RE: PURPOSE I REFRAMING THE PURPOSE OF CONSTRUCTION WASTE

By:

Mark Barclay Grimsrud B. Tech
British Columbia Institute of Technology
2010

A design thesis project presented to
Ryerson University in partial fulfillment of the requirements
for the degree of Master of Architecture

Toronto, Ontario, Canada, 2014

©Mark Grimsrud 2014

Author's Declaration

I hereby declare that I am the sole author of this thesis project.

I authorize Ryerson University to lend this thesis project to other institutions or individuals for the purpose of scholarly research.

I further authorize Ryerson University to reproduce this thesis project by photocopying or by other means, in total or in part, at the request of other institutions or individuals for the purpose of scholarly research.

Abstract

This thesis is an investigation into the extended use of waste in an architectural context. As resources are becoming depleted, new systems and techniques need to be developed to use what we have more effectively. By studying the material flows of urban construction, new purposes for construction waste can be revealed. This thesis challenges the current perceptions of waste to that of a nutrient. In order to showcase and frame waste as nutrient, the project proposal is for urban interventions built from waste to be placed throughout public spaces on Ryerson's Campus. These interventions will inform the public on material reuse and at the same time increase the quality of public space. Typically when waste is used in architecture, the material sources are unique, this thesis questions that notion by investigating materials that are ubiquitous. This thesis strives to answer if and how architecture can add value to waste materials.

Acknowledgements

This thesis would not be possible without the assistance and support of many greatly appreciated individuals. I would first like to thank my supervisor, Dr. Mark Gorgolewski. His vast knowledge and insight into my topic of research was invaluable to my work. Many of the current thinkers and literature in material reuse would have gone undiscovered by me if it were not for Mark's guidance. I am thankful for Mark's patience when my work drifted off course at times, he was always there to point me in the correct direction while allowing me to explore and experiment along the way. This thesis would not have been what it is without his assistance.

I am also thankful and appreciative of Professor Vera Straka, my second reader. She was always there to remind me of the realities of my design work and also to have connected me with individuals involved in the construction of the Ryerson Student Learning Centre.

I would like to thank Frank Bowen, the Department of Architectural Science workshop manager. Many of my explorations involved building 1-to-1 detail models that would not have been realized without Frank's enthusiastic assistance. Whenever I had an issue with a connection detail, he would have multiple solutions to the problem.

Dominic Magnone from Capitol Projects & Real Estate at Ryerson University played a large role in connecting me with the construction of Student Learning Centre. I am thankful for his selfless assistance in providing me access to the site, collecting some waste materials from the project and connecting me with Andrew Visconti from Ellis Don who was also very helpful with my research.

Lastly I would like to thank my friends and family but especially my parents Wanda and Milo for supporting me along this long journey. I am grateful to have been able to bounce ideas off of them and get a fresh perspective. They have always been there to encourage and remind me that the stresses of the work were only temporary.

Table of Contents

Author's Declaration.....	i
Abstract.....	ii
Acknowledgements	iii
Table of Figures	v
1. Introduction	1
Thesis Statement	1
Methodology	2
2. What is Waste?.....	3
What Happens to Waste?	7
Landfills	7
Incineration	8
Recycling / Composting.....	9
Reuse / Repurposing.....	11
3. Nature Doesn't Waste	13
Industrial Ecosystem	13
Superuse Studio	14
Inside Flows – Jan Jongert.....	16
Recyclicity – Superuse Studio	18
Cradle to Cradle – McDonough and Braungart	22
The Upcycle – William McDonough and Michael Braungart	24
4. Material Reuse in Architecture	25
Drop City / Earthship	25
LOT-EK	26
Tres Birds Workshop	27
Community Engagement Through Material Reuse.....	28
Rural Studio	29
Superuse Studio	30
5. The Waste of Buildings	32
Construction Case Study: St. David's Custom Home Framing.....	34
Renovation Case Study: Etobicoke, ON Residential Home	34
Demolition Case Study: Department of Defense Downsview Park Housing	35
A Building's End of Life.....	36
Demolition.....	37
Deconstruction.....	38
Design for Disassembly.....	38
6. Temporary Structures & Programs	40
Tactical Urbanism.....	43
7. Ryerson Student Learning Centre Waste Study	46
8. Design Process	59
Introduction	59
Bench Designed from Waste	59
Architectural Response.....	65
Site Selection/Research	66
Ryerson Campus Master Plan.....	66

Urban Intensification.....	66
People First: Pedestrianization of the Urban Environment.....	67
Commitment to Design Excellence.....	67
Design Exploration 1.....	69
Design Exploration 2.....	72
One-to-One Mockup.....	73
Design Exploration 3.....	74
Design For Disassembly	78
Final Design.....	82
Architectural Quad Structure	84
Lake Devonian Structures	89
9. Conclusion.....	95
Appendix.....	98
Waste 2x4 Bench.....	98

Table of Figures

Fig. 1 Jungen - Nike AirJordan Haida Masks.....	6
Fig. 2 Jungen - Garbage Bin Turtle Shell.....	6
Fig. 3 Recycling by Material. NRCan, 2006	10
Fig. 4 <i>Harvest Map</i>	15
Fig. 5 Linear Ecosystem	19
Fig. 6 Semi-Cyclical Ecosystem.....	20
Fig. 7 Cyclical Ecosystem	21
Fig. 8 Kalundborg Flows	22
Fig. 9 Drop City	25
Fig. 10 Earthship Mike Reynolds	27
Fig. 11 LO-TEK - Puma Pop-up Retail.....	27
Fig. 12 Tres Birds Workshop Table	28
Fig. 13 Tres Birds Workshop Stair.....	28
Fig. 14 Rural Studio - Podhouse Cladding.....	30
Fig. 15 Mason's Bend Community Center	30
Fig. 16 Superuse Studio - <i>Wlkado Playground</i>	31
Fig. 17 Adjaye Associates, London Design Festival, Sclera, 2008.....	41
Fig. 18 Rebar – <i>Walklet</i>	43
Fig. 19 Rebar – <i>Panhandle Bandshell</i>	43
Fig. 20 DoTank - <i>Chair Bombing</i>	45
Fig. 21 Stair Covers	47
Fig. 22 Waste Plywood	48
Fig. 23 Temporary Wood Guards.....	48
Fig. 24 SLC Concrete Waste	49
Fig. 25 Metal Ducting Waste.....	50
Fig. 26 Rebar Offcuts	50
Fig. 27 SLC Packaging Waste	51
Fig. 28 SLC Pallets	51
Fig. 29 Offsite Waste Sorting Facility	52

