation. Structural steel has four distinct source options as a construction resource; (1) virgin steel produced from iron ore mined in the US, (2) recycled steel (domestic), (3) recycled steel (imported), and (4) reused steel (domestic for purposes of the research). Figures 2-3, 2-4, and 2-5 illustrate the differing levels of E_e consumed in their production and installation.

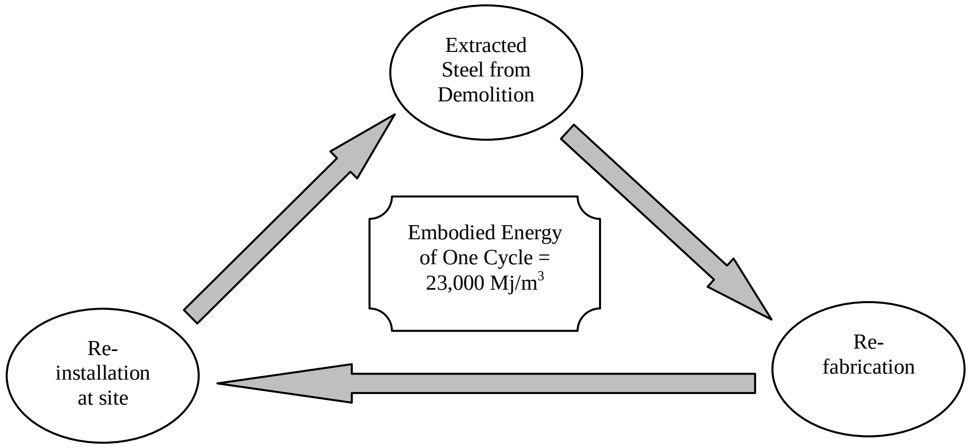


Figure 2-3. Embodied energy of reused steel (Architecture, 2030)

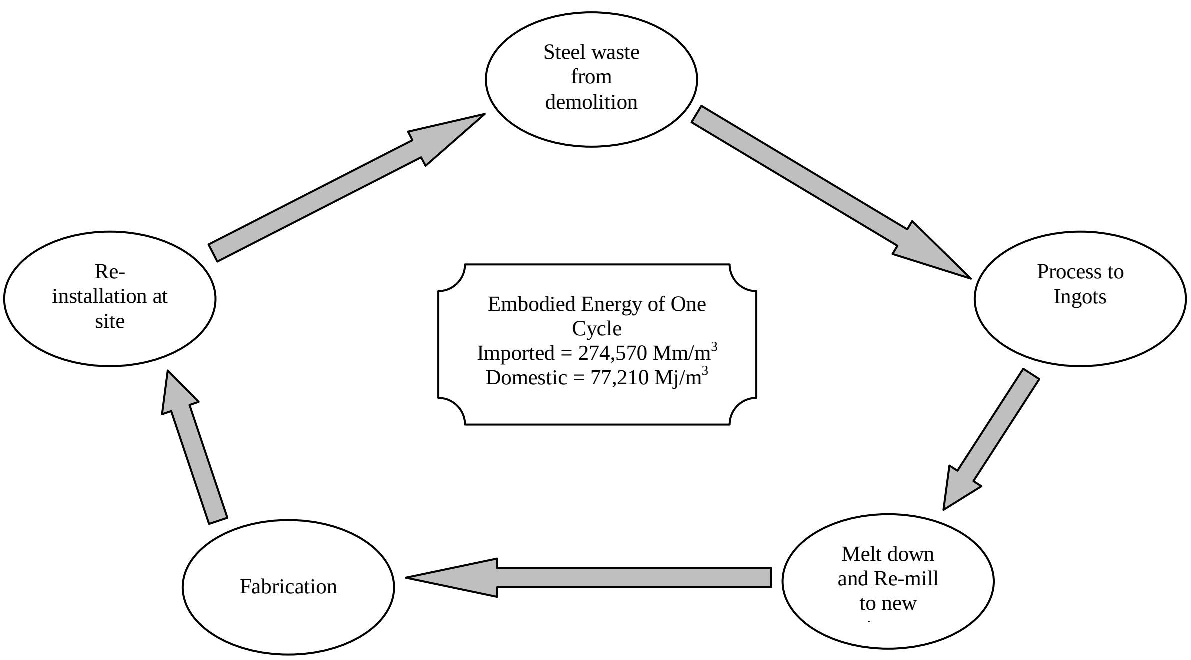


Figure 2-4. Embodied energy of recycled steel (Architecture, 2030)

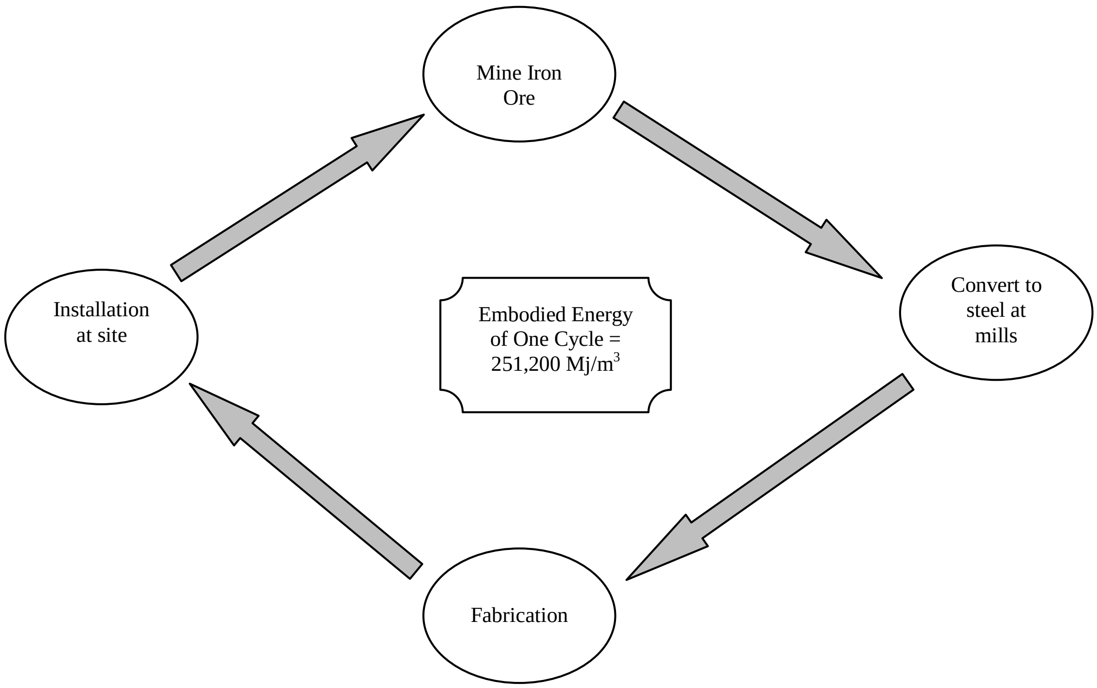


Figure 2-5. Embodied energy of virgin steel (Architecture, 2030)

Since the vast majority of recycled structural steel comes from imported sources the key relationship that bears analysis is between imported recycled steel and domestic reused steel. On that basis the differences in E_e are significant; reused steel consumes less than one tenth that of imported recycled steel.

Importance of Embodied Energy

Embodied energy is one measure of the environmental impact of construction and the effectiveness of any recycling, particularly CO_2 emissions. Evaluation of construction materials selection and use on the basis of their amounts of embodied energy conforms to a standardized way in which one material or system can be compared to another. Materials are currently compared in unlike terms such as cost, quality, and durability which cannot be translated into common units of comparison unless you implement processes such as Multi Criteria Decision Making (Schuyler, 2001) to measure the expected utility (EU) or Expected Monetary Value (Schuyler, 2001) to synthesize the amount of impact they end up having on the environment.

Converting all materials and the processes that support them up to and including final installation into units of embodied energy (MegaJoules (Mj)) is an objective type of analysis.

Variances

One example is the embodied energy per unit mass of materials used in building varies enormously from about two G_j per ton for concrete to hundreds of G_j per ton for aluminum. We must be careful however in considering all values for materials over the life-cycle of the structure. Using embodied energy values alone to determine preferred materials is inappropriate because of the differing lifetimes of materials, differing quantities required to perform the same task and different design requirements. We can however use this appropriately as the initial measure of assessment in the selection of our materials and systems.

Embodied Energy in Steel

Structural steel components manufactured from raw materials contain very high amounts of embodied energy. Since over 97% of structural steel used in construction comes from recycled steel materials (SRI, 2008), the embodied energy in the structural steel systems for a typical project are lower than its virgin steel equivalent but still very high as compared to other structural materials such as concrete or masonry. Reuse of structural steel still does contain significant amounts of embodied energy although they are derived out of the handling, transportation, and installation processes with little energy needed for remanufacturing. As table 2-1 indicates reused steel has approximately one-tenth the embodied energy of recycled steel in terms of the material comparison only.

Material Recycling

Recycling of building materials is the most common and oldest form of practicing sustainable construction applications within the expansion of the built environment (CBO). Of all of the options available to the project team this is the least desirable in terms of lowering the environmental impact of the project. This is due mostly in part to the significant amounts of energy needed to re-process the materials and get them back into the material supply stream. For many building materials this option is viable and desirable due to the properties of the materials themselves. For example, the only acceptable way to reuse concrete is via a recycling process where it is demolished entirely, the reinforcing bar is separated out, and the concrete itself is crushed to a predetermined size to be used as road bed material or foundation backfill. This process can be fairly energy-intensive, much more so than reuse of structural steel components in their extracted state where reinvestment of energy is minimal.

Adaptive Reuse

When the original use of a structure changes or is no longer required, as with older buildings from the industrial revolution, architects have the opportunity to change the primary function of the structure, while often retaining some of the existing architectural details that make the building unique. In local communities, unused schools such as Post Office buildings have been adapted for reuse as retail stores or offices. Adaptive reuse, along with Brownfield reclamation, is seen by many as a key factor in land conservation and reducing the amount of sprawl. For those who prescribe to the smart growth concept, it is more efficient and environmentally responsible to redevelop older buildings closer to urban cores than it is to build new construction on faraway Greenfield sites (Kibert, 2008). Old buildings often outlive their original purposes. *Adaptive Reuse*, or *Re-use*, is a process that adapts buildings for new uses while retaining their historic features. An old factory may become an apartment building. A rundown church may find new life as a restaurant, and a restaurant may become a church. This form of reuse approach can be very attractive and in truth is the most beneficial of all the forms of material reuse or recycling in terms of sustainability (See Figure 1-1 in Chapter One). Because this approach is centered on reusing an existing structure in its current state very little materials derived from non-renewable resources will have to be invested in the project. In the pursuit of sustainable development, communities have much to gain from adaptively reusing historic buildings. Bypassing the wasteful process of demolition and reconstruction alone sells the environmental benefits of adaptive reuse. Environmental benefits, combined with energy savings and the social advantage of recycling a valued heritage place make adaptive reuse of historic buildings an essential component of sustainable development.

Demolition and Extraction

Progress in the realm of steel reuse is limited at best and even in the genesis initiatives which are increasingly and somewhat aggressively attempting to increase, progress is slow and laborious. The literature review process has revealed a small number of companies which have just started to dabble in the reuse of structural steel products. There are also a very limited number of written publications to include textbooks, white papers, peer-reviewed articles, and online sources which speak to this subject area with any real definitiveness. A number of distinctive steel extraction methods have been used to some degree of success and are available in the demolition industry. Each of the methods has specific advantages and disadvantages respective to extracting a specific component without causing any significant damage to its future load-bearing capabilities. The results of the literature review did not expose any one method as being appropriate to meeting the objectives of this research.

Deconstruction

Deconstruction is a process of building disassembly in order to recover the maximum amount of materials for their highest and best re-use. Re-use is the preferred outcome because it requires less energy, raw materials, and pollution than recycling does in order to continue the life of the material. As a consequence of deconstruction, there are also many opportunities for recycling other materials along the way (Guy, 2003).

The benefits of deconstruction, ranging from the diversion of demolition debris from landfills to the creation of jobs and job skills have been documented elsewhere. Numerous examples from across the country illustrate how buildings can be successfully deconstructed and how salvaged materials can be collected and distributed for reuse. A complement to demolition, this process allows crews to enter a building and systematically dismantle its systems and components within the intention of putting the materials back into the construction material supply stream. The recovered materials are then resold for use in new construction and renovation projects, or for remanufacture (i.e., turning wood framing into fireplace mantles). Items that can't be reused are recycled - by turning damaged wood into mulch, or cement foundations into aggregate for new foundations and sidewalks. Since deconstruction will eventually play a crucial role in the development of structural steel reuse it is important to understand the process itself, the coherent steps, and the overall function it will play in increasing the reuse of structural steel. Numerous examples from across the country illustrate how buildings can be successfully deconstructed and how salvaged materials can be collected and distributed for reuse. To date, steel has not been the major construction material targeted for reuse deriving from the deconstruction process. Since deconstruction of buildings both in the context of current construction processes as well as 'designing for deconstruction' are critical to the idea of structural steel material reuse, it is critical to understand the key role deconstruction plays and will play in the advancement and increase of structural steel material recovery and reuse.

Reasons to Deconstruct

Every year, many buildings are demolished without much consideration given to the negative impacts or alternative removal approaches such as deconstruction. A wrecking ball tears through the walls, the structure is reduced to rubble, and literally tons of waste is carted away to landfills and incinerators. The benefits of deconstruction, ranging from the diversion of demolition debris from landfills to the creation of jobs and job skills, have been documented elsewhere. Deconstruction provides an alternative; a way to take down buildings while building local economies, creating new jobs, preserving natural resources, saving millions in public sector funding. Via this process, social, environmental, political, and economic benefits are realized across a wide spectrum of the building industry.

Role of Deconstruction in Materials Reuse

Deconstruction is widely regarded as a relatively low-skill activity. While this is true for the bulk of work conducted at a deconstruction site, the overall deconstruction process must be managed with skill and expertise. The most important skills required for the successful implementation of deconstruction projects are the ability to assess a structure for its deconstruction potential, to plan the optimal sequence of tasks, and to train and direct laborers in proper deconstruction techniques to ensure that salvaged materials retain their maximum value (Chini, 2003). There are many challenges facing the demolition sector of the construction industry when it comes to deconstruction; especially in the area of deconstructing structural steel components. These challenges included but are not necessarily limited to existing buildings not initially designed for dismantling; specific building components that have not been designed for disassembly without damaging the integrity of the component (especially true with structural steel); tools and equipment have not reached the stage of technological development to efficiently and effectively remove materials targeted for reuse; building codes, regulations, and restrictions currently do not adequately address the concept of materials reuse; material performance standards have not been developed to address materials reuse; and the cost of deconstruction is for the most part an unknown variable. Overall the most significant problem facing deconstruction today is the fact that architects, engineers, and builders of the past visualized their creations as being permanent and did not make provisions for their future disassembly (Chini, 2003).

The process of dismantling structures is an ancient activity that has been revived by the growing field of sustainable, green building. Buildings, like everything, have a life-cycle. Deconstruction focuses on giving the materials within a building a new life once the building as a whole can no longer continue. When buildings reach the end of their useful life, they are typically demolished and hauled to landfills. Implosions or 'wrecking-ball' style demolition is relatively inexpensive and offers a quick method of clearing sites for new structures. On the other hand, this method of thinking dictates a wasteful process. It is important to realize that many of the components within old buildings remain almost as, if not more, valuable than at the time the building was constructed. Deconstruction is one method of harvesting what is commonly considered "waste" and reclaiming it into useful building material. Deconstruction helps to close the resource loop that we now realize is so valuable in this world of finite resources. Due to few clearly defined processes or procedures for deconstructing buildings many materials will not enter the reuse cycles. Further exploration and research will eventually increase reuse of materials that are currently not deconstructed.

Connection to Sustainability and Reuse

Deconstruction has strong ties to environmental sustainability. In addition to giving materials a new life cycle, deconstructing buildings helps to lower the need for virgin resources. This in turn leads to energy and emissions reductions from the refining and manufacture of new materials. As deconstruction is often done on a local level, many times on-site, energy and emissions are also saved during the transportation of materials. Deconstruction can potentially support communities by providing local jobs and renovated structures. Deconstruction employs 3-6 workers for every one employed in a comparable demolition job. In addition, solid waste from conventional demolition is diverted from landfills. This is a major benefit due to the fact that construction and demolition (C&D) waste accounts for approximately 20% of the solid waste stream (Gorgolewski, 2006).

Common Deconstruction Methods

Deconstruction is commonly separated into two categories; structural and non-structural. *Non-structural* deconstruction, also known as "soft-stripping", consists of reclaiming non-structural components appliances, doors, windows, and finish materials (reference). The reuse of these types of materials is commonplace and considered to be a mature market in many locales. *Structural deconstruction* on the other hand involves dismantling the structural components of a building. Traditionally this had only been performed to reclaim expensive or rare materials such as used brick and extinct wood. Throughout history, it was common to raze stone buildings and reuse the stone; it was also common to extract stones from a building that was not being totally demolished. Used brick in particular has a long tradition of reuse due to its durability and color changes over time. Recently, the rise of environmental awareness and sustainable building has made a much wider range of materials worthy of structural deconstruction. Low-end, commonplace materials such as dimensional lumber have become part of this newly emerging market.

Economic Viability

Deconstruction's economic viability varies from project to project. As with most construction processes they are driven by financial viability and passing the cost/benefit test. The amount of time and cost of labor are its main draw backs. Harvesting materials from a structure can take weeks, where as demolition may be completed in relatively short time period. However, some of the costs, if not all, can be recovered. Reusing the materials in a new on-site structure, selling reclaimed materials, donating materials for income tax write-offs, and avoiding landfill "tipping fees" are all ways in which the cost of deconstruction can be made comparable to demolition.