Fig. 30 SLC Waste Recycling	53
Fig. 31 December 2013 Waste, (Waste Management Inc., 2013)	54
Fig. 32 Queen St. Fashion District	60
Fig. 33 Waste Paper Tubes	60
Fig. 34 Joint Connection Test	61
Fig. 35 Shigeru Ban Connection - <i>Library of a Poet</i>	61
Fig. 36 Cut Sections.....	62
Fig. 37 Unused Pallet.....	62
Fig. 38 Disassembled Pallet	63
Fig. 39 Waste CNC Circles	63
Fig. 40 Joint Detail, Pallet Block & CNC Waste	63
Fig. 41 Bench Supports	63
Fig. 42 Turnbuckle	64
Fig. 43 Completed Bench	64
Fig. 44 Design Exploration 1 Sketch Model Plan View	69
Fig. 45 Design Exploration 1 - Trinity Bellwoods Site Plan	70
Fig. 46 Design Exploration 1 - Wall Seating.....	71
Fig. 47 Design Exploration 1 Plan/Elevation.....	71
Fig. 48 Design Exploration 1 Connection Sequence.....	72
Fig. 49 Design Exploration 2a Elevation	73
Fig. 50 Design Exploration 2a Plan.....	73
Fig. 51 Design Exploration 2b Elevation	73
Fig. 52 Design Exploration 2b Plan.....	73
Fig. 53 One-to-One Mockup	74
Fig. 54 Design Exploration 3 Exterior Plan/Elevation.....	75
Fig. 55 Design Exploration 3 Interior Plan/Elevation.....	75
Fig. 56 Design Exploration 3 Architecture Quad Site Plan.....	76
Fig. 57 Design Exploration 3 Lake Devonian/Gould St Site Plan.....	77
Fig. 58 Exploration 3 Connection Sequence 1	78
Fig. 59 Exploration 3 Connection Sequence 2.....	78
Fig. 60 Exploration 3 Connection Sequence 3.....	78
Fig. 61 Exploration 3 Connection Sequence 4.....	78
Fig. 62 Exploration 3 Connection Sequence 5.....	78
Fig. 63 Exploration 3 Connection Sequence 6.....	78
Fig. 64 Design Exploration 3 Bandstand Elevation/Plan.....	79
Fig. 65 Design Exploration 3 Architectural Quad Rendering.....	80
Fig. 66 Design Exploration 3 Lake Devonian Rendering	80
Fig. 67 Design Exploration 2 - 1:25 Model	81
Fig. 68 Main Structure Perspective View	82
Fig. 69 Main Structure Plan.....	83
Fig. 70 Main Structure Section.....	83
Fig. 71 Main Structure Exploded Axonometric.....	84
Fig. 72 Arch Quad Site Plan.....	85
Fig. 73 Arch Quad North/South Site Section.....	85
Fig. 74 Main Structure Front Elevation.....	86
Fig. 75 Main Structure Rear Elevation	86
Fig. 76 Main Structure Side Elevation	87
Fig. 77 Performance Venue	87
Fig. 78 1:25 Model	88

Fig. 79 1:25 Site Model	88
Fig. 80 Lake Devo Structure Perspective View	89
Fig. 81 Lake Devo Structure Front View	89
Fig. 82 Lake Devo Structure Rear View	89
Fig. 83 Structural Wall End Pieces	89
Fig. 84 Lake Devo Site Plan	90
Fig. 85 Lake Devo East/West Site Section	90
Fig. 86 Lake Devo Structure Plan	91
Fig. 87 Lake Devonian Front Elevation	91
Fig. 88 Lake Devonian Side Elevation	92
Fig. 89 Lake Devonian Summer Rendering	93
Fig. 90 Lake Devonian Winter Rendering	93
Fig. 91 Movable Bench Front View	98
Fig. 92 Variable Seating Configurations	98
Fig. 93 Platform Additional Seating	99
Fig. 94 Gould Street Benches	99
Fig. 95 Multiple Configurations	100
Fig. 96 Waste 2x4 Bench Construction Axonometric	101
Fig. 97 Disassembled Wood Bedframe	102
Fig. 98 Stop Night Market Food Cart	102
Fig. 99 Constructed Bench	102

1. Introduction

Most Canadians who live in urban areas have never been to a landfill or have any idea where they are. Often this is because they are on the peripheral of the city in industrial areas, where, if you do not have a reason to be, you will not go. As well, most waste produced from residents is collected by municipal staff and taken to a sorting facility or landfill. But homeowners often undertake renovations and require the landfill to dispose of construction materials and debris. Once at the landfill they will be struck with the materials that are present. There are golf clubs, children's toys, kitchen sinks, dressers, lumber, books and on and on. One thing they all have in common is that they are often perfectly fine. So what are they doing here? Why had someone thrown them out if they still have value? Could architecture play a role in returning value to something that had very little or no value? If so, what is architecture's role and can it be applied universally? This thesis strives to answer these questions or at the very least, shed more light on the issue.