Reclaiming the materials for a new on-site structure is the most economically and environmentally efficient option. Tipping fees and the costs of new materials are avoided; in addition, the transportation of the materials is non-existent. Selling the used materials or donating them to non-profit organizations is another effective way of gaining capital. Donations to NPO's such as Habitat for Humanity's Restore are tax deductible. Many times you can claim the value to be half of what that particular material would cost new. When donating rare or antique components it is sometimes possible to claim a higher value than a comparable, brand-new material (reference).

Value can also be added to new structures that are built by implementing reused materials. The U.S. Green Building Council's (USGBC) program entitled Leadership in Energy and Environmental Design (LEED®) offer seven credits relate to reusing materials. (This accounts for seven out of maximum sixty-nine credits) These include credits for building-shell reuse, material reuse, and diverting waste from landfills.

Practice

When choosing to deconstruct a building there are some important aspects that need to be taken into consideration. Developing a list of local contacts that are able to take used materials is an essential first step. These might include non-profit organizations, contractors, and a local landfill (some materials will need to be disposed). The next step involves identifying which, if any, are hazardous materials. Lead paint and asbestos are two substances in particular that need to be handled extremely cautiously and disposed of properly.

It is common practice, and common sense, to "soft-strip" the structure first; remove all appliances, windows, doors, and other finishing materials. These will account for a large percentage of the easily sellable components. After the non-structural deconstruction, structural is the next step. It is best to start at the roof and work down to the foundation although the actual sequence or deconstruction is left up to the contractor responsible for work under what is generally known as means and methods. Building components that are dismantled will need to be stored in a secure and dry location (if applicable). This will protect them from water damage and theft. Once separated from the structure, materials can also be cleaned and/or refinished to increase value. Building an inventory list of the materials at hand will help determine where each item will be sent.

Designing for Deconstruction (D_fD)

An upstream approach to deconstruction can be implemented into buildings during their design process; a current trend in sustainable architecture. Often times simple construction methods combined with high-grade, durable materials work best for D_fD structures

(LifeCycleBuilding.org). Separating layers of a building's infrastructure and making them visible can significantly simplify its deconstruction. Making components within systems separable also assists in being able to dismantle materials quickly and efficiently. This can be achieved by using mechanical fasteners such as bolts to connect parts. Allowing physical access to the fasteners is another needed aspect of this design. Also, it is important to use standardized materials and assemble them in a consistent manner throughout the project.

Some conventional construction methods and materials are difficult or impossible to deconstruct and should be avoided. The use of nails and adhesives significantly slow down the deconstruction process and have a tendency to ruin good materials. Avoid hazardous materials altogether as they detrimental to the natural environment and are non-reusable. Using mixed material grades make the process of identifying pieces for resale difficult. Attempts to use similar grade woods and metals and identical length members throughout the structure are a much more comprehensive approach. Deconstruction is important for more than just the end of a building's life-cycle. Buildings that have been designed with deconstruction in mind are often easier to maintain and adapt to new uses. Saving the shell of a building or adapting the interior space to meet new needs is the ultimate choice in terms of environmental sustainability. Flattening a salvageable building and building a similar one in its place is generally inadvisable.

Construction Material Supply Loops

Since the main focus of this research is to close the material supply loop (Souren, 2004) of structural steel in construction by increasing its reuse, it is important to understand where and how steel components fit into the material supply chain for a typical construction project. The current material supply loop for structural steel contains many steps as part of recycled steel being the main supply source for construction projects. As Figure 2-5 illustrates the new concept of reusing structural steel components saves many steps in the supply loop all of which have inherent time, money, and resource implications. Additionally, each step in the supply loop that can be eliminated will serve to reduce the cumulative embodied energy of the material and thereby create less impact to the environment.

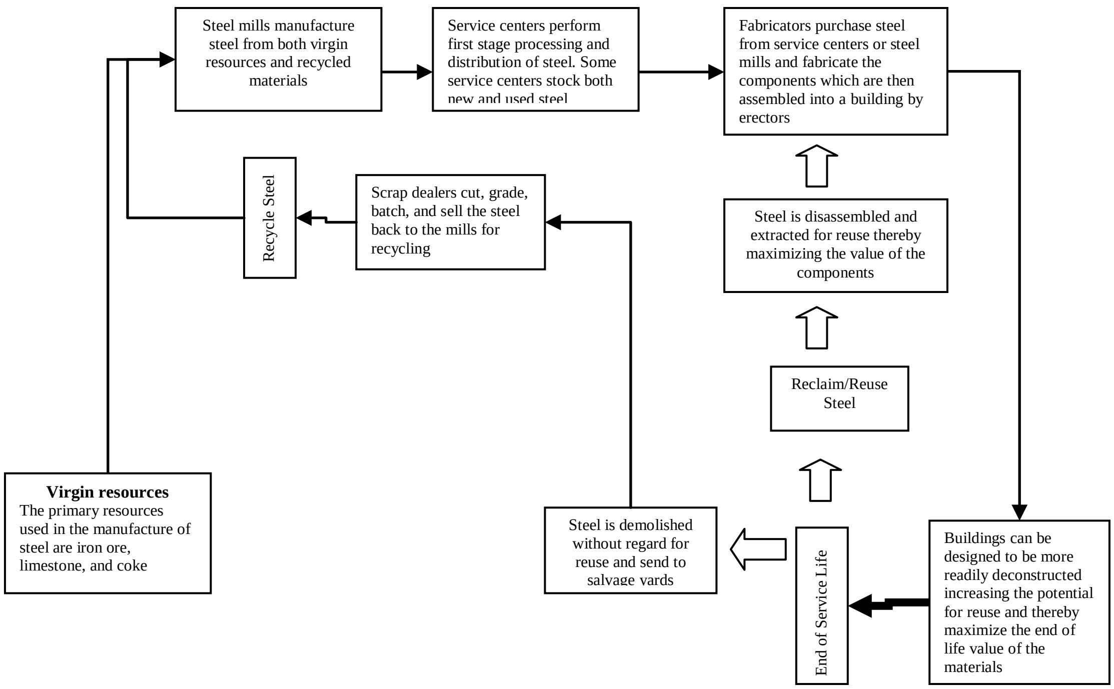


Figure 2-6. Material supply loop for structural steel

Construction Costs

Since the reuse of structural steel components in the construction process is in the genesis stages at this point, there is very little data available regarding the costs of reclaiming and reusing this type of construction material. Some general assumptions can be made however within the context of costing of similar materials and systems. The approximate construction costs of using reusable members is made up of materials, disassembly (extraction), storage, temporary work, transportation, maintenance, re-fabrication, and erection. Although there is no hard data available due to the steel reuse process being a leading-edge concept, Figure 2-7 illustrates the approximate percentages each area of cost would represent relative to the total cost of reusing structural steel. These costs have been derived out of the known costs of new steel construction with added categories of cost unique to the reuse process. As this new process unfolds and matures detailed and accurate costing will become available thru experience and repetition.

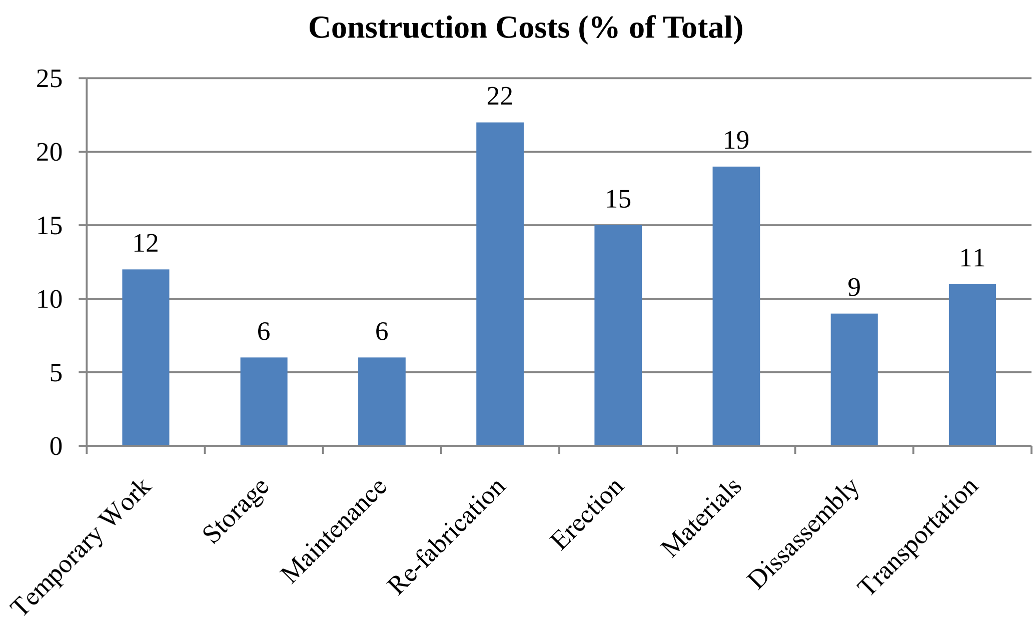


Figure 2-7. Construction cost allocation for reused steel components (Fujita & Iwata, 2008)

As figure 2-5 indicates the major portion of costs of reused steel is the materials and re-fabrication. The more we initiate the idea of structural steel reuse and attempt to use reclaimed sections in their extracted state as much as possible the more cost-effective the process will become via reduction in re-fabrication and disassembly costs.

Structural Performance Considerations

For serious consideration to be given to the idea of reusing structural steel components their needs to be a significant focus on the performance characteristics reclaimed steel must meet similar to those of recycled steel products. The reclaimed materials must meet the performance characteristics of recycled or new steel products and essentially be able to perform comparably to recycled or new steel sections. One of the most positive aspects of structural steel is that it retains is structural performance capabilities over time (Smith, 1996). In other words steel sections removed from buildings that have been in use for many years will in most cases have retained their strength properties. Steel undergoes no major changes owing to aging, except for rust and plasticization caused by large-scale earthquakes. Such excellent material properties render steel suitable for reuse (Fujita & Imata, 2008). The limitations however are connected to the type of loads the steel has been under during its service life. Steel sections which have been subject to vibrational or cyclical loading would most likely not be qualified candidates for reuse. Also, steel sections which have been subjected to extreme heat or undo loading would also not be selected for reuse (limitations for reuse are discussed in later chapters).

Increasingly, designers are looking for opportunities to use steel components from demolition of existing buildings in their new designs. Reuse of steel components requires designers and contractors to be more flexible in approach. Salvaged components may not be readily available off the shelf, and may be difficult to source. One of the principal problems with reuse is to co-ordinate demand with supply, and this can affect the whole design and construction process - reclaimed materials do not show up at the right time, in the right amount or the right dimension (subject to availability). With a traditional approach to design, the steel components are specified and sized to suite the spanning requirements of the architect's proposals. This is not a problem if new steel components are to be used, i.e. off the shelf. However, reused components do not generally come "off the shelf"; rather they are identified on demolition sites by salvage contractors. Thus, when moving to the construction phase the required size of salvaged steel may not be readily available. This may necessitate redesign to suite available salvaged components or choosing whichever oversized components are readily available. To maximize the potential for reuse, the starting point for the new design may in the future be an inventory of the available materials from salvage.

Steel Reuse: LEED® and Environmental Impacts

The applicable section in the LEED® rating system (see Appendix D) that covers materials and resources (Credit 1) focuses on reuse of building components, waste management, recycling, and certification of material sources. Incorporating steel components targeted for reuse can be a significant step forward as a means of accumulating additional points under this section. The concept of reusing steel components has far-reaching and significant environmental impacts. One ton of imported recycled steel contains approximately 275,000 Mj of E_e. This translates to 2,270 tons of carbon released into the atmosphere. Reuse of structural steel components significantly reduces the need to draw on already depleted natural resources.

Summary of Literature Review

The review of existing literature directly related to the research topic was limited in nature do to its significant cost and logistical constraints for reusing structural steel components. A limited number of case studies were revealed which partially touched on steel reuse or reused steel in a very limited application. Extensive literature material indirectly related to the research topic was discovered which helped intensely in framing the research questions and objectives. The main source of material discovered was via articles published on the internet and papers published in professional journals. Very few textbooks specifically cover material usable for this research project. From the literature review it is apparent that various recommendations exist, however there is still no solid evidence in the history of previous research that indicates the reuse of structural steel components, at least within the context of this research project, i.e. reuse in the structural steel systems/frames of new construction.

CHAPTER 3
METHODOLOGY

Introduction

The goal of this research is to develop a decision process model to address the issues necessary to increase the reuse of structural steel components in construction. This chapter contains a comprehensive framework and descriptive narrative of the methods used in the conduct of this research study. The research is for the most part exploratory in nature and requires a comprehensive approach to identify and analyze the potential of reusing structural steel members by reintroducing them back into new structures as part of the expansion of the built environment. The approach to developing the methodology for this research project was conceived from the construction industries need for a structured and comprehensive process, which is not presently in place; that efficiently and cost-effectively increases the reuse of structural steel members extracted from existing structures slated for demolition or deconstruction. Within those parameters a four-phase methodology process was developed that addressed current deterrents and challenges inhibiting the current reuse of structural steel components. Since the design and construction process contains many separate entities each with their own agendas and goals, one of the aims of this research was to bring them together in a more collaborative initiative to support the idea of structural steel reuse.

Case Studies

Within the built environment there are many projects either slated or targeted for demolition or deconstruction that on the surface seem suitable for steel reuse. Most of these projects have some elements of structural steel contained within them. This does not mean however they are appropriate projects for use in this research. A suitable project must contain a minimum set of conditions and meet minimum objective set of criteria to qualify as being a reasonable study subject for steel reuse.

To allow a more comprehensive research approach as well as suitable access to actual samples of structural steel components, specific projects were identified for use as case studies. Several Milwaukee area contractors agreed to provide access to select projects or buildings for purposes of this research project. Each of the case study projects were scheduled for removal or demolition as part of a larger project. Additionally, the case study buildings were assessed to be good candidates for structural steel reuse, i.e. contained some amounts of wide-flange steel beams. The process and criteria for their selection is outlined in Figure 3-1.

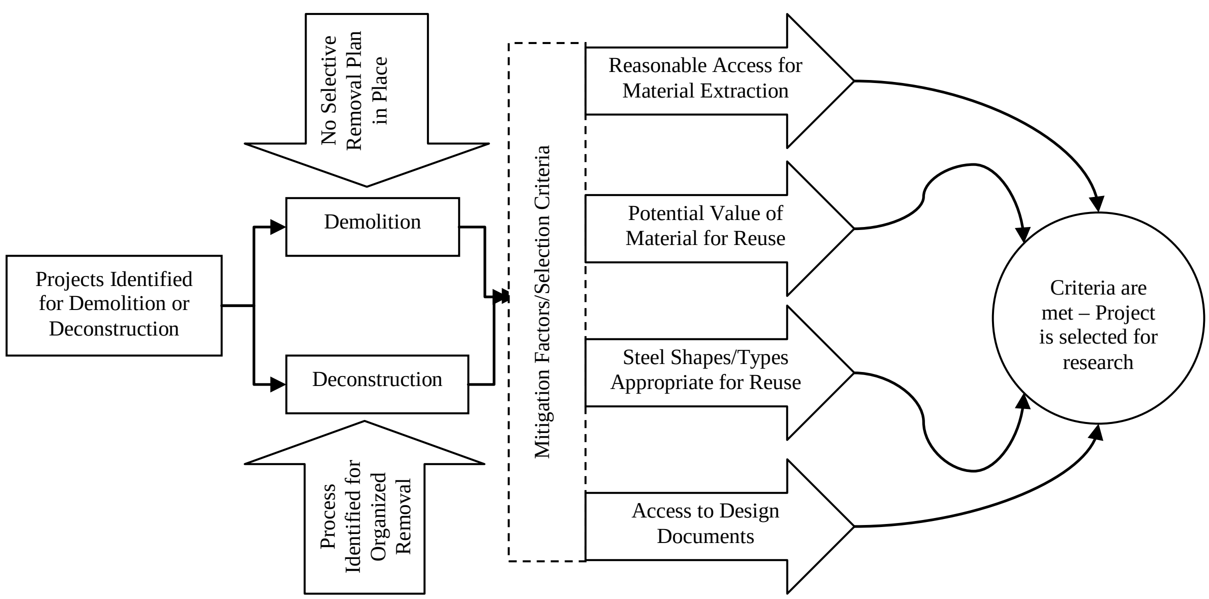


Figure 3-1. Project selection model

Once the preliminary projects were fed through the selection model only two were deemed appropriate to conduct further study per the model's analysis: (1) reasonable access was available to remove steel sections for reuse without compromising time or safety, (2) the steel targeted for extraction was in good shape (visually) and contained a high resale value potential, (3) the steel shapes available for extraction were very common in use in many types of buildings (good marketability), and (4) access was given to design documents (albeit of limited nature) of the building about to be demolished or deconstructed. Analysis of the case study projects produced valuable information in the development of the specific steps in the methodology of the research. For example, the information extracted from the case study projects contributed to development of questions asked in the surveys and interviews with the target groups.

Research Questions

In order to clearly define the most appropriate research questions for this project a process was developed to elaborate on all potential factors; direct, indirect, or peripheral that will bring about the most accurate results. Figure 3-2 below outlines the research question development process and illustrates the outcome of the development of the most appropriate research questions. Although Figure 3-2 was not a specific step in the research process it did contribute significantly to placing the research project in proper context within current industry practices which then led to development of the most appropriate questions that addresses the problem statement.