Thesis Statement

We live in a culture that generates tremendous amounts of waste. Perceptions and systems of waste need to be redesigned to become more effective. By framing waste as a nutrient rather than something awful and negative, human processes can be analogous to natural systems. This thesis is an investigation into the value of waste as nutrients for architecture and construction. What is architecture's role in returning value to waste materials that would otherwise have had very little value or none?

Methodology

To understand issues of waste reuse it is important to see what has been done in the past and also contemporary uses of waste. Along with the review of pragmatic uses of waste, researching past and current literature on the issue is important. An examination has been done on an extensive base of writings that deal with perspectives on waste, systems and flows of waste, temporary structures and literature that has focused on the inclusion of the community with respect to waste materials. Built and proposed projects by academics, architects, artists and builders that utilized waste materials have also been studied.

Waste associated with the construction industry and buildings have been focused on as it is closely linked to architecture. Case studies of construction, renovation and demolition projects have been reviewed to understand common waste materials and the processes involved in handling construction waste. To get a more in-depth look at waste, the construction of a new building on Ryerson University's campus; the Student Learning Centre and its waste have been reviewed. A site visit was arranged, where photos of this waste were taken. Insight into construction waste was given by individuals representing both Ryerson University and Ellis Don, the construction company responsible for the build. From this, materials were determined that were suitable for reuse and a project based on the waste materials was developed.

Once the usable waste materials had been determined from the Student Learning Centre I began sketching and building scale models based on these materials. As well, 1-1 scale mockups of details to test connections, form and aesthetics were built.

2. What is Waste?

The word waste stems from the Latin word *vastus*, which means unoccupied or desolate (Lynch, 1984). The definition originally intended for the waste of place or space can now define a multitude of things including: time, people, money (unfortunately considered the worst) and objects. If you are to look up the synonyms for waste you find words such as debris, junk, refuse, ruffraff, rubbish and trash, all words that associate negativity. Urban Planner and Educator, Kevin Lynch discusses the concept of waste in his critically acclaimed book *Wasting Away*.

“It is the lessening of something without an apparently useful result; it is loss and abandonment, decline, separation, and death. It is spent and valueless material left after some act of production or consumption [...]” (p. 146)

When dealing with waste materials it is first important to understand the perceptions society has of waste. Lynch makes the point that the perceptions and values of waste are dependent on the culture in question. This is due to varying levels of income, resource availability, consumption habits, and policies. In developed countries, Canada included, there is little value placed on waste, in 2008, Canadians sent 25.8 million tonnes of solid waste to landfill (777kg/person) (Statistics Canada, 2012). In Canada, the cost of labour is quite high so people do not have the time or need to find new uses for waste. Canada is also currently rich in natural resources so new products can be produced with raw materials often cheaper than recycling or reusing existing products. On the other hand in developing countries, waste is seen as a resource. India for instance, places a greater value on waste. In Mumbai there are communities of “rag pickers” who sort through municipal waste for useful items that can be restored and sold, either through melting down or simply cleaning (Wiecha, 2010). This helps reduce waste accumulation and also increases the local economy.

Lynch argues that our perceptions of waste need to change:

“The two rational judgments about wasting are complicated by our perceptions and feelings. Perceived waste may not be waste at all, in either of the two preceding senses. It may be apprehended in a smooth ecological process, or in an efficient act of production.” (p. 164)

The creation, disposal and reuse of waste is closely connected to the economics of a particular period of time. Income and skill levels largely determine whether or not waste will be disposed of or reworked into something useful. Lynch argues that when skills and income are low, waste accumulates. But as skills and income increase, waste is collected and reused as it is or recycled. When skills rise faster than income, all waste is carefully collected, sorted and repaired. Eventually income will increase with advanced skills. At this point skills can be used more efficiently to process raw materials and waste begins to accumulate once again (Lynch, 1984). This scenario is hypothetical and does not take into consideration external forces such as governmental carbon taxes or material shortages, which force the reuse and recycling of waste materials, regardless of income levels.

Alejandro Bahamón & Maria Camila discuss waste reuse through various architectural projects in their book *Rematerial: From Waste to Architecture*. One particular project that deals with negative perceptions of waste is the World Bottle by Heineken (Bahamón & Sanjinés, 2010). Heineken was being imported to the former Dutch colony of Curacao yet there was no infrastructure for recycling, so the bottles became garbage and could be found scattered throughout the island. In 1957, the owner, Freddy Heineken noticed this on a trip to the island and had an idea that would give another life to the bottles. Working with the architect John Habraken, they developed a bottle that was in the shape of a brick and could be stacked to form the outer walls of a small home. 60,000 bottles were produced and it was almost put in motion but the marketing division of Heineken put a stop to it. They believed it would be negative to the Heineken image if their bottles were used to create homes for the less fortunate. This is an early example of how there has been a negative perception of waste within architecture.

As the public becomes more aware of material scarcity and issues of sustainability, examples like the World Bottle could be used to improve the image of a corporation rather than tarnishing it. In the eyes of the people of Curacao, having homes built from Heineken bottles would be a blessing and not something to be embarrassed about. The marketing team at Heineken perceived the empty bottle to be waste but in reality it was just a building block that could have been part of “an efficient act of production” as Lynch would put it.

The problem with the World Bottle is that the bottle was perceived to have only one function, transporting beer. But in reality, once transporting had happened, it could be used for any number of purposes only limited by one's imagination. Humans become attached to one function for all things produced and have a hard time adjusting when that function has run its course. The Canadian sculptor, Brian Jungen explores the concept of product function by literally deconstructing consumer items and repurposing them into art, giving new meaning. In the exhibition *Prototypes for new Understanding* he deconstructed well-known consumer goods and repurposed them into works of art (Vancouver Art Gallery, 2005). Many of the pieces are Haida masks created from Nike Air Jordans (Fig. 1). His work mainly focuses around traditional Haida artwork, having many ties to nature (Fig. 2). Jungen practices a form of art called "Found Art", which is created from undisguised, usually unmodified objects. Objects are not traditionally seen as art because they have a non-art function. Jungen prefers that people viewing his work do not initially notice that they are made from ubiquitous consumer items (Vancouver Art Gallery, 2005). There could potentially be greater impact if the viewer does not initially know they are looking at Nike Shoes or recycling containers, and accepts them for a mask or turtle shell. Then once they realize what they initially were, it begs the question of whether something can have multiple functions. If they had just seen the shoes, they might have gotten hung up on their initial function and cultural context and not been able to see their new use as a mask.

Fig. 1 Jungen - Nike AirJordan Haida Masks
(Photo Credit: Michael Chernoff, 2010)

Fig. 2 Jungen - Garbage Bin Turtle Shell
(Photo: Lisa Katayama, 2010)

McDonough and Braungart argue that products are designed for one function only and once this function has been fulfilled it is considered useless even if fully intact. (McDonough & Braungart, *The Upcycle*, 2013). This throwaway culture was accelerated in the 1930's when automobile manufacturers began designing a new car model each year. Prior to this the market had been saturated with very few car models and people were less likely to buy the same model again (Babaian, 1998). By introducing new models each year it made older models seem less desirable. This way of manufacturing is called Planned Obsolescence and can be seen in most of the products that are produced, from cellphones to coffee makers. Planned Obsolescence leads to products that do not last long as materials are chosen not for their durability but for their inexpensiveness. The product is inexpensive so when it breaks or is last years model, the new one can be purchased for a relatively low price. Also, the cost of fixing most products outweighs purchasing brand new, not to mention finding someone to repair the product. The sociologist Zygmunt Bauman discusses consumerist culture and its implications in his book *Consuming Life* (Bauman, 2007).

“Fully fledged consumers are not finicky about consigning things to waste. As a rule, they accept the short lifespan of things and their preordained demise with equanimity, often with only thinly disguised relish, and sometimes with unalloyed joy and the celebration of victory.” (p. 86)

Consumerist culture constantly demands the latest things and once there is a “new” thing, the previous new thing is disposed of with little regard and even “joy” as Bauman puts it.

Architecture on the other hand is less influenced by Planned Obsolescence and more so by Perceived Obsolescence. Perceived Obsolescence has more to do with style changes than functionality. For example, kitchen and bathroom fixture manufacturers regularly release new models and over time people perceive their fixtures to be out of style and in need of the current models. Their existing kitchen and bathroom fixtures may still have been functioning properly but because they are old, they are replaced. In many instances they end up at the landfill. Organizations like Habitat for Humanity’s ReStore offer some hope in this matter as they take many products for construction among them are old makes and models of kitchen and bath fixtures. Or another solution would be to come up with a new use for the old sinks like a backyard planter.

Architecture is also affected by code changes that actually do make components or whole buildings obsolete. For example the National Building Code of Canada requires that all windows installed in a heated space be at least double-glazed (National Research Council Canada, 2010). Older buildings which were built before current buildings codes were in effect had single-glazed windows, which are now not allowed. When these buildings are renovated, the single-glazed windows have to be replaced and find themselves often heading to the landfill.

What Happens to Waste?

Landfills

The worst way to deal with waste is to put it in a landfill. Landfills have negative consequences on the environment, the economy and human health. Landfills produce large quantities of greenhouse gases (GHG), in particular methane. Methane is 21 times stronger than CO₂ in regards to its global warming potential. CO₂, nitrogen, oxygen and a wide variety of other gases associated with waste are also emitted. In 2009, 22% of the methane produced in Canada came from landfills, which made up 3% of Canada’s GHG emissions. These gases are not only an issue of air quality but are highly combustible, causing fires and explosions and ruin surrounding vegetation. In addition to

gases, water from precipitation makes its way through the landfill becoming contaminated with pollutants and toxins in the waste, creating leachate. Leachate seeps into the ground and can potentially contaminate the water table (Statistics Canada, 2012). Also the land that a landfill occupies cannot easily be used for anything else after it has reached its capacity.

Landfills negatively effect the economy in a variety of ways but most evident in property values and taxes. When given the option most homebuyers will choose to live in an area that does not contain a landfill. In 2003 a study was done at Ryerson University regarding property values in proximity to three Toronto municipal landfills. The study concluded that property values were lower for homes near a landfill vs. homes of similar style and size in areas that did not contain a landfill (Lim, 2003).

In Canada, most waste operations are dealt with by the municipality who pays for the logistics, storage and operations of waste management with taxes collected from residents and businesses. In 2008, the total tax dollars spent by municipal governments in Canada was \$2.8 billion. Transportation of waste accounted for 42% and the actual landfill's management accounted for 18% (Statistics Canada, 2012). For private disposal of goods beyond what is picked up at residents, "tipping fees" are placed on the weight of garbage taken to a transfer station. In Toronto, the price per metric tonne of garbage is \$100 (City of Toronto, 2013).

Incineration

Another way waste is handled is through incineration. Incineration plants are usually located next to landfills and sorting stations. Waste material is sorted for combustible and non-combustible materials. The combustible materials are then placed in large facilities where they are burned at temperatures of 900-1,100° Celsius. The heat generated spins turbines and electricity is created. In Canada, only 5% of the total municipal waste is incinerated (Statistics Canada, 2012). Another benefit of incineration is the opportunity for the heat to condition spaces in colder climates. The heat can be used to heat near by occupied buildings or greenhouses in the winter.