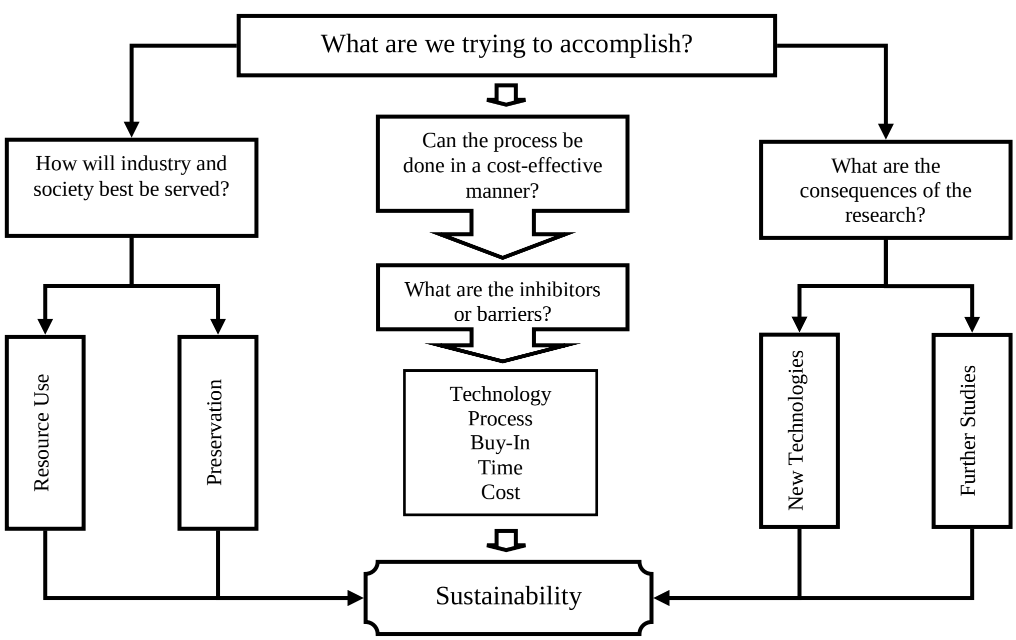


Figure 3-2. Research question development model

The resulting research questions were developed from the model input-output process:

Primary: (1) How can the building industry significantly increase the reuse of structural steel components in their extracted state?

Secondary: (1) How can the cost of steel component extraction and reuse be reduced to the point where it is more economically attractive to potential users?, (2) What is the best way to market the extracted products to designers and builders?, (3) How does steel reuse compare with steel recycling within a specific set of comparison metrics such as cost, embodied energy, material selection?, (4) What kind of testing criteria are necessary to re-certify steel components identified for reuse?, and (5) What kinds of methods are available to extract structural steel components in a non-destructive manner?

Research Objectives

The approach of the research will be focused on two major objectives. The primary objective is to develop a decision process model which will enable us to significantly increase reuse of structural steel components in their extracted state. The model will outline the critical and necessary steps from identification of a potential project to reintroduction of the reused steel back into the construction materials supply stream. The second objective will be to find ways to decrease the cost and resources needed to extract structural steel components thereby making the idea more palatable and achievable to the stewards of the built environment.

Limitations of the Research

As stated in Chapter 1 the scope of the research is limited by a number of distinct factors to assure a definitive focus in achieving the primary objectives. The following variables were the controlling factors in the research parameters:

- Finding suitable contractors and projects in which sample sections could inspected and potentially removed for analysis

- Response rate for surveys
- Participation of survey respondents for interviews
- Funding for testing and recertification of extracted steel shapes
- Code compliance for materials reuse
- Lack of a well established mechanism for exchange of steel components
- Technology available to remove steel components without damaging their structural properties
- Only wide-flange rolled sections were studied in the research

Research Design

The design of the research is focused on the appropriate and practical steps needed to allow the construction industry to implement a pragmatic approach to increasing the reuse of structural steel components. Presently there are numerous tasks that will have to be accomplished in each phase of the research process, each with their own challenges. Each of these tasks has been addressed in detail in order to develop a content of efficiency to the entire process of steel reuse. Figure 3-3 outlines each the information gathering process model and how it was used to develop the major phases of the research. Figure 3-3 also serves to summarize the scope and depth of the research as well as a conceptual outline of the basic approach.

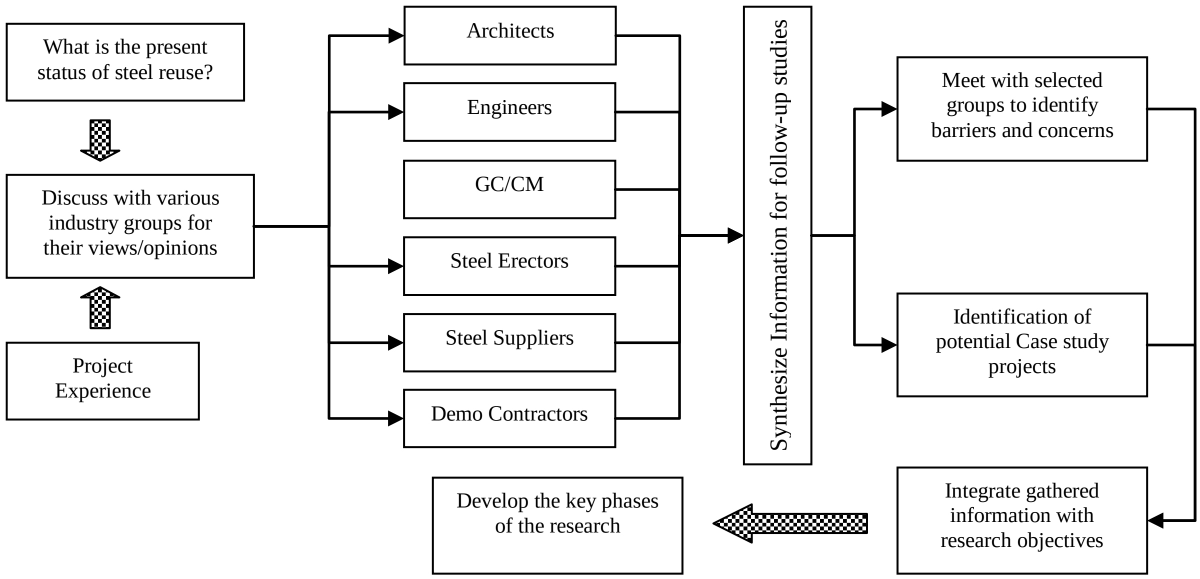


Figure 3-3. Information gathering process model

The first step in the information gathering process was to compare the current state of structural steel reuse with anecdotal experiences for a wide range of industry representative groups. This somewhat informal process provided the base approach to determining those factors that were either preventing steel reuse, had the potential to, or were distinct concerns within the context of the point of view of each industry group. The information that was gathered was synthesized down to key cogent points and integrated into the research objectives. The end of the information gathering process was the key driver in the development of the five phases of the research. The information gathering process, as illustrated in Figure 3-3, is essentially a precursor action to Phase I; and initiated after the literature review was complete.

From the information gathering process the distinct phases of the research were developed as outlined in Figure 3-4. The research is divided up into five distinct phases encompassing all relevant steps to address the overall focus of the research project. Each phase is discussed in detail to present the logical steps necessary to accomplish the research objectives.

At each phase critical action-items were developed to gather the information and data necessary to eventually develop the final decision process model.

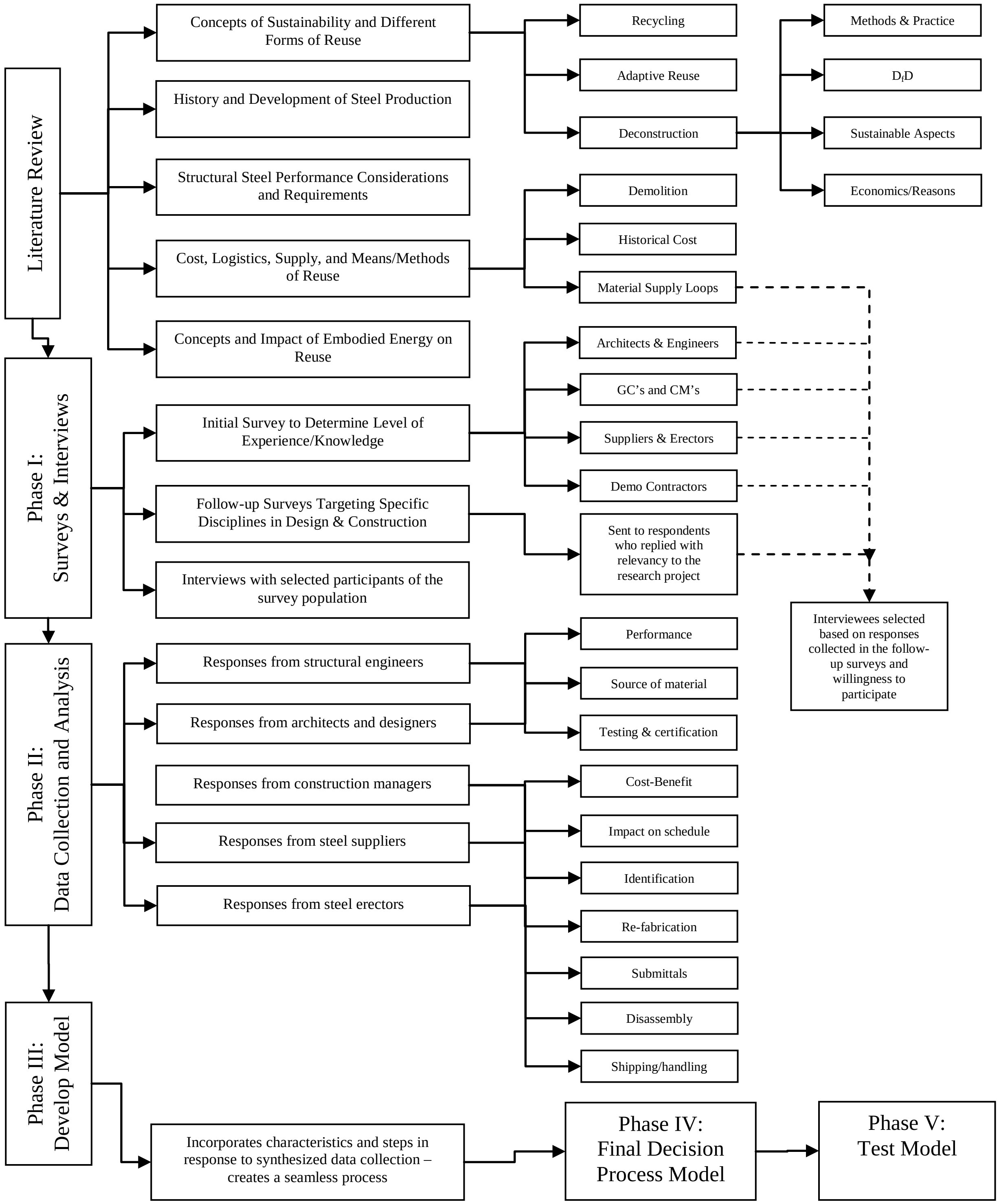


Figure 3-4. Methodology of the research

Phase I: Surveys and interviews

The first surveys were data gathering by nature and were sent out to the same industry groups as represented in Figure 3-3 to collect basic information regarding their general level of experience in various aspects of sustainability to include structural steel reuse. Once the surveys were collected and the responses analyzed they were used to develop the questions for the second set of surveys. The second round of surveys were targeted at specific disciplines and groups with questions directly relating to their experience and views of steel reuse and how their own community fit into the overall concept (See Appendix A and B for samples of the surveys).

Once all of the surveys were conducted, collated, and analyzed the results were used to develop the interviews questionnaires with those survey respondents who agreed to sit for an interview. The main objective of the interviews was to confirm survey responses, clarify and qualify their comments and concerns, validate the information that was collected, and ask follow-up questions that arose out of the survey responses. The aim of the survey and interview process was to determine their experiences in retrieval and reuse of structural steel components as well as identify specific projects where structural steel components were reused. The information gathered from the responses played a key role in the final development of the extraction and removal process. A secondary goal of the interviews that were conducted with the target research population firms was to determine the following: (1) coordination of sample removal, (2) logistical considerations for onsite procedures, and (3) feedback from the crews removing the samples.

Phase II: Data collection and analysis

All of the survey and interview responses were then culled through to find common points of professional concern and ideological intersections between the various constituencies.

These concerns and intersections (crossing points) provided the logical starting point and were the initiator for Phase III, developing the decision process model (Chapter 5 contains the findings of the surveys and interviews).

Phase III: Develop prototype model

Development of the model had to consider many aspects of the entire construction process; from conception to completion. These considerations included the following as a base minimum:

- Engineers concerns regarding performance of reused steel as compared to new steel
- Architects concerns about condition of steel after the extraction process
- Construction managers concerns regarding the cost-benefit of reusing steel, availability and ability to supply the demand for steel, and logistics
- Erectors concerns focused on training (or the lack thereof), safety, and technology and equipment that supports the research objectives
- Suppliers and fabricators concerns regarding material approval

Many other issues that were revealed in Phase III are addressed in more detail in Chapters 4 and 5 which help close the material supply loop of structural steel.

Phase IV: Develop final decision process model

In order to provide stakeholders of the built environment with accurate and relevant information regarding reuse of structural steel components a decision analysis process model (see Chapter 4) was developed which will assist decision-makers in applying the most efficient steps to achieve the goal of significantly increasing the reuse of structural steel sections in the construction industry. The results of Phases I thru IV is shown in the decision process model as illustrated in Figure 4-1.

Phase V: Test model

The final step will be to test the model and its effectiveness in real project situations within the AEC Industry. This will require participation from a wide range of stakeholders to ensure all steps within the model are adequately supported. Testing of the model is discussed further in Chapter 7, Recommendations for Further Research.

Summary of Methodology

The goals and objectives of this research project was to develop a decision process model to increase the reuse of structural steel sections thereby closing the material supply loop of this frequently used construction material and decreasing the cost and resources necessary to extract structural steel sections for reuse. The outcomes of this research will provide the stepping stones or critical next steps in providing a foundation of knowledge for future builders of the built environment to reuse structural steel sections in lieu of recycling them. The resulting impact of this research will provide the underlying theory as well as practical steps necessary for real-world applications in the building industry. Additionally, a clear direction as to the next steps in continuation of research in this area is discussed.

CHAPTER 4
RESULTS

Introduction

This chapter outlines the results of the surveys, interviews, and discussion/analysis of the findings of the research. The findings of the research generally support what was revealed in the literature review; specifically the lack of literature, research, or writings regarding structural steel reuse. Data that was collected and analyzed was the basis of the development of the decision process model in Chapter Five as well as the supporting models which were used to cultivate the specific steps in the model itself.

General Findings

A coordinated or collaborative process does not exist within the AEC industry which synchronizes all participants in the construction process to make structural steel reuse more common; consequently no substantive steel reuse is occurring today that incorporates reclaimed components into new facilities as part of the permanent structural frame system. The general findings of the research are:

- Design and engineering methods do not address reuse of structural steel components
- Comprehensive testing requirements for steel reuse have not been clearly defined
- Construction means and methods specifically dealing with removal and extraction of structural steel components do not encompass quick, safe, and cost-efficient ways to remove the steel sections
- Building codes and regulations do not address reuse of structural steel components
- Education and awareness of the enormous potential of benefits to society and the building industry are lacking
- The cost of reusing steel is significantly more than purchasing new
- The environmental impact of reused steel is significantly less than that of recycled

- Lack of well established and easily available mechanism for exchange of reclaimed components

- Steel maintains its strength, durability, and shape if not subjected to undo forces such as vibration, cyclical loading, excessive wind, earthquakes, corrosive chemicals, or fire therefore structural steel sections reclaimed from existing structures can be reused with little or no re-fabrication

- Most reuse is either occurring in vertical and horizontal shoring and forming or the random use of single sections in various parts of the design and not be reused as part of new structural steel systems

- Current building codes and regulatory requirements do not address this type of material reuse

Surveys and Interviews

Surveys and interview questionnaires were developed to collect data relevant to the research objectives as well as query industry professionals as to their thoughts and concerns regarding the research project. The initial surveys targeted a wide-ranging group of stakeholders in the built environment and the follow-on interviews focused on specific professional groups to gather more specific data and information for use in the decision process model. The validity and reliability of the findings is derived out of the numerous responses for the surveys and the cooperation of many industry professionals for the interviews.

An initial survey was sent out to 55 (See Table 5-1) architects, construction managers, and general contractors to determine the general status regarding materials use and/or reuse within the building industry with a response rate of 58%. The purpose of the survey was to:

1. Determine the level of experience where building demolition or deconstruction was part of the scope of work for their projects

2. Determine the level of experience where material recycling or reuse was part of the project scope of work

3. Determine the level of experience where structural steel component reuse was part of the new building design and construction

Responses from the initial survey were used to develop the specific target groups for the interviews, develop the format of the interview questionnaires, and generate specific question types to be asked.