Incineration is typically considered better than landfilling as waste does not accumulate and electricity is generated but there are serious environmental and health

problems associated. Materials burned create gaseous waste, ash and contribute to air pollution. In 2009, Canadian incineration plants released 350 tonnes of sulphur oxides, 1,364 tonnes of nitrogen oxides, 1,330 tonnes of carbon monoxide along with particle matter, volatile organic compounds and ammonia into the atmosphere (Statistics Canada, 2012). Sulphur oxides, nitrogen oxides, carbon monoxide and particle matter are among the six common air pollutants that have been proven to cause health problems such as lung disease (U.S. Environmental Protection Agency, 2012).

Recycling / Composting

Recycling is generally regarded as a more preferable option to landfilling and incineration as it reduces the need for raw material extraction. Raw material prices increase every year due to high demand, decreased supply and technologies not advanced to a level that is required for extraction. The earth being a finite system only has a limited supply of resources. It is estimated that the world's accessible supply of copper will run out in 25-30 years and iron in roughly 100 years (Crawson, 1992). Both minerals are used widely in construction so recycling is an inevitable future for most resources. Both landfilling and incineration do not address issues of material scarcity and extraction.

In 2008, Canadians diverted 8.4 million tonnes out of 25.3 million tonnes of waste from landfill and incineration by recycling and composting. Ontario alone diverted 2.8 million tonnes of material (Natural Resources Canada, 2006).

Fig. 3 Recycling by Material. NRCan, 2006

Of the material diverted, paper derivatives such as cardboard, newsprint and mixed paper accounted for over 40% of the recycled materials (Fig. 3). Organic matter in the form of compost made up 29% of Canada's waste diversion. In 2008 the Construction, Renovation and Demolition industry diverted 720,000 tonnes of material or 8.5% of the total waste produced, still leaving a considerable amount to be landfilled (Statistics Canada, 2012). It should be noted that in Canada, recycling has been increasing. From 2002 to 2008 total waste diverted from landfill as a proportion of total waste, has risen from 22% - 25%. Though there is still work to be done, as there was over 25 million tonnes of material placed in Canadian landfills in 2008 (Statistics Canada, 2012). Canada as a whole does not have a target for waste diversion that is mandated by the Federal Government. The European Union has set a target of diverting 50% of municipal waste by 2020 (European Environment Agency, 2014). Austria and Germany divert the most out of the European Union with 63% and 62% respectively and the Netherlands, not far behind with a 51% diversion rate.

Typical construction materials that are recycled include steel, timber and concrete. Steel is one of the most recycled construction materials with a recycling rate of

75%. Using recycled steel lowers the cost of steel production, as it is less expensive to recycle scrap steel than mine ore. Steel has a high melting point so it is important to note that substantial energy is required in the production of recycled steel, but it is still more desirable than mining virgin ore (Calkins, Materials for Sustainable Sites, 2009).

Wood is typically recycled into mulch or composite lumber. The production of mulch is considered a downcycling of the material, as it can no longer function as it initially did. Composite lumber on the other hand can be used in structural applications but many of the material binders contain harmful chemicals including formaldehyde. As well, the embodied energy in composite lumber is higher than in kiln-dried lumber. Wood products, which are treated with chromated copper arsenate (CCA), a now banned preservative, cannot easily be recycled or landfilled as the chemicals can leach into the ground and water table (Calkins, Materials for Sustainable Sites, 2009).

Concrete, which is crushed is typically used as gravel for road construction and as fill. Crushed concrete can be used as reclaimed concrete aggregate but generally only in paving applications and limited structural applications as the final product is often weaker. Reclaimed concrete aggregate often has cement attached to it so the aggregate is more porous than natural aggregate, which makes it less resistant to chemical bonding (Tam & Tam, 2008). If concrete recycling is possible on-site there are major cost and energy savings as transportation is not required and less aggregate of fill needs to be purchased and delivered to site.

Reuse / Repurposing

Reuse of materials is typically regarded as a more environmentally beneficial approach for dealing with waste because it deals directly with the issue of resource and energy scarcity. Reusing materials with little alterations can save energy vs. recycling. Recycling requires energy to ship and return the material to its raw form, in some cases of lesser quality than the original. If reusing is done locally, even more energy and cost savings are achieved as the cost of shipping is dramatically reduced. By repurposing an item, the useful life is extended and its impact on the earth is greatly reduced. For example, as trees grow they take in carbon dioxide and emit oxygen. When a tree is cut down and used for building materials, the carbon that was consumed by the tree is sequestered. If wood flooring from an old building was put in the landfill, the carbon that

was stored would be released and contribute to the GHGs in the atmosphere. By reusing the flooring, the carbon continues to have a useful purpose on the ground and not in the air. Also, more trees do not need to be cut down. Ilka and Andreas Ruby argue that cities can be mined for their useful materials.

“And isn’t the city, after all, nothing but a giant yard sale? We only have to scan it in search of its discarded assets, excavating them and putting them to good use in new ways and places.” (p. 247)

There is now more copper within cities than there is in the natural environment (Ruby & Ruby, 2010).

Steel and wood members are two construction materials that are often reused. Steel structural members are generally formed in standard sizes that have the potential to be reused on new projects after they have been removed from an existing building or structure. The members do not need to be regraded by structural engineers but are generally tested to ensure designated strengths are achieved. Some finishing work may be necessary like removing old paint or fire resistant coatings and applying new coatings. If welds were used in the original construction, reuse can be difficult, as they will require additional cutting to remove.

The reuse of wood is quite widespread and the sources for collection are continually growing. Older buildings such as warehouses, factories and barns offer great sources for reclaimed wood as many of the structural wood members come from large old growth trees. The reuse of wood structural members such as beams and columns, requires regrading by structural engineers, so it is not a straightforward process but can still limit the need for tree harvesting. Depending on whether the wood was initially painted, additional finishing work is required. Older paints often contain lead, which if above 5mg/L, cannot be sold or even given away. Another source of reclaimed wood is “sinker” logs from lake and riverbeds. When wood is transported on water, some logs end up sinking and stay preserved, as there is no oxygen to biodegrade the wood. There are some cases where logs have been submerged since the 1860’s. This is a great source of potential old growth timbers but the process of harvesting the submerged timbers can be harmful to the local ecosystem, underwater and on shore (Calkins, Materials for Sustainable Sites, 2009).

3. Nature Doesn't Waste

Nature does not know waste. There are no systems in nature that produce an output that cannot be used by it or another system. A classic example is a tree that blossoms. Each spring the tree produces buds that eventually turn into flowers or fruit. The flowers produce pollen that insects and birds carry with them to other trees, which they then pollenate. Birds, squirrels and other animals eat the fruits or nuts and then excrete the consumed food. The animal's droppings are not considered waste in this system but rather a nutrient for the tree to absorb so that it can grow and produce more. At the end of the season whatever leaves, fruits and nuts are not eaten, fall to the ground, decompose and are nutrients for animals and plant life below the tree. More waste from the tree means more life for the tree and animals.

All systems in nature with the exception of humans, function in a closed-loop. The term *waste* is not the right term for the tree's droppings but rather a *nutrient*. By simply changing our perceptions of waste to that of a nutrient, new and creative uses of materials can be realized. Not to mention saving precious land from landfilling, resource extraction and pollution.

There is an effort to transform human activities to be more analogous to natural systems. It is being led by academics, practitioners and as architecture is intrinsically linked to the material world there are many architects involved. The following is a review of current and past literature to see where and how material reuse within architecture can play a role.

Industrial Ecosystem

Industrial processes are linear with regards to their flows. Energy and resources are inputs used to produce a good or service as an output. Energy and resources are also outputs in the form of waste. Fortunately, researchers and practitioners have been working towards turning human processes into closed loops, this was initially termed Industrial Ecosystems.

In 1989, Robert Frosch and Nicholas Gallopoulos, two research directors for General Motors wrote a paper for *Scientific American* that addressed the issue of isolated manufacturing processes, the paper was titled *Strategies for Manufacturing*. The

main concept of the paper was to create an Industrial Ecosystem, which was analogous to and part of the Biological Ecosystem. Traditional industrial processes had been operating in a linear system; an industrial ecosystem operates closer to a cyclical system or closed loop. They argued that one process's waste should become the inputs for another industrial process (Frosch & Gallapoulos, 1989).

After the paper was published many people in the scientific community began to elaborate on the concept. Schools began offering courses and programs based on Industrial Ecosystem principles and many others began writing on the topic. Janine Benyus's concept of biomimicry is closely linked to the concept of an Industrial Ecosystem. *Cradle to Cradle* by William McDonough and Michael Braungart takes many cues from *Strategies for Manufacturing* and will be discussed further.

As architecture deals with the material world, it is important that it too work towards the industrial ecosystem model, as there are tremendous amounts of waste as a byproduct of the built world. It is difficult for architectural practices to implement these strategies, as their project scope is often limited to a property line, which may only include one building. Existing neighbouring buildings and processes may be unwilling to share their information, which would allow for potential loops to be closed or there may be no other buildings or processes in close proximity. On the other hand when architects work on master plans for large areas, Industrial Ecosystem principles can be implemented. It requires collaboration with engineers and consultants early on in the design phase as it goes beyond the traditional role of the architect. As well, once the project is built it requires constant monitoring to see what is working and what is not and potential opportunities that were not initially realized (Superuse Studio, 2009).

Superuse Studio

The Dutch architecture firm Superuse Studio is one of the first architecture firms to apply Industrial Ecosystem principles to their work. In their seminal book *Superuse* they discuss concepts of waste reuse. They coined the term *Superuse* with regards to adding value to materials that would have otherwise had very little. Superuse Studio has also developed a way of sourcing materials, which they call a "Harvest Map" (Peeren, Jongert, & van Hinte, 2007). A Harvest Map has a defined local boundary where various waste materials are mapped (Fig. 4). Each project they do has its own harvest map with

specific materials identified. Over time as more materials are identified, compiling a harvest map becomes easier. Superuse Studio has developed a Beta version of the harvest map at <http://www.oogstkaart.nl/oogstkaart/>. The public can log on and see what materials can be found within their area. At the moment it is limited to Rotterdam but over time, as more people get involved more cities will be included.

Fig. 4 *Harvest Map*
(Superuse Studio, 2005)

This way of sourcing and using materials has implication on how architects design. Typically when designing, the architect creates a design then specifies the properties of materials to be used. Then, the builder selects the materials that best match the specifications. When designing with waste materials sourced from a Harvest Map, the material often comes first and then the design is detailed according to the specifications of the particular material. The overall concept and program for the design can be determined before the materials are found but the form is dependent on the materials selected. The builder involved needs to be part of the design process as there may be additional work required to make the material workable. Mockups are a crucial part in the process, as some of the materials may not have precedence as building materials. Testing and mockups need to occur in tandem to the detailing of the project.

One of the first projects that Superuse Studio designed and built was the Miele Space Station. It was built out of old Miele washing machines for the purpose of an art installation. It also served as a fashion runway and construction trailer before it was

permanently installed in the Architecture department at Delft University as an espresso bar. One of the key design concepts that Superuse Studio wanted to emphasize was that you couldn't initially tell what the components were. The washing machine doors appeared to be spacecraft portal windows from a distance. Then when the visitor got closer they realized they were washing machines, which was usually met with playful reactions and surprise.