Table 4-1. Initial survey responses (n = 32)

Question	Responses
What type of work is the main focus of your company?	General Contractor (22%) Construction Manager (25%) GC/CM (31%) Architect (12%)
Does your company have experience with projects where building demolition was part of the scope of work?	Yes (100%) No (0%)
Does your company have any experience with projects where deconstruction as part of the scope of work	Yes (75%) No (25%)
Does our company have any experience with material recycling as part of the project requirements?	Yes (100%) No (0%)
Does your company have any experience with material reuse as part of the project requirements?	Yes (23%) – See note 1 No (77%)
Does your company have any experience with projects where structural steel components were used a part of the permanent structure?	Yes (6%) – See note 1 No (94%)

<u>Note to Table</u>

1. For both yes responses the structural steel components were not reused as part of the new structural frame but rather for filling in of masonry lintels and mechanical openings on a building that was being remodeled

The results shown in Table 5-1 clearly indicate a number of fundamental conditions present in the construction industry today regarding aspects of the research:

- All respondents had some experience with projects that included building demolition
- 75% of the respondents had some experience with projects that included limited elements of deconstruction
- All respondents had some experience with projects that included recycling as a requirement or incentive
- Very few of the respondents had some experience with material reuse as part of the project scope

Once the surveys were analyzed within the relevance parameters of the research the results and comments were used to develop and structure the interview questionnaires. The survey results provided a clear indication of which specific professional groups should be interviewed to gain the greatest insight into identifying those issues directly related to the problem statement and research questions; (1) structural engineers, (2) steel erectors/suppliers, and (3) construction manager/general contractors.

The first set of interviews were conducted (see Table 5-2) with structural engineers to collect data regarding their professional perceptions of reusing structural steel components as well as their opinions about specific elements of structural steel design that would be affected by reusing structural steel components. The objective of the survey was to:

1. Determine the level of experience (if any) that the structural engineers have had with deconstruction or materials reuse (specifically structural steel)

2. Determine their general and specific concerns with the idea of reusing structural steel components and how they might be addressed
3. Determine what specific testing would be required and what specific industry standards would be applicable for structural steel reuse

4. Determine the relevant inspection processes that must be employed for structural steel reuse

Table 4-2. Structural engineer interview responses (n = 17)

Question	Responses
Do you have any experience in projects involving deconstruction as part of the structural engineering design or scope of work?	Yes (6%) – See note 1 No (94%)
Do you have any experience in projects involving materials reuse as part of the structural engineering design or scope of work?	Yes (18%) – See note 2 No (82%)
Do you have any experience in projects where reused structural steel components were part of the structural engineering design or scope of work?	(Yes 24%) – See note 3 (No 76%)
	Individual Responses - # in ( )
What do you think are the biggest hurdles to overcome for the idea of reusing structural steel components recovered from existing structures?	Owner acceptance (5) Verifying the grade of steel (6) Code officials (5) Cost (15) Storage/transportation (2) More design review time (4) Testing (6)
What testing processes or procedures would you require before a recovered structural steel component could be reused in a new project?	Tensile for Yield stress (14) Elongation (8) Weldability (4) Hardness (3) Equivalent to mill cert. (9) F_y strength (15)
How would the shop drawing/submittal process have to be altered for reuse of structural steel components?	Needs to include reused component identifications (11)
How would the specifications have to be different for reused structural steel components?	Should include unique aspects of reused steel (9)

4-2. Continued

Question	Response
Would you require any type of affidavits or verification that the proposed steel to be reused has never been subject to extreme heat, known overloading, or unusual atmospheric conditions? If so, please elaborate on your response.	Yes (100%)
What kind of visual inspection criteria would you require as part of the initial assessment as to whether or not a specific steel component could be reused? Please explain.	Per AISC guidelines
What specific ASTM standard would be the most appropriate for addressing the reuse of steel such?	Not sure
Would you as a professional get involved in this type of materials reuse?	Yes (88%)
What ideas do you have in this area of research which would increase the likelihood of structural steel reuse?	See specific findings

Notes to Table

1. Deconstruction did not involve structural steel
2. Material reuse did not involve structural steel
3. Steel section reuse was not part of the new structural steel frame

The results shown in Table 5-2 reveal some key points on where structural engineers stand regarding sustainable segments of the construction process and specifically reuse of structural steel components:

- Cost of reusing structural steel components was a major issue
- Ideas on testing requirements was fairly consistent as to what types of tests would be adequate and appropriate
- Unanimous agreement on requiring source material information
- Vast majority of respondents would get involved in this process at the professional level

A second set of interviews were conducted (see Table 5-3) with steel erectors/suppliers to collect data regarding their professional concerns and ideas regarding the reuse of structural steel components as well as their opinions about specific elements of structural steel design and construction process that would be affected by reusing structural steel components. The purpose of the interviews were:

1. To determine their level of experience in materials reuse

2. To determine their level of experience in deconstruction

3. To query the respondents for new ideas as well as any obstacles that may exist to reuse of structural steel components

Table 4-3. Steel erector and supplier interview responses (n = 18)

Question	Responses
Do you have any experience involving deconstruction as part of the structural steel scope of work?	Yes (0%) No (100%)
Do you have any experience in projects involving reuse of structural steel sections in the scope of work?	Yes (11%) – See note 1 No (89%)
What do you think are the biggest hurdles to overcome for the idea of reusing structural steel components recovered from existing structures?	Buildings designed for deconstruction 83% Lack of technology17%
What sort of extraction (reverse erection) issues would need to be addressed?	Efficiency Safety
Should the extraction of steel sections be part of the demolition or steel erectors scope of work?	Yes 100%
Would their need to be additional training for steel erectors for this idea to succeed?	Yes 100% - See note 2
What is the safety concerns involving deconstruction and extraction of structural steel members?	Unfamiliarity with the process
Are the appropriate equipment, methods, and technology available to extract steel sections safely and cost-effectively?	Yes (6%) No (94%)
What do you believe the cost of extraction will be relative to the initial erection costs?	

Notes to Table

1. Only in terms of limited application such as lintels for masonry walls but not part of the new structural steel frame

2. The necessary training would involve use of new equipment and technologies not yet developed

The results shown in Table 5-3 clearly indicate a few fundamental conditions present in the construction industry today regarding aspects of the research:

- Additional training in areas such as disassembly is necessary

- Significant improvement needs to be made in new technologies and equipment for the disassembly activities

- Structural steel deconstruction should be done be steel erectors, not by demolition contractors as is presently the case

A third set of interviews were conducted with construction managers/general contractors to verify and augment information collected in the initial survey. Table 5-4 displays the responses to the interview questions. The purpose of the interviews were:

- To determine the level of experience in materials reuse and deconstruction
- To reveal issues and concerns regarding the research topic and what changes need to be made in order for the idea to go forward
- Identify safety and means/methods issues connected to the disassembly process

Table 4-4. CM/GC and architect interview responses (n = 23)

Question	Responses
Do you have any experience involving deconstruction as part of the structural steel scope of work?	Yes (13%) No (87%)
Do you have any experience in projects involving reuse of structural steel sections in the scope of work?	Yes (30%) – See note 1 No (70%)
What do you think are the biggest hurdles to overcome for the idea of reusing structural steel components recovered from existing structures?	Buildings designed for deconstruction 83% Lack of technology17%
What sort of extraction (reverse erection) issues would need to be addressed?	Efficiency, Safety
Should the extraction of steel sections be part of the demolition or steel erectors scope of work?	Yes 100%
Would their need to be additional training for steel erectors for this idea to succeed?	Yes 100% - See note 2
What are the safety concerns involving deconstruction and extraction of structural steel members?	Lack of experience in disassembly
Are the appropriate equipment, methods, and technology available to extract steel sections safely and cost-effectively?	Yes (6%) – See note 3 No (94%)
What do you believe the cost of extraction will be relative to the initial erection costs?	Average response = 25 – 50%

<u>Notes to Table</u>

1. Only in terms of limited application such as lintels for masonry walls but not part of the new structural steel frame
2. The necessary training would involve use of new equipment and technologies not yet developed

The results shown in Table 5-4 clearly indicate a few fundamental conditions present in the construction industry today regarding aspects of the research:

- Current equipment and technology available today does not meet the needs of deconstruction and disassembly

- Efficiency of disassembly and deconstruction processes need to be reviewed and improved

- Additional training will be required for many aspects of the deconstruction process

Following the structured question/answer portion of the interview the interview was asked to provide general and specific thoughts to the concept of reusing structural steel.

Specific Findings and Discussion

Within the construct of all aspects of the construction process, the findings are categorized by corresponding representations of architects, structural engineers, construction managers, steel erectors, and steel suppliers/fabricators.

Design

Architects thoughts and concerns, more generalized and less technical in nature, focus on the following issues:

1. The ability of the industry to meet the material demands for structural systems with reused steel as the key resource component, i.e. a steady supply of reused steel

2. Lack of overall industry experience in deconstruction of structural steel systems

3. Lack of supportive historical cost data regarding the comparative cost of reused steel vs. new

4. Convincing their clients (owners) that reuse of a structural material of this type is safe and appropriate

5. Lack of supportive documentation as to the environmental benefits; more research is needed to identify valid data to support belief that steel reuse is sustainable

6. Furthering the concept of designing buildings for deconstruction --- responding architects believe this will only happen with a collaborative effort within the AEC continuum

Engineering

Structural engineers performing in the capacity of the EOR are hesitant to move forward and be willing to stamp the approval drawings until the following concerns are addressed:

1. Comprehensive testing program to certify the reclaimed steel can perform as well as new --- a wide range of testing procedures (both non-destructive and destructive) are available for implementation and requirement by the EOR and the most appropriate tests must be identified to meet the structural performance requirements without adding undo cost and time delays to the reuse process

2. Certification that the reclaimed steel has not been subjected to undo loading or other conditions which could reduce its load carrying capacity or performance characteristics to include extreme heat, vibration (earthquakes), or corrosive chemicals

3. Source documentation via affidavits confirming the source of the reused steel to include building type, age, and location

4. Specification (CSI Division 05000) that addresses the specific and unique issues reuse of structural steel brings to the table (see Appendix I)

5. Develop alternate types of steel connections which are easier to release during the disassembly process

Construction

Construction managers, steel erectors, and supplier/fabricators discussed some ideas and of concerns in terms of cost, methods, and logistics:

1. Find ways to reduce the cost of reuse so it will be equivalent (or relatively close) to that of new steel

2. Creating a supply database that will incorporate available reused steel sections to allow broader access for contractors

3. New ways of deconstructing buildings --- interview respondents felt this is a means and methods issue but should be addressed by architects, engineers, and contractors

4. Training of erection and demolition contractors in more efficient and safe ways to disassemble buildings --- this will be especially necessary as new technologies come line within the industry

5. The current state of technology and knowhow regarding removal of structural steel sections is limited to methods that in many cases can be destructive to the individual components during the removal process**.** Current removal methods are limited to torch cutting, shearing, or sawing; all of which are not very efficient unless the structural steel frame was originally designed for deconstruction. The interview respondents (in this category CM’s and erectors) clearly indicated a few key areas that need attention; (1) new technologies that will allow safer and quicker removal of individual components and (2)

new equipment that is specifically designed to disconnect the individual members at their connection points.

6. Safety – since there is little industry experience in taking apart structural steel systems the uncertainty of the process creates safety concerns until new training is devleoped

Regulatory

Regulatory findings were not generated by interviews with code officials but rather from responses from the interview population of the research. In the US most states use the International Building Code (IBC) as their principal design and structural engineering guidelines to ensure codes are met and public safety is maintained. At present the IBC does not address the reuse of structural steel sections reclaimed from an existing structure into new structural steel framing systems. Additionally, the relevant AISC design standards do not address steel reuse. As indicated by the responses shown in Table 5-2, as well as the open-ended discussion portion at the end of the interviews, respondents indicated it was their belief that bringing code officials 'on board' with this idea would be a key component to the success of the concept although they conjecture it would be a difficult path due to past experiences involving new ideas in matters related to systems tied to life-safety and load bearing conditions.

Structural Steel Reuse Specifications

One of the key contributions of the decision process model is that it identifies areas of concern or weakness in the current processes that incorporate reused steel components. Specifically, there is a need to develop a structural steel specification (CSI Division 05000) that incorporates the unique aspects of materials reuse. The findings of this research have assisted in producing a *'draft-sample'* set of structural steel specifications (see Appendix H) which addresses the relevant procedures that must be accounted for when reusing structural steel sections. A sample specification widely used by structural engineers which is consistent with the

AISC Manual of Steel Construction was the underlying basis of development of the reused steel specification.

Cost of Reuse

Consistent with the Total Cost Management (Hollmann, 2006) approach used by the AACE, it is crucial to identify all primary as well as ancillary costs in detail before the actual total cost can be arrived at. The base cost of reused steel as a material component only, was discussed in Chapter 4 in general terms but did not include all cumulative costs that are accrued throughout the entire material supply chain process. This is due to the additional processes and logistical requirements associated with the entire reuse procurement cycle. One of the most significant additional costs is the extra shipping necessary to complete the entire material acquisition sequence. Other costs include re-fabrication processes, testing, cleaning, and painting following re-fabrication. The following information was used to develop the comparison costs in Table 5-5 between new and reused steel:

- 10,000 square foot, 2-story office building
- 50’ wide x 100’ long
- 20’ high
- Beams – W 12 x 24
- Columns – W12 x 24
- Purlins – W8 x 16

Table 4-5. Comparative cost of new vs. reused steel[1]

Based on 36 ton project order	New	Reused
New material from mill ($952/ton)	$34,272	Na
Reclaimed material ($440/ton)	Na	$15,480
Survey & Assessment	Na	$1,500
Additional testing	Na	$5,000
Remove oils and paint	Na	$1,500
Primer paint	Na	$1,200
Fabrication ($800/ton)	$28,800	Na
Re-fabrication (+ 50%)	Na	$43,200
Ship from fabricator to jobsite	$11,200	$11,200
Ship from mill to fabricator	$11,200	Na
Ship from demo site to fabricator	Na	$11,200
Disassembly & removal at jobsite	Na	$29,700
Installation at jobsite	$19,800	$19,800
Total Cost	$105,272	$139,780
Cost per ton	$2,924	$3,883

Note to Table

1. Source of cost data was obtained from local contractors, erectors, and supplier/fabricators

On a comparative cost basis reused steel is approximately 30% more expensive than new steel (see Table 5-5). Costs for the individual categories were retrieved from follow-up phone interviews with fabricators and erectors that participated in the original interviews. The prices shown are current as of 11/3/2008.

Summary of Chapter

On the basis of cost in dollars alone in today's building industry, reusing structural steel components is significantly more expensive than new components. Within the context of sustainability however we must consider the environmental cost of recycled steel or inversely the significantly reduced environmental impact of reusing structural steel components in lieu of recycling them. Collaboration of all participants within the AEC will be a necessary component of addressing the issues exposed in this section.

CHAPTER 5
DECISION PROCESS MODEL DEVELOPMENT

Introduction

Chapter 3 outlined the methodology and approach conceived to develop a decision process model which would lead to an eventual increase in reuse of structural steel components. This chapter explores in detail the specific steps that led to the development and makeup of the decision process model which will assist future stakeholders in bringing together the various representative groups of the built environment to increase reuse of structural steel components. The internal components of the methodology process revealed the complications and potential obstructions (or call them concerns by the various respondents) that are presently delaying or will delay future development of this idea.

By analyzing the totality of responses from the surveys and interviews, within the context of the research objectives, the decision process model was developed with sensitivity to all relevant factors that must be taken into consideration. Since collaboration and buy-in between the various stakeholders is crucial to the success of this research, the decision model (See Figure 4-1) shows clear and concise collaborative connections, relevant decision points, relationships and interdependencies between key steps, and a natural/uninterrupted flow of information from one constituency to the next. The decision model clearly indicates key party responsibilities and how they are precursors to follow-on steps. The decision process model begins its implementation right after the end of first-use service life of a given structure and ends with installation of the reused components. This decision process model then constitutes one new cycle of use for the reused steel. Conceivably, the cycles could continue thru 2nd uses and beyond.