The approach to disguising waste as other objects is a fascinating aspect of Superuse Studio's work. For many people waste is considered a negative thing and when it is disguised these negative perceptions do not come to fruition. If waste material can be used in aesthetically appealing ways it could potentially change the way people perceive waste once they realize it was built out of discarded materials. This aspect of their work is similar to Jungen's "found art".

The Miele Space Station was an important project to get the discussion of waste reuse going and increase the value of a waste material. Although the design itself is unique and one-off that may not be applicable universally. Washing machines are a constantly flowing waste material that have great potential for reuse but it is difficult to standardize. There are many different makes and models and the designs are constantly changing which make its ubiquitous reuse difficult.

Inside Flows – Jan Jongert

Jan Jongert, one of the founding members of Superuse Studios also engages in research and academic pursuits. *Inside Flows* is a publication of research carried out by the Master's of Interior Architecture at the Royal Academy of Art in The Hague under the direction of Jan Jongert. *Inside Flows* dissects systems into their basic components which they term *flows*. The idea is to understand flows so that unseen connections between systems can become transparent and also illustrate how multiple facets are affected and not just the flow of money. Flows have been divided into three categories: physical, energy and values.

The physical layer includes all the tangible flows in a system including users, nature, food and other organics, inorganic matter, water and liquids, air and various gases and traffic.

- Users are the people involved who manipulate other flows.
- Nature is a flow that consists of living flora and fauna.
- Food and other organics are all the dead organic material.
- Inorganic matter is made up of sand, rocks and minerals.
- Water and liquids flow via gravity or engineered pump systems.
- Air and gas flow via natural convection or mechanical systems.
- Traffic is a more literal flow that can range from motor vehicles, rail, planes or boat.

The energy layer is either the outcome of a physical flow or that which allows the physical layer to flow. It consists of electricity, heat, light and sound.

- Electricity is the flow of an electric charge. It can be created by water flowing via gravity through a turbine that spins and creates a charge or by air flowing past a wind turbine.
- Heat is the next flow, which is the by-product of a chemical reaction or friction. Light is the visible energy flow produced by the sun or excess heat.
- Sound is an energy flow that is perceived by the ear or picked up by radio antenna, which transforms it into electromagnetic waves.

The last layer of flows, are values that include data/information, money and identity/culture. Value flows are the least tangible yet without them, the connections between the physical and energy flows will never be made.

- Data, information and knowledge come in the form of numbers, words and images with respect to other flows. Increased flow and sharing of data, information and knowledge is important in creating a sustainable system. For example a manufacturer may need a certain flow that another manufacturer outputs, without the flow of information there will never be a connection between the two.
- Money is the flow that comes in the form of a credit or a debt from work, a service or product that is or will be produced.

- Lastly, identity and culture flow when people migrate and take with them their tradition, food, fashion, etc. This flow has increased as people are more and more connected via the internet and social media.

This way of breaking flows down into their components can be applied to waste flows as well. By applying this same logic to waste, you can identify potential opportunities along its path, like a business or person who may have use for the material. Or just the sheer distance it has to travel could provide insight into the real cost of handling the material.

By reusing waste materials within architecture, all three of the major flow categories are affected. Fewer virgin materials need to flow into the system as reuse limits extraction. Depending on where the reuse is taking place, there may be a reduction in traffic if used in close proximity to the waste generation source, alternatively it may increase traffic. The flow of energy can be greatly reduced. If materials were originally going to be recycled, this would potentially require inputs of electricity and heat. Adversely, if the material was going to be incinerated it would create electricity and heat but contributes to health and environmental problems. Again, if reuse occurs close to the source of generation, less energy is required. In order for reuse of waste materials to take place there needs to be an increase in the flow of knowledge and information. Many waste streams go unnoticed and the potential for reuse is impossible. The flow of money is affected as many waste materials have an initial reduced cost vs. new materials. This may reduce the flow of money for the material in a project but depending on the cost of labour to restore or finish the material, it may not make a difference. Culture and identity is a less tangible flow with regards to waste reuse within architecture but can be seen in the current aesthetic of reuse. The reuse of waste is often seen as rustic or containing nostalgic values.

Recyclicity – Superuse Studio

Superuse Studio has published an online PDF, *Recyclicity*, which elaborates on the Industrial Ecology concept with respect to an architectural context. From the onset of any of their projects they determine all the systems that are integral for their project and work to connect them.

They divide ecosystems into two main categories, the Biosphere and the Technosphere. In nature you have the Biosphere, which is a naturally occurring ecosystem made up of animals and plants, not including human or more precisely processes that humans have ignored. The biosphere operates as a closed ecosystem; one process's waste becomes another process's resource. Also, the only source of energy in the closed-loop biosphere is the sun. Humans have created the Technosphere, which include all the man made technologies, industries and economic systems.

They define ecosystems as one of three: linear, semi-cyclical or cyclical. Linear ecosystems operate under the assumption that there is an endless amount of resources and energy entering the system. From here they are used to make a product or deliver a service. The product or service is made in isolation from all other products or services. Additional outputs are waste materials, heat and water. There is also the assumption in a linear system that the land available for disposing waste is endless (Fig. 5).

Fig. 5 Linear Ecosystem
(Superuse Studio – *Recyclicity*, 2009)

Semi-cyclical ecosystems operate with an increased flow in knowledge. There is the knowledge that there is not an endless supply of resources and energy. Resources and energy are used to produce products and services. Production of goods is not in isolation; one processes waste becomes another processes resource. Once a product

cannot be utilized it is disposed of with the knowledge that there is a limited amount of space for disposal. Waste heat and water are also byproducts. An industrial ecology functions within a semi-cyclical ecosystem.