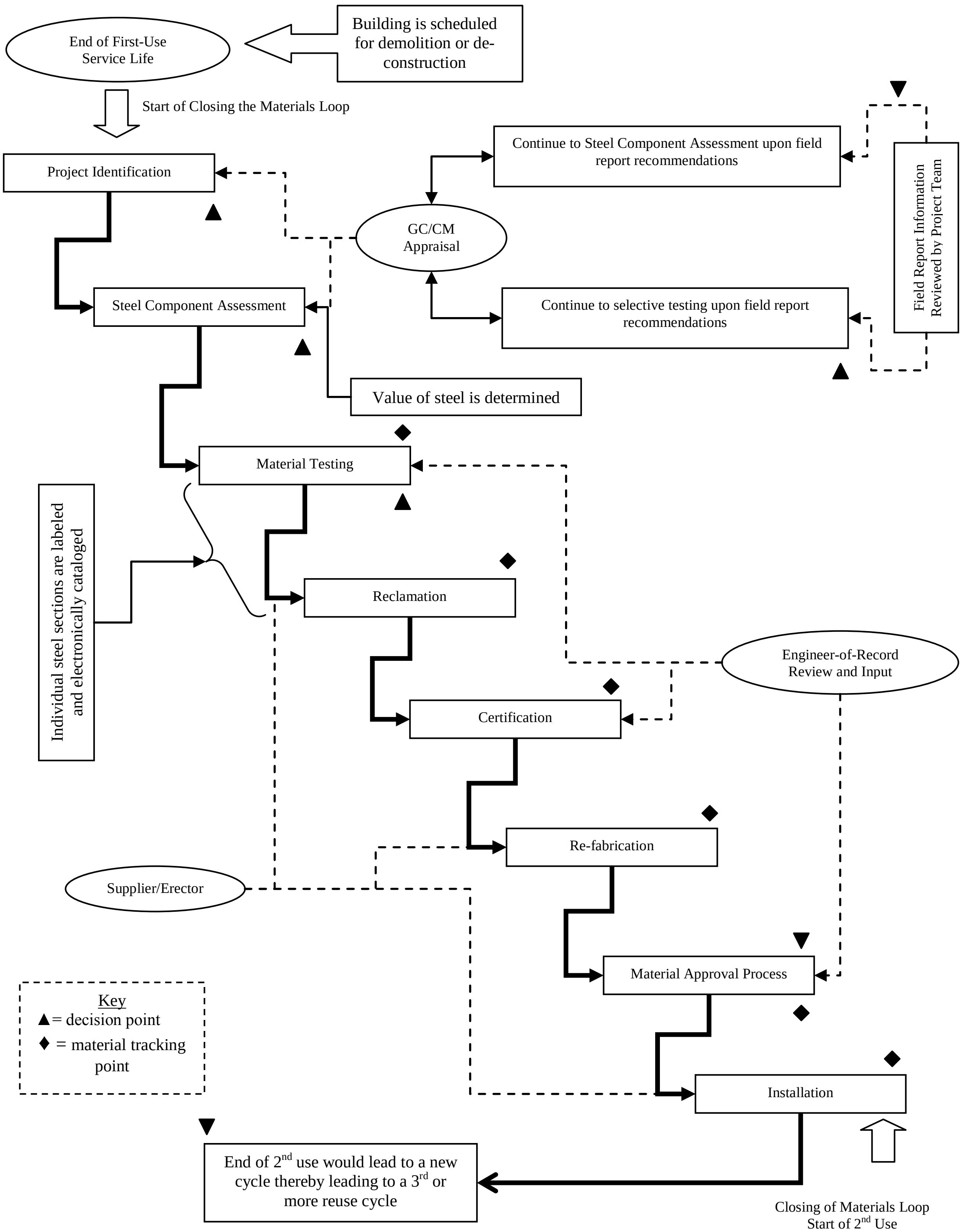


Figure 5-1. Decision process model

The follow on sections specifically describe each step of the decision model process, how they are inextricably linked to one another, and how they contribute to achieving the overall research objectives. The causational relationship between each step is elaborated upon to show how success at each step is crucial to the preceding one; similar to the activity relationship and interdependence in a critical path method (CPM) schedule.

At or near the end of each step project (as identified by a ▲) decision-makers will be making key decisions as to how to advance to the next step. In addition there are key points in the model where the material needs to be tracked (as identified by a ♦) for logistical reasons and procurement requirements. This needs to be done in collaboration with the entire project team due to the perspective cost, time, and resource commitments that are necessary to move the process forward.

Project Identification

Not all projects targeted for demolition or deconstruction, which contain structural steel components, are suitable or appropriate for material reuse when targeting structural steel. Numerous factors have an effect on whether or not the steel should, or will be reused. Interviews and surveys conducted in the data collection phase (discussed later in Chapter 5) indicate a number of significant variables such as logistical access, size, connections, and steel condition that need to be addressed in order for the idea of reuse to become efficient and realistic enough to gain momentum and acceptance.

The logical first step is that of identifying buildings that have a high potential for material reuse of this type. This step can be accomplished with little investment of resources and consequently will provide the impetus for furthering the research objectives. The initial building assessment will determine if reasonable follow on investigation is justified. Figure 4-1 illustrates a sample initial project assessment field report (IPAR) with its primary purpose to conduct an initial assessment on a structure slated for demolition or deconstruction and determine if there are prospective structural steel components that can be reused (limited to wide-flange beams as outlined in the limitations in Chapter 3). The conclusions and recommendations of the IPAR will determine whether or not further investigation is warranted within the context of reusing some or all of its structural steel components. This report can be used to assess any structure to determine its viability, potential, and appropriateness of reuse of individual structural steel members. Initial assessment is a key component of the structural steel reuse decision process model in that most stakeholders will not want to invest a lot of time, money, and resources looking into which buildings are reasonable candidates for structural steel reuse. Developing a simple and quick initial assessment that can be achieved with minimal investment of resources will allow a greater number of potential buildings to be surveyed with minimal investment thereby increasing the probability for reuse of its structural steel components.

Project Name:	*Hill Road Mall*		Report #:	*00015*
Date of Report:	*7/1/2008*	Location:	*West Allis, WI*	
Description of Project:	*7-tenant strip mall, single story, approximate dimensions of 125' long x 50' wide x 18' high, exterior masonry walls, ballasted rubber roof, storefront entrance elevation, xxx*			
Structural System:	*Load bearing 12" CMU exterior walls, wide-flange columns and beams (25' x 25' bays), bar joists ½ building width span, xxx*			
Age of Building:	*8-12 years*	Condition:	*Good*	
Recommendations for Reuse:	*The building contains a structural steel frame which supports the roof system made up of open-web steel bar joists. The steel members seem to be reasonably accessible for extraction. I recommend that a specific component assessment survey be conducted to determine the specific data necessary to successfully recover and reuse its relevant components.*			
General Notes:	*Building scheduled to be demolished in four months with no plans for material reuse salvage or deconstruction. Contact with demolition and general contractor indicates the demolished materials will be either scrapped out or headed for landfill.*			

Figure 5-2. Initial project assessment report (IPAR) – *Sample*

Figure 4-2 represents a sample report of a building surveyed in Milwaukee, Wisconsin that had been previously scheduled for demolition. The data in the IPAR shows that this specific structure has great potential for structural steel reuse due to its design characteristics, inherent steel components, and common sizes of steel sections. The review of the IPAR should be done within the following context; (1) value of steel (recycle and reuse), (2) reasonable access for removal, (3) common shapes that are in demand, (4) ability to assess size of target members (lbs/ft), and (5) age of structure. If the initial assessment report recommends further analysis the process moves on to the next step; analysis and assessment of individual structural steel components.

Steel Component Assessment

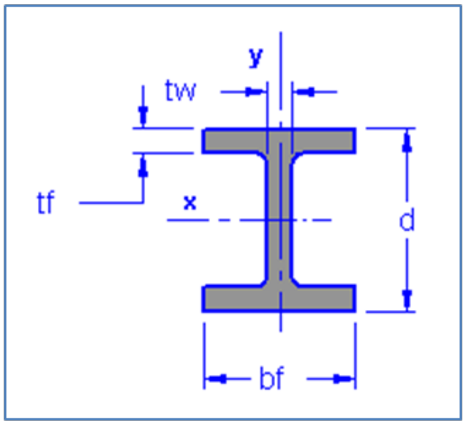
Once the initial project assessment process has been completed specific projects will have been identified to contain suitable and appropriate structural steel components for extraction and reuse. The follow on step is to survey each selected project for explicit information essential for removal and reuse. Figure 4-3 illustrates a sample steel component assessment report (SCAR) and how it focuses its assessment on individual steel sections (follow on to sample IPAR, Figure 4-2). Addition SCAR field reports can be found in Appendix F. The primary purpose of this report is to confirm a specific project contains the appropriate type of structural steel components intended for reuse within the limitations of this research. Additional functions of the SCAR is to identify the types and size of the steel beams, types of connection(s), condition of the steel, description of the various steel components, approximate values (reuse and scrap), plus recommendations from the person assessing the building and filling out the report.

<table>
<tr><td colspan="2">Project Name</td><td colspan="2">Hill Road Mall</td><td colspan="2">Date:</td><td colspan="2">7/7/2008</td></tr>
<tr><td colspan="2">Project Description</td><td colspan="2">7-Tenant Strip Mall</td><td colspan="2">Location:</td><td colspan="2">7400 W. 70th Street
West Allis, WI</td></tr>
<tr><td colspan="2">Description of Steel Components</td><td colspan="6">Wide-flange columns and beams, open-web steel bar joists, misc. channels and angles at roof and wall openings</td></tr>
<tr><td colspan="2">Condition of Steel Members</td><td colspan="6">Columns, beams, and bar joists appear to be in good condition; all are primed with no rust, corrosion, dents, cracks, or visible surface deformities</td></tr>
<tr><td colspan="2">Types/Sizes of Steel Members</td><td colspan="6">Columns (4 each), W10x16; 18' long
Beams - W16x24(125 lf)</td></tr>
<tr><td colspan="2">Connection Methods</td><td colspan="6">Bar joists are tack-welded to the center support beams on one end and to a bearing angle bolted to the CMU exterior walls on the other. All beam-to-beam connections are bolted. Columns are anchor-bolted to the floor slab</td></tr>
<tr><td>Total Weight</td><td>4152 lbs.</td><td>Scrap Value</td><td colspan="2">$913</td><td colspan="2">Reuse Value</td><td>$1,976</td></tr>
<tr><td colspan="2">Recommendations</td><td colspan="6">Remove and reuse wide-flange beams; beam to beam connections are all bolted and there is minimal welding at the bar-joist to center beam connection no unique or unusual removal problems are anticipated; reuse to scrap value is approximately 9-1; on a financial basis this is a good decision</td></tr>
</table>

Figure 5-3. Steel component assessment report (SCAR) – *Sample*

One of the crucial steps in assessing structural steel members (in this case a wide-flange beam or column) in existing buildings for potential reuse, is determining their size and weight to some degree of certainty. If possible, this should be done prior to removal more for a couple of reasons. Potential reuse is intrinsically linked to the size and weight characteristics. The earlier these two can be determined the higher the likelihood the individual components will be introduced into the materials procurement cycle.

There are two principal methods available to accurately determine the size and weight of each individual member. Method #1, a non-destructive and relatively inexpensive method involves measuring two critical dimensions; the thickness of the top/bottom flanges and the thickness of the center web. From these measurements (b_f, t_w, and t_f from Figure 4-4) an engineer or assessor can refer to Table 1-1 in the AISC Manual of Steel Construction, 13th Edition (see excerpt in Table 4-1 in Appendix I) and determine the lbs/ft of the beam as well as its specific size as indicated in Figure 4-4.



Critical Dimensions

tf = thickness of top and bottom flanges

tw = thickness of center web

bf = width of top and bottom flanges

d = height of beam

Figure 5-4. Wide-flange beam size determination

This method is preferable as a non-destructive technique and would provide quick results without investing time, money, and resources to remove steel sections. Method #2 would involve removing a sample piece one foot in length from each type of section, weighing it to determine the lbs/ft., and combining this information with the web and flange thicknesses to determine the size of the beam. The determined weight will be useful information to the project team to include scrap value and shipping weight for logistical arrangements. At this point, since the critical measurements have now been determined, the approximate reuse value of the beam can be established.

Steel Section Marking and Tagging

The conclusive stage of the identification process is marking or tagging each individual piece of steel for future use and classification of its inherent and unique characteristics. This stage is essential for logistical, scheduling, and financial functions that include; (1) real-time tracking of where each piece is at any given point of the entire material supply chain, (2) real-time inventory of entire stock of reused steel to include size (W x lbs/ft), length, condition, coatings (if any), camber, total weight, and other unique features, (3) up-to-date value of entire stock, (4) customer information which will be added once the piece has been sold, (5) what stage each piece may be at in the submittal and approval process (this would require some level of retagging as the individual piece information changes).

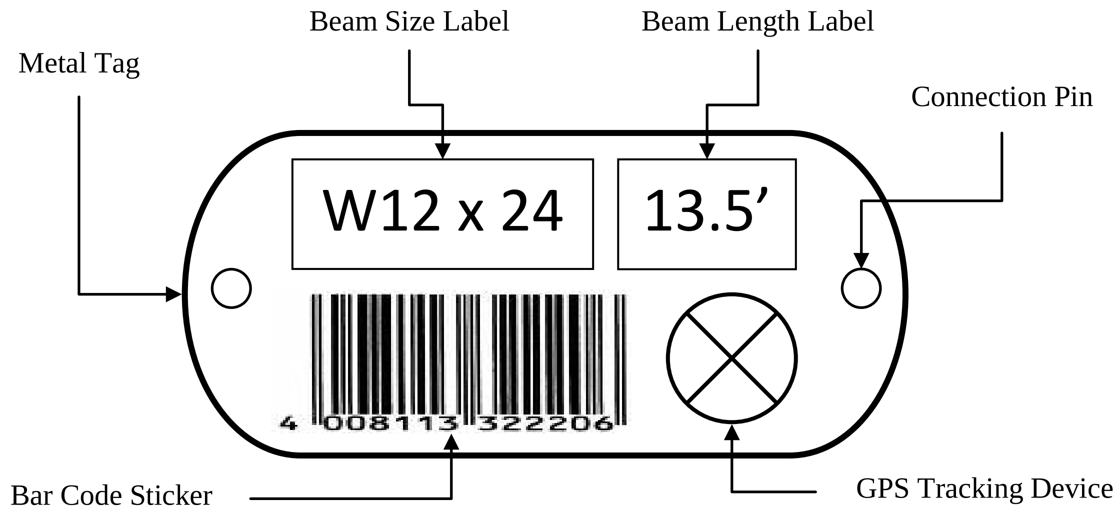


Figure 5-5. Sample tracking tag (NTS)

Each piece of steel will have a metal tag (see Figure 5-5) attached to the center web of the beam and incorporate the following features:

- Bar code with each beam’s unique information embedded within to include:
    - Length
    - Size (Example: W8 x 24: 8” high x 24 lbs. per lf)
    - Source (where the steel came from to include type of building)
    - Coatings
    - Camber (if any)
    - Date removed
    - Customer information (if applicable)
    - Specific shipping and logistical information
- Global Positioning System (GPS) tracking device
- Labels indicating the beam size and length so the basic information can be readily seen by the handlers

A personal digital assistant (PDA or similar device) will imprint the data on the tag and once it is attached the piece is instantly incorporated into the reused steel database. After the piece has been permanently installed and inspected the tag is removed and deactivated thereby ‘removing’ the piece from the database and inventory stock and the tags could be used multiple times. The bar codes would need to be re-calibrated for the newest information. The entire inventory of reused steel accompanied by its precise data can be managed over the Web by use of a simple data base. Field and management personal will be kept appraised of all relevant information of each project and piece as well as the entire inventory stock readily available to potential users.

Material Tracking

Once each piece of steel is tagged and marked for identification purposes they can be traced anywhere in the procurement process by means of real-time tracking programs via the GPS device. This process of identification, marking, and tracking allows the contractor to insert the used steel into the material supply stream at a much earlier time than would be possible for steel coming out of the steel recycling supply stream. In many cases the steel identified and tagged for reuse could be entered into the material availability continuum before it is even reclaimed from a structure. Although it is not part of this research it would be entirely possible to market and even sell the steel before it is extracted if the pieces matched up with an individual need as identified by an interested party.

Material Testing

The primary goal of a comprehensive testing plan is to ensure the steel sections will perform as expected when they are reintroduced back into the material supply stream. A secondary goal is to raise the level of confidence and lower the level of liability with the engineer of record (EOR) for the structural steel design. Results of the testing procedures will determine how and where individual sections can be reused. A wide array of testing procedures, destructive and non-destructive, are available to the EOR to assure compliance with required performance standards such as:

1. Liquid penetrant test (LP): is used for detecting surface-breaking flaws, such as cracks, laps and folds, on any non-absorbent material's surface; ASTM E165-02; NDT

2. Ultrasonic test (UT): to detect minor defects or flaws in the material (NDT Resource Center); NDT

3. Electromagnetic test (EM): the process of inducing electric currents or magnetic fields or both inside a test object and observing the electromagnetic response. If the test is set up properly, a defect inside the test object creates a measurable response (Libby, 1971); NDT

4. Acoustic emission test(AE): use of sound waves to detect fatigue cracks (NDT Resource Center); NDT

5. Chemical and metallurgical tests: to determine the approximate percentage of elements such as carbon, magnesium, etc. (NDT Resource Center); NDT

6. Tensile strength test (TS): to measure yield and ultimate stress levels for the steel

7. For Group 4 and 5 wide flange shapes for use in tension, it is recommended that the purchaser consider specifying supplementary requirements, such as fine austenitic grain size and Charpy V-notch impact testing (Hibbeler,2002)

Results from the field interviews (discussed in detail in Chapter 5) indicate that many of the aforementioned testing would not be necessary. The consensus among the structural engineers interviewed (elaborated upon in Chapter 5) was the following tests would be sufficient in determining the structural integrity of any individual steel section targeted for reuse: (1) chemical and metallurgical test to verify the specific metal elements, (2) tensile strength test to determine yield and ultimate stress levels, and (3) a hardness test such as the Brinell hardness test (Tabor, 2000).

Reclamation

The re-use of building materials in their existing state without down-grading and reprocessing is the most environmental option for supplying construction projects. There is a massive resource of materials coming out of demolition sites, deconstruction projects, or being dismantled from temporary works. The potential for using these materials, diverting them from landfill or reprocessing, and displacing the need for new materials is enormous. One of the key components of the reuse process is the ability to reclaim structural steel sections from existing buildings. The extraction process for purposes of this research is a comprehensive approach that includes all necessary steps from right after the identification and assessment to delivery to the fabricator for re-fabrication. Figure 4-6 illustrates the necessary steps to efficiently and safely remove a structural steel component.

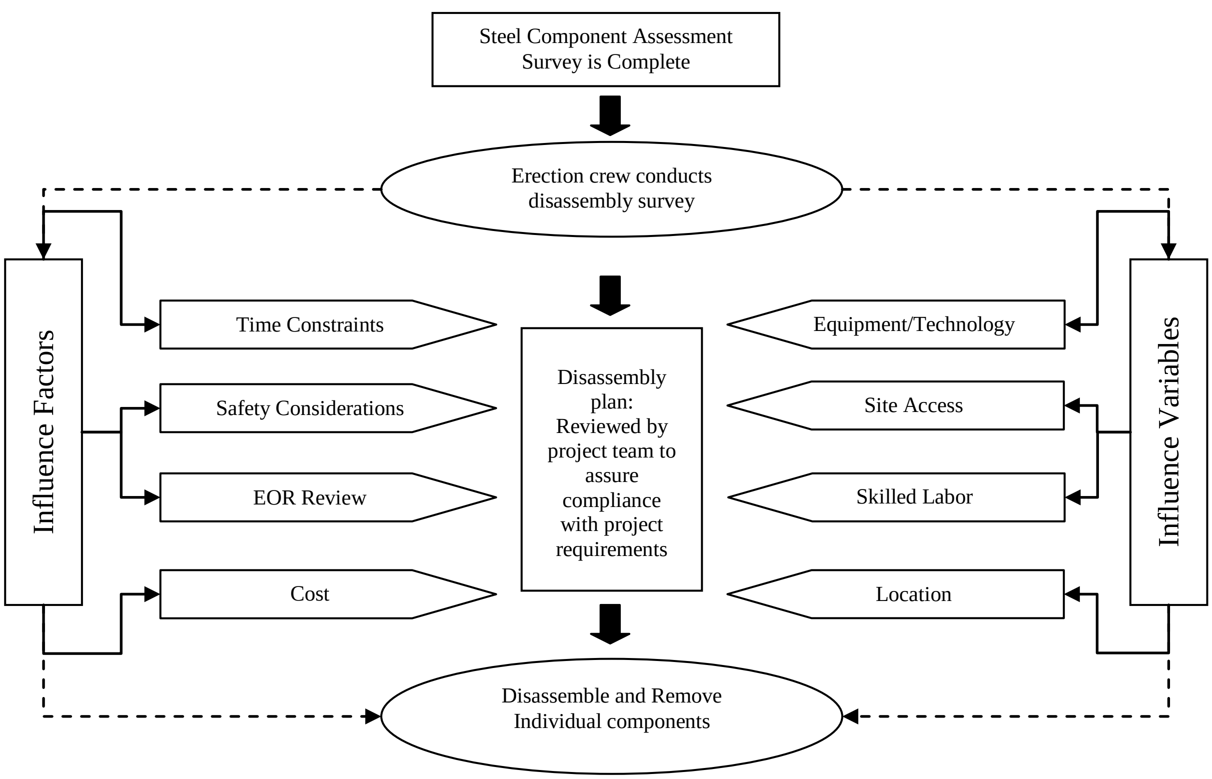


Figure 5-6. Reused steel component extraction process

Once the assessment process is complete and individual components have be identified and marked for removal the erection contractor will conduct a disassembly (reverse erection) survey to determine the most efficient method of removal for tagged beams. Influence factors that must be considered by the erector are; (1) time constraints which affect overall project schedule as well as interdependency with closely related construction activities, (2) safety considerations --- this is critical and must be approached with diligence and care since this type of work is somewhat unique and means/methods are not yet fully established, (3) review by the EOR as to the actually disassembly steps to avoid undue stress on the structural frame during the removal process, and (4) cost of removal --- the erection contractor most likely competitively bid the work and will want to minimize investment in time, material, equipment, and labor. Their also a number of variables for the erection contractor to consider which will have an effect on the removal process; (1) availability of the proper equipment and technology to remove each beam without causing damage or deformities --- this is especially important at the point of connections for each beam where the current methods are limited to torch cutting, shearing (not recommended due to the high probability of damage and distortion of the member), and saw cutting; the actual disconnection process is one area which further research as discussed in Chapter 8 will improve the removal method, (2) access to the steel members so they can be removed efficiently without hindrance from other contractors or activities --- for both safety and productivity reasons the site should be at the complete disposal to the erection contractor during the removal process, (3) having skilled labor available that are experienced in reverse erection --- since this is a new area of construction activity it is anticipated that new training will be needed (discussed in Chapters 5, 6, 7, and 8), and (4) the location of the building under deconstruction or demolition will have an effect on certain logistical considerations such as equipment positioning and crew coordination.

Once all of the influence factors and influence variables have been duly taken into consideration, the disassembly plan will be reviewed by the project team to assure it is compliant with the overall project goals, objectives, and requirements such as schedule compliance, safety plan compliance, and site impact logistics. Upon review and approval of the disassembly plan the erection crew will then proceed with its removal process.

Disassembly for all practical purposes, and with a few variants added, will be the reverse order of the original erection process or previously referred to as reverse-erection. Disassembly and removal of steel has traditionally been done by demolition contractors since concern for maintaining integrity of each piece was not a factor. With the intention of reusing extracted components as the main focus of the research a more sensitive and condition-caring method must be employed. This can be done more efficiently by steel erectors (or ironworkers as they are known) who are much more familiar with the erection process, the types of connections, and the stresses that are inherent to a structural steel frame system that can occur during erection and disassembly (see Figure 4-7).

Deconstruction of small office building

Figure 5-7. Structural steel disassembly

Certification

The certification process involving reuse of structural steel components is extremely critical in the overall success of this project. The majority of structural materials used in the construction process must be certified by the manufacturer or supplier before their installation and end-use. In the case of structural steel this certification process is usually provided by the mill supplier and/or fabricator. In the case of new steel at the request or requirement of the EOR, the mill will supply certificates guaranteeing the materials' properties (see Table 4-1for sample mill certificate). A mill certificate is a steel industry document that is used to certify the manufacturing standards of the products produced by the mill. It can specify the following:

- A recognized standard specification number such as an ASTM or AISI number (Ex. ASTM A106). This identifies the type of product (sheet, plate, tube, bar, etc.) and the set engineering standards to which it is produce
- An analysis of the elements (%) that make up the content of the mill product, i.e. carbon, nickel, titanium, etc.
- Brief description of the material such as wide-flange rolled sections

Table 5-1. Sample steel mill certificate

	DHT METAL **QUALITY AND QUANTITY** **MILL TEST CERTIFICATE**	K-Q TSE-ISO-EN 9000

NUMBER:			DATE:
Shipping Documents::	Invoice #:	L/C #:	Consignee:
Producer: DHT Metal AT. JV			Notify Party:
Description of Goods:			
Description and type of packing:			

No,	Steel grade	Bundle No.	Color Marking	Quantity of Bundles	Pieces per bundle	Weight, kg	Weight, kg
						Gross	Net

Technical Tolerances		
Chemical Analysis	Dimensions	Mechanical Properties
GOST 380-94	GOST 8509-93, 8240-89	GOST 535-88
Chemical Characteristics GOST 380-94		

STEEL GRADE	CHEMICAL COMPOSITION															
	C		Mn		Si		P		S		Cr		Ni		Cu	N
	min	max	min	max	min	max	min	max	min	max	min	max	min	max	min	max	min	max
	x 100						x 1000				x 100				x 1000			

Dimensions & Tolerances GOST 8509-93, 8240-89		
Width (mm)	Thickness (mm)	Length (mm)

Mechanical Properties GOST 535-88	Minimum %	Maximum %
Tensile Strength		
Yield Point		
Elongation		

Re-fabrication

Once the steel has been certified by the EOR it can be sent on to the supplier/fabricator for re-fabrication. For the most part the re-fabrication of the reused steel components will not differ to any level of significance to that of new steel. A few procedures must be added to ensure the components are brought back from the reclaimed state and made ready and suitable for re-installation. The specific steps necessary to bring used steel from its extracted state to being ready for reinstallation are illustrated in the re-fabrication process as shown in Figure 4-10 and the additional steps such as the removal of unwanted substances and initial prep will be added costs above and beyond the standard fabrication process and are appropriately accounted for in cost section in Chapter 5.

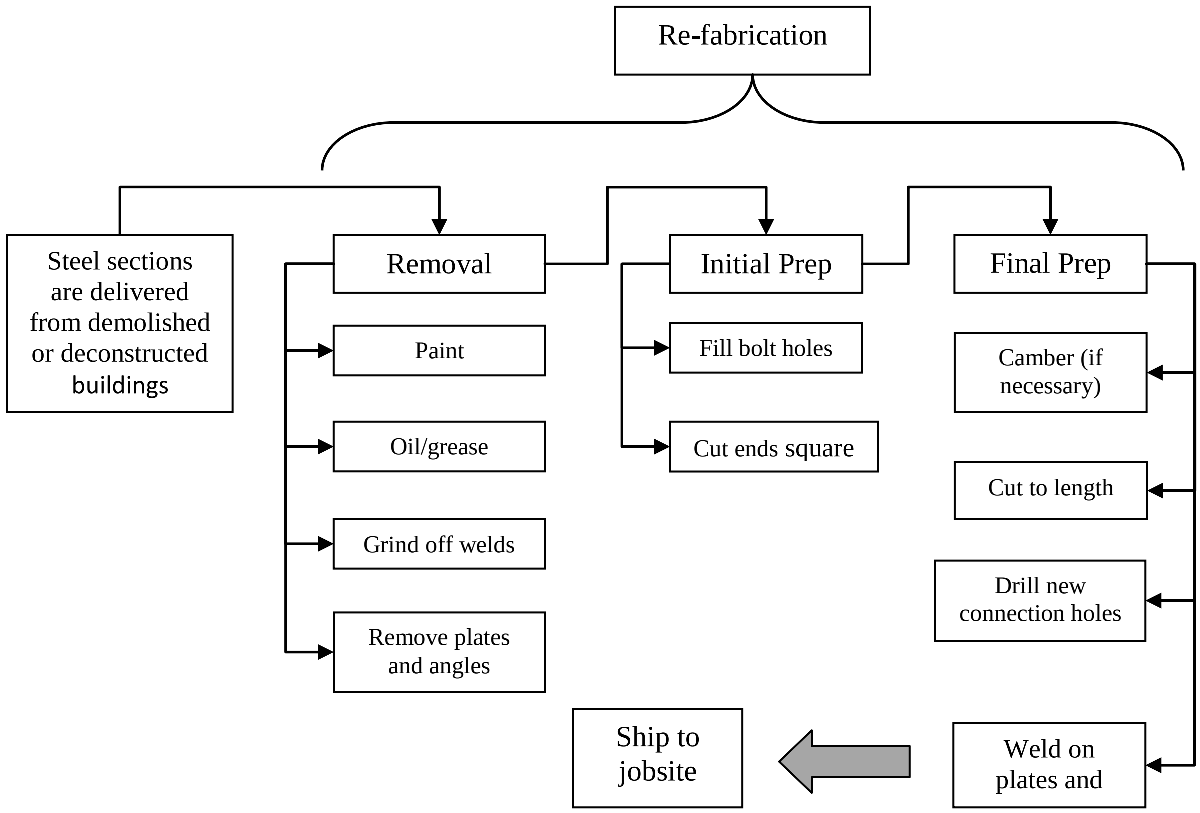


Figure 5-8. Reused steel re-fabrication process

Material Approval Process

The approval process for most materials in the construction supply chain contain specific steps which must be undertaken to ensure the new structure is sound, safe, in compliance with the contract documents (plans and specifications), and meet the project goals and objectives. The most common approach we have in use today is the shop drawing and submittal process (see Figure 4-3).

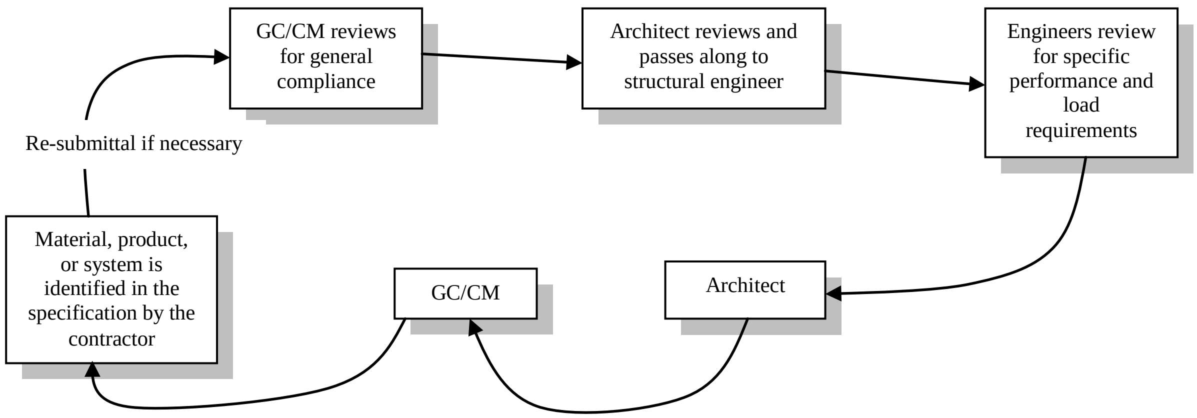


Figure 5-9. Material review and approval process

Each step in the review and approval process contains within itself measures of checks and balances to ensure not only the correct product or material is being used but also the design and engineering intent is fully met. For structural steel components this process is generally much more rigorous and stringent due to the higher risk associated with the system that forms the backbone of the facility. For the most part the approval process does not change when reused structural steel components are part of the structural design. The structural engineer of record would still produce design documents and detailed specifications outlining the size, shape, location, and connection for each steel member.

The steel supplier/erector that has been sub-contracted to provide the steel would then be required to submit shop drawings of their system showing specifically where the reused steel is located and the extent of reuse. A modified and more comprehensive approval process, that specifically addresses reuse, is illustrated in Figure 4-11 below. A couple of steps have been added to incorporate the unique aspects of structural steel reuse and where in the approval process the focus is necessary for tracking by the CM.

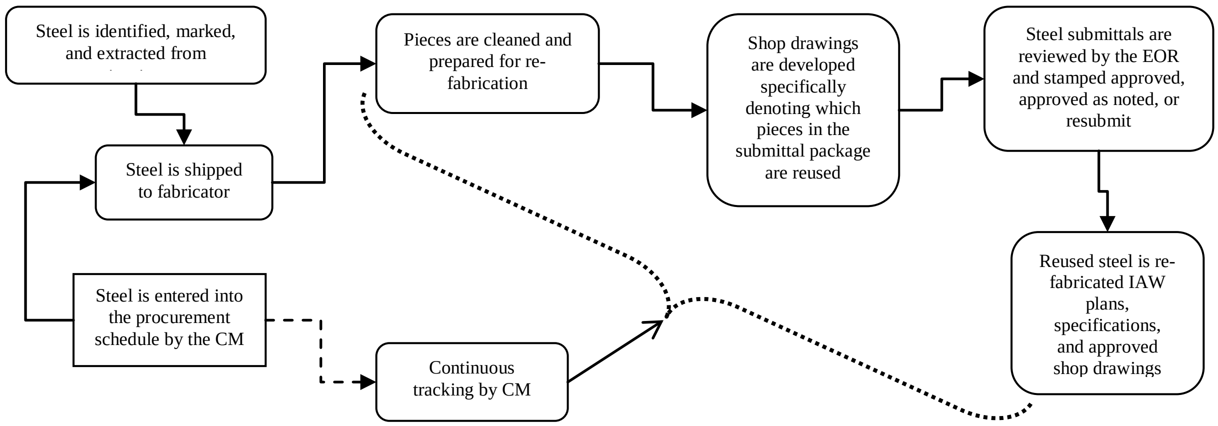


Figure 5-10. Reused steel approval process

Shop Drawings

Figure 4-12 illustrates a sample structural steel shop drawing where the reused sections are clearly denoted so the EOR can see precisely where and how much of the submitted materials are reused components. The $R_u1/24$ designation is used to indicate each piece that is sourced from reclaimed steel with the 1 representing the reused piece number and the 24 indicating the total number of reused sections within the submittal. This method of identification and designation will allow the EOR to quickly assess the extent of reused material within the context of the entire submittal package.

Structural Steel Specification for Reused Sections

As with any materials approval process the guiding documents and set of standards is the project specifications. The specifications are where the requirements are elaborated on for each material, product, or component. In the case of reusing structural steel a new and revised specification should be developed due to the unique nature of the materials to be used in the new facility. Chapter 5 outlines an example of what a structural steel specification might look like when reused steel will be part of the structural framing system. This specification would incorporate commonly used specification language for new steel as well as special language and requirements for reused materials.

Installation

The last step in the completion and closing of the structural steel materials loop is to install (re-install) the newly re-fabricated steel sections into a new building. At this point the steel is shipped, handled, and installed using the same methods and processes and new steel. It is at this point when one cycle of reuse has been brought to an end the full benefits of this new process can be realized by the various stakeholders. In theory, the reused steel could be reclaimed in multiple cycles or reuse as long as the structural integrity of each piece can be ascertained and verified by running them through the progression of steps as outlined in the decision process model.

Summary of Chapter

The potential for increasing the reuse of structural steel components is made possible by the decision process model developed as a result of this research project. Since the literature search and review revealed only fragmented and minimal reuse of structural steel components removed from existing buildings and re-installed in new facilities as part of the structural frame, the process had to be created from very little information. Professionals from various disciplines in the construction industry were interviewed to collect critical data as to their professional concerns regarding the reasons why steel reuse has not been more prevalent and what can be done to make increasing its reuse a reality.

CHAPTER 6
CONCLUSIONS

Introduction

This chapter develops logical and reasonable inferred conclusions based on the findings and analysis in previous chapters. The subsequent conclusions are presented in a articulated in a commonsensical manner to fully illustrate the connection imperative between the findings of the research and what can be reasonably offered as recommendations for further research in this field (see Chapter 8).

Conclusions

A comprehensive analysis of the results in Chapter 5 revealed a number of relevant and realistic conclusions within the ideological framework of current status and knowledge of steel reuse within the AEC industry. The conclusions are presented within the context of the positive conditions and professional optimism of the construction industry and the negative circumstances that exist within the context of what specifically is inhibiting more reuse of structural steel components and what needs to be addressed to achieve the objectives of the research.

A brief review and examination of the problem statement(s), research questions, and research objectives will help demonstrate and confirm how the research addressed these items throughout the study by use of the methodology in Chapter Three, the decision process model in Chapter Four, and the findings in Chapter Five:

- Problem statement(s):
    - the vast majority of structural steel components removed from buildings that are demolished are inserted in the recycling process, much of it by overseas fabricators

    - The current steel material supply process significantly increases the embodied energy of the building procurement and construction cycle
    - There is not a clearly defined decision process in place within the building industry to advocate, coordinate, facilitate, or support structural steel reuse

- Research questions:

    - Primary
        - How can the building industry significantly increase the reuse of structural steel components in their extracted state or with very limited modifications (re-fabrication)?

    - Secondary
        - How can the cost of steel component extraction and reuse be reduced to the point where it is more economically attractive to potential users?

        - How does steel reuse compare with steel recycling within a specific set of comparison metrics such as cost, embodied energy, and material selection?

        - What kind of testing criteria are necessary to re-certify steel components identified for reuse?

        - What kinds of methods are available to extract structural steel components in a non-destructive manner?

- Research objectives:

    - Primary – to develop a decision process model which will enable construction industry participants to significantly increase reuse of structural steel components in their extracted state by virtue of a more coordinated and collaborative effort within the AEC industry

    - Secondary – to decrease the cost and resources needed to extract structural steel components

In general terms there are two main categories of conclusions; (1) the major overriding (broad-spectrum) conclusions that affect all aspects of the structural steel reuse process and (2) the specific conclusions intrinsic to each constituency identified earlier in this research; design, engineering, logistical, means and methods, cost, and regulatory of which all are linked back to the express findings and analysis.

Broad-Spectrum

1. The AEC industry must find ways to decrease the cost of structural steel reuse if it is to become a more accepted concept. This will require an approach which is not only collaborative and cooperative, but also considers the social and economic benefits that would be derived out of the research idea. Since cost is one of the overriding issues that is preventing more steel reuse some measures of government mandates requiring materials reuse may be needed to get this idea moving. The construction industry itself is traditionally hesitant to move forward on an idea that does not meet the initial cost/benefit analysis

2. Government sponsored tax credits for applying materials reuse of this type would help get the idea moving. This is similar to energy tax credits in that the research has shown reused steel consumes significantly less energy than new steel made from recycled materials

Design (architectural)

1. More projects using structural steel frames must be designed for deconstruction in order to simplify the disassembly of future buildings and continue the supply of reused steel sections

2. Building code officials will need to be convinced and the code itself will need to be modified to incorporate the reuse of steel sections

3. The LEED® process (or other sustainability assessments such as Green Globes) should give more credit to material reuse of this type since it creates many more positive environmental impacts than many of the other credits regarding materials usage.

Engineering (structural)

1. A clear, consistent, and comprehensive testing plan must be developed for use with reused structural steel members. Structural engineers must collaboratively decide the most appropriate and cost-effective testing procedures that will ensure performance of each reused section.

2. The EOR in conjunction with the construction manager, should agree on the timing of the testing process as to when, where, and how the testing should occur

3. Less projects should be designed using the composite deck design or similar designs that make it very difficult system to disassemble and extract steel components

4. The actual deconstruction and disassembly process should be designed by the EOR and incorporated into the specification where applicable.

5. Steel submittal and approval process will have to be modified to include review of submittal drawings that include some or all reused sections

6. Steel source documentation process should be developed to require standardized documentation as to where the reused steel came from. The best place to meet this requirement is via the building codes.

7. Typical structural steel specifications will need to be modified to incorporate the unique aspects of reusing structural steel components (see Appendix H for a sample specification that has been modified as a result of this research).

Logistical

Since the construction manager is responsible for overall control and coordination of materials necessary for the erection of new structures, the findings indicate a number of logistical concerns that must be addressed in order to make material reuse a viable option:

1. An efficient method of identifying each steel section and quickly accounting for each piece in the procurement process must be developed, similar to the process identified in Chapter 5. Continuous and real-time tracking is a key component in this research due to the fact that the material supply of reused steel will come from many more sources than the traditional new steel.

2. New non-destructive testing procedures should be developed to enable inspectors to more easily and less expensively assess whether or not structural steel components contained within existing structures are likely candidates for reuse. This is a key step since the initial assessment is the start of the reuse cycle and must be made as seamless as possible.

3. For this idea to take hold an industry-wide procurement process of accounting for all reused steel sections available for reuse is needed. Within the current process of using new steel all participants know where the materials are coming from. Steel reuse will create many more 'supply or source points' and therefore the logistical challenges will be significant in the absence of a well coordinated effort across many different constituencies.

Means and Methods

The findings clearly indicate wide-ranging advances must be made in the application of means and methods with regards to deconstruction, disassembly (reverse-erection), and re-fabrication of structural steel sections targeted for reuse.

1. Since current methods of disconnecting the individual sections at the connection points is too costly and time-consuming new ways must be developed to speed up the process so it is competitive on a time basis with that of the normal erection process

2. New technologies and equipment must be developed for the disassembly process

3. Disassembly of steel structures should be done by steel erection contractors, not demolition contractors. Steel erectors have the expertise to disassemble the structural frame without causing undo damage.

4. Steel erection contractors will need to be trained in reverse-erection processes

5. New safety guidelines will need to be developed for deconstruction due to lack of industry experience in these types of activities

Cost

The discussions of cost in previous chapters has led to the general conclusion that structural steel reuse in more expensive than the current and predominant process of recycling steel sections reclaimed through the demolition or deconstruction of existing buildings. Reuse of structural steel components adds a couple of steps to the normal procurement cycle used by most projects. It is at these additional points (steps) that additional costs are accrued to account for the process of getting the reused steel section back into the construction materials supply loop. Even with current steel prices approaching all time highs reuse is still a more expensive option. At some point if steel price increases go unabated, reuse could become the more viable option. Based on the findings of the research the approximate price point at which reused and new steel become equal is when the cost of steel from the mill hits $2,100 per ton (an assumption here is that scrap prices would remain somewhat steady). For purposes of this comparison it is assumed that the other costs such as fabrication, shipping, fuel surcharge, erection, and applicable taxes will remain proportionate.

Summary of Chapter

Generally speaking, the industry has a long way to go before steel reuse is the method of choice for installing structural steel systems. Many hurdles exist that are preventing more reuse of structural steel components and until all participants who continually expand the built environment are "on board" with this idea and are willing to support this type of materials reuse it will not become more prominent in application.

In order to develop more achievable recommendations to this research and eventually see actual progress regarding steel reuse within the AEC industry, the five most critical of the aforementioned conclusions have been prioritized as per the following:

- More projects using structural steel frames must be designed for deconstruction in order to simplify the disassembly of future buildings and continue the supply of reused steel sections

- Less projects should be designed using the composite deck design or similar designs that make it very difficult system to disassemble and extract steel components

- Steel source documentation process should be developed to require standardized documentation as to where the reused steel came from. The best place to meet this requirement is via the building codes

- New non-destructive testing procedures should be developed to enable inspectors to more easily and less expensively assess whether or not structural steel components contained within existing structures are likely candidates for reuse. This is a key step since the initial assessment is the start of the reuse cycle and must be made as seamless as possible

- New technologies and equipment must be developed for the disassembly process

In the present scheme of construction activity within the built environment, reuse of structural steel will only be increased if we are willing to consider the environmental impact reductions as part of the overall cost. The conclusions developed in this chapter as a result of the research are realistic, achievable, and consistent with the results of the entire research project.

CHAPTER 7
RECOMMENDATIONS FOR FUTURE RESEARCH

Introduction

Consistent with the extensive and comprehensive approach in the conduct of the research and cooperation of many industry professionals, a wide range of specific recommendations have been identified as the logical and appropriate next steps to this research project. Additionally, many benefits have been derived out of the research findings and conclusions as well as outputs of the decision process model.

Recommendations

The primary end product of the research is the recommendations for further research or creative implementation of new frontiers identified in the research. The following recommendations (in order of importance) have been developed within the broader context of testing the decision process model on real projects and are prioritized within the context of those which will have the most impact on successfully achieving structural steel reuse:

1. Create new technologies to make it easier, more efficient, and more productive to remove structural steel components for existing structures

2. Create tax breaks or subsidies via regulatory agencies to provide support for those stakeholders who are willing to reuse structural steel components even though the cost is higher than recycled steel

3. Require new projects to implement some level of ‘design-for-deconstruction’ within the overall design as part of the plan approval process to make the steel removal and reclamation process more straightforward

4. Develop an on-site testing process to test steel section in place that is inexpensive and not time-consuming

5. Expand for the AEC industry as well as the public in terms of increasing reuse of materials necessary to feed the building process

6. Develop specifications specifically designed for taking apart buildings as part of the deconstruction process

7. Conduct similar research with other steel sections such as open-web bar joists and other rolled sections

8. Mandate new buildings to contain a minimum level of reused materials; especially in regards to structural steel systems

Benefits of Future Research

The secondary end product of this research (and possibly the most critical) is the benefits realized from a number of different points of view, varying perspectives throughout the community of stakeholders of the built environment, and results of the research. A quick summary of the stakeholder's viewpoints as well as findings of the research determines the benefits to fall into a varying range of categories; (1) social, (2) environmental, (3) economic, and (4) the AEC industry as a whole. All of these individual constituencies benefit in different ways from the products of this research.

Social

Society at large will enjoy a host of benefits if this type of material reuse is implemented to any significant degree to include:

1. Employment opportunities in new and emerging fields such as deconstruction of existing structures; many abandoned or unused structures are located in depressed areas where unemployment is high and the skills necessary to work in the deconstruction field would seem to be well suited to the unskilled worker or workers who need little training to gain meaningful employment

Environmental

The most obvious and some would say the most important benefit of this research and similar research projects of this ilk are the positive gains the environment and our ecosystems will realize. Reuse of structural steel produces several positive impacts on the environment or significantly reduces the negative impacts that recycled steel imposes on our environment.

Economic

Economic benefits derived out of this research are diverse, practical, and achievable. They include but are not limited to the following:

1. More jobs in fields such as steel erection, deconstruction, equipment manufacturing, steel fabrication, steel design (designing for reuse could become a separate field), and testing

2. Making use of materials that are suitable for reuse; many buildings stand idle and unused because the AEC industry has not found new ways to reuse the materials contained within them

3. More deconstruction means more construction projects overall

AEC Industry

The AEC industry will realize several distinct benefits out of this research; better collaboration efforts across the entire team of professionals and new means and methods developed as a result of structural steel reuse. This research project opens up a number of distinct research areas that could be pursued such as new equipment, new technologies, and new design applications.

Summary of Chapter

Stakeholders of the built environment, which includes industry professionals, public officials, and society as a whole need to embrace sustainable concepts and processes as those developed in this research project. Adaptation of environmentally conscious and collaborative approaches like reuse of structural steel components will lessen the burden on our resources for future generations and provide for a more eco-holistic society whereby an understanding of how we can expand our built environment without jeopardizing that ability of those who follow, is not only realistic, but promising.

APPENDIX A
CASE STUDIES

The intent of the research at the time it was originally envisioned was to study eight to ten projects as part of agreements with Milwaukee area contractors. Due to economic and logistical reasons, only three of the original projects were accessible for analysis in the conduct of the field studies and data collection (also listed as a limitation in Chapter One).

Project No. 1: Strip Mall

The first project is a one-story strip mall consisting of 7 individual tenant units that housed retail shops. This project was located (it has since been demolished) in the city of Racine, WI and at the time of the survey was being decommissioned and prepared for demolition with no plans for salvage and reuse of any of the building materials (shown in Figure 4-2 in Chapter Four). The building is constructed with 12” (presumably reinforced) load-bearing exterior masonry walls, wide-flange beams and columns, steel bar joists with metal deck for the roof structure. The maximum span of the wide-flange beams is 25’ and the span for the bar joists is also 25’. The dimensions of the building are 50’ wide by 100’ long by 18’ high (dimensions are approximate). The building is approximately 8-12 years old (unable to verify the exact date) and in reasonably good condition. The structural steel frame is in very good shape and does not appear to have any defects or damage. The IPAR was used to record the project specifics as part of the initial project assessment and analysis and continue as the second step in the decision process model. Since the initial assessment report identified this project as suitable for further study the steel component assessment report (as shown in Figure 4-3 in Chapter Four) was used to record the specific information necessary to determine how much steel components could be reused.

Project No. 2: Strip Mall

The second project was a one-story strip mall consisting of 12 individual units that housed retail and food service businesses. The project was located in the south part of Milwaukee, WI and at the time of the initial survey it was scheduled to be demolished. The construction of the building was 8” CMU exterior walls with a brick veneer, a structural steel frame using wide-flange beams, metal bar joists, and metal deck for the roof system. The dimensions of the building were 48’wide by 144’ long by 22’ high. The building was 19 years old and in fair condition with limited amount of structural steel in good condition. The demolition plan did have some aspects of recycling and reuse for limited materials. The face-brick was targeted for reclamation and reuse and the carpet was to be removed for recycling. Since the demolition and reclamation plan was not complete at the time of the survey it was not known what other materials, if any, were schedule for reuse or recycling. As in Project No.1 the IPAR and the SCAR were used to determine the suitability of the building for this research project.

Project No. 3: Restaurant

Project No. 3 was a one-story building housing a Cousins sub shop in the city of Racine, WI. The construction of the building was a structural steel frame using wide-flange beams and columns and metal bar joist and metal decking roof system. The maximum span of the wide-flange beams was 18’ and the bar joists spanned free-spanned the structure. The dimensions of the building were 35’ wide by 70’ long by 16’ high. The exterior walls were steel stud infill between the wide-flange columns with an exterior finish system of rigid insulation and plaster. The building is approximately 15 years old and in fair condition although the structural steel frame was in good condition with no visible damage or defects. As in Project No.1 the IPAR and the SCAR were used to determine the suitability of the building for this research project. This building has since been demolished and the information made available post project was that the steel components were sent into the recycling process.

APPENDIX B
MATERIALS USE SURVEY

Please respond to the following questions by either checking the appropriate box and/or writing your answer in the space provided. *Note: All information provided will be treated in the strictest of confidence*

Section One – Questions related to company details

1.1 What type of work is the main focus of your company? (architect, engineer, construction manager, general contractor, demolition, steel erection, steel supply)

Section Two – Questions related to your experience with material demolition or deconstruction

2.1 Does your company have experience with projects where building demolition was part of the scope of work?

Yes		No	

If yes, please explain

2.2 Does your company have any experience with projects where deconstruction was part of the scope of work?

Yes		No	

If yes, please explain

Section Three – Questions related to materials use

3.1 Does your company have any experience with material recycling as part of the project requirements?

Yes		No	

If yes, please explain

3.2 Does your company have any experience with material reuse as part of the project requirements?

Yes		No	

If yes, please explain

3.3 Does your company have any experience with projects where structural steel components were reused as a permanent part of the structure?

Yes		No	

If yes, please explain

Name of Company:	
Position or Title:	
Date:	

APPENDIX C
INTERVIEW QUESTIONNAIRE

1. Do you have any experience in projects involving ***deconstruction*** as part of the structural engineering design or scope of work?

Yes		No	

If yes, please explain

2. Do you have any experience in projects involving ***materials reuse*** as part of the structural engineering design or scope of work?

Yes		No	

If yes, please explain

3. Do you have any experience in projects where ***reused structural steel components*** were part of the structural engineering design and scope of work?

Yes		No	

If yes, please explain

4. What do you think are the biggest hurdles to overcome for the idea of reusing structural steel components recovered from existing structures?

5. What testing processes or procedures would you require before a recovered structural steel component could be reused in a new project?

6. How would the shop drawing/submittal process have to be altered for reuse of steel components?

7. What ideas do you have in this area of research which would increase the likelihood of structural steel reuse?

8. Would you require any type of affidavits or verification that the proposed steel to be reused has never been subject to extreme heat, known overloading, or unusual atmospheric conditions? If so, please elaborate on your response.

9. What kind of visual inspection criteria would you require as part of the initial assessment as to whether or not a specific steel component could be reused? Please explain.

10. Which specific ASTM standard would be the most appropriate reference standard for the reuse of steel?

11. What other structural reference standards might be appropriate for addressing the reuse of steel such as AISC Appendix 7 or ASCE publication?

12. Would you as a professional get involved in this type of materials reuse?

13. How would the steel spec be different for reused steel sections?

Name of Company:	
Position or Title:	
Date:	

APPENDIX D
LEED CHECKLIST

LEED-NC Version 2.1 Registered Project Checklist

Yes	?	No	Sustainable Sites		14 Points
Y			Prereq 1	**Erosion & Sedimentation Control**	Required
			Credit 1	**Site Selection**	1
			Credit 2	**Development Density**	1
			Credit 3	**Brownfield Redevelopment**	1
			Credit 4.1	**Alternative Transportation**, Public Transportation Access	1
			Credit 4.2	**Alternative Transportation**, Bicycle Storage & Changing Rooms	1
			Credit 4.3	**Alternative Transportation**, Alternative Fuel Vehicles	1
			Credit 4.4	**Alternative Transportation**, Parking Capacity and Carpooling	1
			Credit 5.1	**Reduced Site Disturbance**, Protect or Restore Open Space	1
			Credit 5.2	**Reduced Site Disturbance**, Development Footprint	1
			Credit 6.1	**Stormwater Management**, Rate and Quantity	1
			Credit 6.2	**Stormwater Management**, Treatment	1
			Credit 7.1	**Landscape & Exterior Design to Reduce Heat Islands**, Non-Roof	1
			Credit 7.2	**Landscape & Exterior Design to Reduce Heat Islands**, Roof	1
			Credit 8	**Light Pollution Reduction**	1

Yes	?	No	Water Efficiency		5 Points
			Credit 1.1	**Water Efficient Landscaping**, Reduce by 50%	1
			Credit 1.2	**Water Efficient Landscaping**, No Potable Use or No Irrigation	1
			Credit 2	**Innovative Wastewater Technologies**	1
			Credit 3.1	**Water Use Reduction**, 20% Reduction	1
			Credit 3.2	**Water Use Reduction**, 30% Reduction	1

Yes	?	No	Energy & Atmosphere		17 Points
Y			Prereq 1	**Fundamental Building Systems Commissioning**	Required
Y			Prereq 2	**Minimum Energy Performance**	Required
Y			Prereq 3	**CFC Reduction in HVAC&R Equipment**	Required
			Credit 1	**Optimize Energy Performance**	1 to 10
			Credit 2.1	**Renewable Energy**, 5%	1

			Credit 2.2	**Renewable Energy**, 10%	1
			Credit 2.3	**Renewable Energy**, 20%	1
			Credit 3	**Additional Commissioning**	1
			Credit 4	**Ozone Depletion**	1
			Credit 5	**Measurement & Verification**	1
			Credit 6	**Green Power**	1

Yes	?	No			
			Materials & Resources		**13** Points
Y			Prereq 1	**Storage & Collection of Recyclables**	Required
			Credit 1.1	**Building Reuse**, Maintain 75% of Existing Shell	1
			Credit 1.2	**Building Reuse**, Maintain 100% of Shell	1
			Credit 1.3	**Building Reuse**, Maintain 100% Shell & 50% Non-Shell	1
			Credit 2.1	**Construction Waste Management**, Divert 50%	1
			Credit 2.2	**Construction Waste Management**, Divert 75%	1
			Credit 3.1	**Resource Reuse**, Specify 5%	1
			Credit 3.2	**Resource Reuse**, Specify 10%	1
			Credit 4.1	**Recycled Content**, Specify 5% (post-consumer + ½ post-industrial)	1
			Credit 4.2	**Recycled Content**, Specify 10% (post-consumer + ½ post-industrial)	1
			Credit 5.1	**Local/Regional Materials**, 20% Manufactured Locally	1
			Credit 5.2	**Local/Regional Materials**, of 20% Above, 50% Harvested Locally	1
			Credit 6	**Rapidly Renewable Materials**	1
			Credit 7	**Certified Wood**	1

Yes	?	No			
			Indoor Environmental Quality		**15** Points
Y			Prereq 1	**Minimum IAQ Performance**	Required
Y			Prereq 2	**Environmental Tobacco Smoke** (ETS) **Control**	Required
			Credit 1	**Carbon Dioxide** (CO_2) **Monitoring**	1
			Credit 2	**Ventilation Effectiveness**	1
			Credit 3.1	**Construction IAQ Management Plan**, During Construction	1
			Credit 3.2	**Construction IAQ Management Plan**, Before Occupancy	1
			Credit 4.1	**Low-Emitting Materials**, Adhesives & Sealants	1
			Credit 4.2	**Low-Emitting Materials**, Paints	1
			Credit 4.3	**Low-Emitting Materials**, Carpet	1
			Credit 4.4	**Low-Emitting Materials**, Composite Wood & Agrifiber	1
			Credit 5	**Indoor Chemical & Pollutant Source Control**	1
			Credit 6.1	**Controllability of Systems**, Perimeter	1
			Credit 6.2	**Controllability of Systems**, Non-Perimeter	1
			Credit 7.1	**Thermal Comfort**, Comply with ASHRAE 55-1992	1
			Credit 7.2	**Thermal Comfort**, Permanent Monitoring System	1
			Credit 8.1	**Daylight & Views**, Daylight 75% of Spaces	1

Yes	?	No	Credit	Title	Points
			Credit 8.2	**Daylight & Views**, Views for 90% of Spaces	1
Yes	?	No			
				Innovation & Design Process	**5** Points
			Credit 1.1	**Innovation in Design**: Provide Specific Title	1
			Credit 1.2	**Innovation in Design**: Provide Specific Title	1
			Credit 1.3	**Innovation in Design**: Provide Specific Title	1
			Credit 1.4	**Innovation in Design**: Provide Specific Title	1
			Credit 2	**LEED™ Accredited Professional**	1
Yes	?	No			
				Project Totals (pre-certification estimates)	**69** Points

APPENDIX E
INITIAL PROJECT ASSESSMENT REPORT (IPAR)

Project Name:			Report #:	
Date of Report:		Location:		
Description of Project:				
Structural System:				
Age of Building:		Condition:		
Recommendations for Reuse:				
General Notes:				

APPENDIX F
STEEL COMPONENT ASSESSMENT REPORT (SCAR)

Project Name				Date:	
Project Description				Location:	
Description of Steel Components					
Condition of Steel Members					
Types/Sizes of Steel Members					
Connection Methods					
Total Weight		Scrap Value		Reuse Value	
Recommendations					

APPENDIX G
AISC MANUAL OF STEEL CONSTRUCTION TABLE 1-1

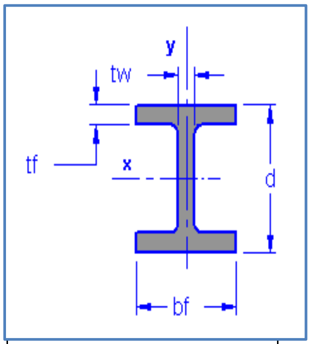


Table 1-1 (continued)

W Shapes

Dimensions

Shape	Area, A	Depth, d		Web: Thickness, t_w		Web: $t_w/2$	Flange: Width, b_f		Flange: Thickness t_f		Distance: k, k_{des}	Distance: k, k_{det}	Distance: k_1	Distance: T	Distance: Work-able gage
	in.^{2}	in.		in.		in.	in.		in.		in.	in.	in.	in.	in.
W8x67	19.7	9.00	9	0.570	9/16	5/16	8.28	8 1/4	0.935	15/16	1.33	1 5/8	15/16	5 3/4	5 1/2
x58	17.1	8.75	8 3/4	0.510	1/2	1/4	8.22	8 1/4	0.810	13/16	1.20	1 1/2	7/8	5 3/4	5 1/2
x48	14.1	8.50	8 1/2	0.400	3/8	3/16	8.11	8 1/8	0.685	11/16	1.08	1 3/8	13/16	5 3/4	5 1/2
x40	11.7	8.25	8 1/4	0.360	3/8	3/16	8.07	8 1/8	0.560	9/16	0.954	1 1/4	13/16	5 3/4	5 1/2
x35	10.3	8.12	8 1/8	0.310	5/16	3/16	8.02	8	0.495	1/2	0.889	1 3/16	13/16	5 3/4	5 1/2
W8x28	8.24	8.06	8	0.285	5/16	3/16	6.54	6 1/2	0.465	7/16	0.859	15/16	5/8	6 1/8	4
x24	7.08	7.93	7 7/8	0.245	1/4	1/8	6.50	6 1/2	0.400	3/8	0.794	7/8	9/16	6 1/8	4
W8x21	6.16	8.28	8 1/4	0.250	1/4	1/8	5.27	5 1/4	0.400	3/8	0.700	7/8	9/16	6 1/2	2 3/4
x18	5.26	8.14	8 1/8	0.230	1/4	1/8	5.25	5 1/4	0.330	5/16	0.630	13/16	9/16	6 1/2	2 3/4
W6x25	7.34	6.38	6 3/8	0.320	1/3	3/16	6.08	6 1/8	0.455	7/16	0.705	15/16	9/16	4 1/2	3 1/2
x20	5.87	6.20	6 1/4	0.260	1/4	1/8	6.02	6	0.365	3/8	0.615	7/8	9/16	4 1/2	3 1/2
x15	4.43	5.99	6	0.230	1/4	1/8	5.99	6	0.260	1/4	0.510	3/4	9/16	4 1/2	3 1/2
W6x16	4.74	6.28	6 1/4	0.260	1/4	1/8	4.03	4	0.405	3/8	0.655	7/8	9/16	4 1/2	2 1/4
x12	3.55	6.03	6	0.230	1/4	1/8	4.00	4	0.280	1/4	0.530	3/4	9/16	4 1/2	2 1/4
x9	2.68	5.90	5 7/8	0.170	3/16	1/8	3.94	4	0.215	3/16	0.465	11/16	1/2	4 1/2	2 1/4
x8.5	2.52	5.83	5 7/8	0.170	3/16	1/8	3.94	4	0.195	3/16	0.445	11/16	1/2	4 1/2	2 1/4

APPENDIX H

STRUCTURAL STEEL SPECIFICATION FOR REUSED COMPONENTS

Table 4-1. Sample Project Specification for Incorporating Reused Structural Steel

SECTION 05100			
PART 1	GENERAL		
1.01	DESCRIPTION		
	A.	This section includes but is not limited to: - Structural steel columns, beams, frames, and lintels - Structural steel accessories - Fabrication and erection of structural steel - **Reused structural steel components**	 Section 01410
	B.	Related work described elsewhere: - Demolition - Wire mesh & deformed bar reinforcing - Precast concrete wall panels - Grouting of bearing plates and level plates - Steel joists - Metal decking - Miscellaneous metals	 Section 02400 Section 03200 Section 03450 Section 04200 Section 05200 Section 05300 Section 05500
	C.	Furnished but installed elsewhere: - Anchor bolts for structural steel - Loose level plates and bearing plates - Loose lintels	
1.02	REFERENCES		
	A.	American Institute of Steel Construction – Allowable Stress Design, 13th Edition	
	B.	American Institute of Steel Construction – Load and Resistance Factor Design, 13th Edition	
	C.	American Welding Society Publication D1.1 – Structural Welding Code	
	D.	Steel Structures Painting Council – Painting Manual	
	E.	**National Association of Demolition Contractors – Best Practices**	
1.03	REQUIREMENTS		
	A.	All material and work shall comply with requirements of state and local codes	
	B.	Fabrication and erection shall be in accordance with American Institute of Steel Construction specifications	
1.04	QUALIFICATIONS		
	A.	Fabricator and erector shall have not less than three years experience	
	B.	Welding shall be by qualified, state certified structural welders	
	C.	**Demolition or erection contractor who disassembles the reused sections must have at least 3 years experience in erection, deconstruction, and demolition of structural steel components**	
1.05	SUBMITTALS		
	A.	Submit, for approval, Shop Drawings indicating all shop and erection details and dimensions including cuts, copes, connections, holes, threaded fasteners, and welds	
	B.	Shop Drawings detailing connections that have been designed by the fabricator shall be sealed and signed by a professional structural engineer licensed in the appropriate state. Submit calculations for all connections designed by the fabricator. **Reused sections should be clearly indicated on submittal drawings. Example: W10 x 26 (R); the R designation indicating the source member is a reused component**	
	C.	Submit mill certifications of materials requested by the architect or engineer of record	

1.06 MATERIAL SOURCE **For Reused Material Only**

A. **Provide the source of the reused steel components to include:**

- **Building type and location components originated from**
- **Year of previous use installation**

B. **Provide affidavits or verification for the following:**

- **The steel sections were never subject to extreme heat conditions such as fire**
- **No known overloading was ever applied to the reused steel sections**
- **No unusual atmospheric conditions or caustic chemicals came in contact with the steel sections**
- **Any visible rust is only at the surface level and not deep flaking**
- **Material was cambered in its previous use**
- **Description of how the steel sections were removed such as torch cutting, grinding, shearing, etc.**

1.07 TESTING

A. **Provide certification that the reused material has been tested using 12" long or full-section samples of each beam size in accordance with the following tests:**

- **Chemical and metallurgical testing – state specifics**
- **Tensile strength**
- **Hardness test**

1.08 PRODUCT HANDLING

A. Deliver anchor bolts and other anchorage devices, which are embedded in cast-in-place concrete or masonry, to the site in time for installation. Provide setting drawings, templates, and directions for installation of same

B. Structural steel members which are stored at the site shall be above grounds, on skids or platforms, to protect from corrosion

C. **Provide affidavits or documentation that material stored off-site meets the requirements of 1.08 B**

D. **Provide affidavits or documentation that reused components were not unduly stressed or heated during the removal process**

PART 2 PRODUCTS

2.01 MATERIALS (Unless otherwise noted on plans)

A. Wide flange shapes: ASTM A992, yield stress of 50 ksi

B. Other hot-rolled structural shapes, plate, and column anchor bolts: ASTM A36, yield stress of 36 ksi

C. Structural steel pipe columns: ASTM A53 Grade B, yield stress of 35 ksi

D. Structural steel square or rectangular tube columns: ASTM A500 Grade B, yield stress of 46 ksi

E. High strength bolts: ASTM A325, connection type N, unless indicated otherwise on Drawings

F. Shear studs: solid, round-headed shear connector studs, yield stress of 50 ksi

G. Include all required structural members and framing including beams, columns, angles, bent plates, lintels, level plates, bearing plates for steel joists and beams, anchor bolts, and structural bracing

H. All materials shall be new, except as specifically noted otherwise on the Drawings.

I. **Reused materials shall be clearly noted and indicated on all submittals, shop drawings, and product information**

2.02 ELECTRODES

A. All arc welding electrodes used shall be only those specifically recommended for the purpose by the American Welding Society

2.03 PRIMER PAINT

A. All primer paint shall be compatible with the finish coats specified in later sections (such as Section 09900)

B. Reused material shall be cleaned and prepared to accept new primers and finish painting products

PART 3 EXECUTION

3.01 FABRICATION

A. Fabrication in accordance with American Institute of Steel Construction Specifications

B. Exposed metal to be smooth, straight, and free of burs and flaws

Reused sections to be prepped in like fashion by removing old welds, filling unneeded connection holes, and correcting any surface deformities.

C. Take all necessary field measurements and dimensions

D. Beam and plate assemblies to be welded

E. Lintels to be of sufficient length to bear a minimum of 8 inches on masonry or concrete at each end, unless noted otherwise on Drawings. Lintel beams shall have masonry ties

F. Provide for slotted hole connections where required

G. Beam connections may be fabricated for bolting, except where splice connections are required for continuity

H. Column base and cap plates, lintel beams, and plates and other shop assemblies shall be welded

I. All beam ends shall have masonry anchors where embedded in masonry systems

3.02 PAINTING

A. All material shall be cleaned of rust, dirt, oil, and other foreign matter

B. Steel work to be encased in concrete shall not be painted

C. For reused material to be encased in concrete all existing paint and coatings must be removed

D. Paint shall be per American Institute of Steel Construction and Steel Painting Council Specifications

3.03 ERECTION

A. All erection shall be in accordance with American Institute of Steel Construction Specifications

B. Do all necessary fitting in the field to make all connections smooth and tight

C. Allow work to line up straight, plumb, level, and true in accordance with American Institute of Steel Construction Code of Standard Practice; except slope beams where noted on Drawings

D. After the erection and installation are complete, touch up all welds and all shop priming coats damaged during transportation and erection using the priming paint specified for shop priming

E. Do not field cut or alter structural steel members without approval of Architect and/or Engineer-of-Record

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END OF SECTION

APPENDIX I
SAMPLE MILL TEST CERTIFICATE

METAL **QUALITY & QUANTITY** **MILL TEST CERTIFICATE**	NAME OF COMPANY
NUMBER :	DATE:
Shipping Documents:: Invoice No L/C No Producer: DHT METAL AT. JV	Consignee : Notify party:
Description of goods:	
Description and type of packing:	

No	Steel grade	Bundle No	Color marking	Quantity of bundles	Pieces per bundle	Weight, kg	Weight, kg
						Gross	Net

Technical tolerances		
Chemical analysis	Dimensions	Mechanical properties
GOST 380-94	GOST 8509-93, 8240-89	GOST 535-88

Chemical Characteristics GOST 380-94																		
STEEL GRADE	CHEMICAL COMPOSITION %																	
	C		Mn		Si		P		S		Cr		Ni		Cu		N	
	min	max	min	max	min	max	min	max	min	max	min	max	min	max	min	max	min	max
	x100						x1000				x100				x1000			

Dimensions&Tolerances GOST 8509-93, 8240-89		
Width (mm)	Thickness (mm)	Length (mm)

Mechanical properties GOST 535-88	Minimum %	Maximum %
Tensile strength		
Yield point		
Elongation		

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BIOGRAPHICAL SKETCH

Professor Emmer has been the director for the construction management program at the Milwaukee School of Engineering (MSOE) since 2005. Professor Emmer has a special interest in sustainable construction and has incorporated many elements of sustainability into the construction management curriculum at MSOE. With over 25 years of construction industry experience he brings a unique perspective and process in furthering the connection between theory and real life situations within the building industry. He is from a small town in Wisconsin with a Bachelor of Science degree in Construction Management from Wentworth Institute of Technology in Boston and Masters of Construction Science and Management degree from Clemson University in South Carolina. He received his Ph.D. from the University of Florida in the School of Design, Construction, and Planning in spring of 2009. His research is focused on reuse of structural steel members deconstructed from facilities targeted for demolition. Prof. Emmer is married to his wife Anita and has six wonderful children with ages from 13 to 30. His interests are camping, golf, and home improvements. Professor Emmer is also interested in promoting more research projects in the field of construction management and sustainable construction.