Fig. 6 Semi-Cyclical Ecosystem
(Superuse Studio – *Recyclicity*, 2009)

A cyclical ecosystem can only be found in natural systems. The only input is solar energy. Cyclical ecosystems have complete knowledge of all the processes within and no outputs that cannot be used are created (Fig. 7). Waste does not exist; waste is considered a nutrient for another process. The only waste that is produced is heat.

Fig. 7 Cyclical Ecosystem
(Superuse Studio – *Recyclicity*, 2009)

Cyclical ecosystems are great examples to learn and study but putting them into practice is quite challenging. It requires that systems (corporations and governments) are completely transparent in their activities. Absolute knowledge is required so there can be a sharing of inputs and outputs. If manufacturers are not required to list the ingredients and components used in the production of a good or service then there will not be effective use of resources.

One major early example of an Industrial Ecosystem that is explained in *Recyclicity* is the eco-industrial park (EIP) in Kalundborg, Denmark (Fig. 8). The park consists of a coal-fired power plant, oil refinery, pharmaceutical manufacturer and a gypsum wallboard manufacturer. The need for the EIP began in the 1970s during an energy crisis, which forced near by industrial processes to think creatively. As the power plant fires the coal, it creates excess heat and steam, which are used to heat 90% of the municipality of Kalundborg, including homes, greenhouses and industrial buildings. The plant also outputs gypsum, which supplies 2/3 of the gypsum required by the wallboard manufacturer. The pharmaceutical company outputs sludge that 1000 local farmers use as fertilizer and an enzyme used in the production of insulin is sold as pig feed. The transformation of Kalundborg has been a slow process that has taken over 30 years to implement and it is still finding new ways to be more efficient.

Fig. 8 Kalundborg Flows
(Superuse Studio – *Recyclicity*, 2009)

Cradle to Cradle – McDonough and Braungart

William McDonough and Michael Braungart, two leading green consultants have been writing and working together as McDonough Braungart Design Chemistry since 1995. McDonough is an architect, educator and consultant who in 1996 won the Presidential award for Sustainable Development, the highest environmental award in the United States. Braungart is a chemist who is leading the way in ecological chemistry and sustainable flows of materials. He is founder of Environmental Protection Encouragement Agency and was the Director of Greenpeace's chemistry section. Their clients include some of the largest corporations in the world including Ford, Nike, Wal-Mart and BASF (McDonough & Braungart, *Cradle to Cradle*, 2002).

In McDonough and Braungart's widely acclaimed book *Cradle to Cradle* they discuss ways of making industrial processes more analogous to biological processes. There is the commonly held assumption that industrial processes have to damage the environment in order to function. They approach industrial processes from a differing perspective, they argue that processes can actually be designed to improve the surrounding environmental conditions. With this approach, more industry is a good thing rather than a negative. In nature the waste that is created is used again as a *biological nutrient*. In industrial processes, the materials that are wastes but able to cycle back into an industrial process are *technical nutrients*, as they have defined it. They argue that current industrial systems create materials that cannot be broken down into either their biological or technical nutrients and are lost to landfill. This way of making things is a *cradle to grave* system and needs to be reconceived as *cradle to cradle*.

At first glance McDonough and Braungart appear to be proposing an unachievable utopian vision of the future. However, many of their ideas have been applied and are making a difference. An upholstery company in Europe was producing a chair fabric whose offcuts were considered hazardous waste and the water leaving the plant had many toxins from their production. So McDonough and Braungart consulted the company on their fabric production processes. They were able to source natural fabrics that did not require any harmful chemicals in their manufacturing, no hazardous waste was created because the offcuts could be composted and the water leaving the plant was actually cleaner than the water entering the plant. As a result the employees did not have to wear protective gloves, could use areas previously reserved for chemical storage as recreational spaces and the environment was not harmed but enriched with the waste being a biological nutrient.

They introduce the concept of a product as a service. A customer leases a product from a manufacturer that after a specified time, go back to the manufacturer, they are getting a service rather than a product. McDonough and Braungart consulted one of the largest carpet manufacturers in the world and applied this concept to their business. Each year millions of tonnes of carpets are disposed of in landfills so they saw this as an opportunity. The company leases their carpets for a period of time and after that are sent back to the manufacturer to be cleaned, repaired and then re-leased to a new customer. This way of thinking allows architectural materials in the technosphere to continue as *technical nutrients*. More architectural product manufacturers could adopt this method. Kitchen and bath manufacturers could lease their fixtures and then when a new model comes out the consumer could send their old one back to be cleaned and sold at a reduced cost to other consumers.

Applying cradle-to-cradle principles to architecture requires that the design does not stop when the building is built but how the materials used can be used again and again as a technical nutrient after the building is no longer of use. Specifying fewer composite materials will aid in keeping the system cyclical as components can easily be broken down and either reused or recycled rather than landfilled. Finding examples in architecture of designs that have a second use or the ease of returning the materials to the technosphere is difficult. Traditionally, architects do not design for the irrelevance of their structure and design for more permanence.

An example of a building which was designed so that it could later come apart and relocate or components reused elsewhere is the Crystal Palace by Joseph Paxton. In 1851 The Great Exhibition was housed in the Crystal Palace, which was constructed out of standard steel members with a glass façade. The building was built to be in operation at its original location for five months, after which it was taken apart and rebuilt on a new site. Unfortunately the building suffered a major fire that led to its demolition (Encyclopaedia Britannica). The success of the building was its use of standard components that could easily be rearranged in new configurations without additional alterations. If it hadn't burnt down, it most likely would have been a heritage building today but with the potential to be taken apart and used elsewhere or in other applications.

The Upcycle – William McDonough and Michael Braungart

In McDonough and Braungart's second book *The Upcycle* they discuss and elaborate on similar issues of material use. They discuss the concept of an *Intelligent Materials Pool*, which is part of the implementation of Industrial Ecology. In order for manufacturers and industrial systems to function as an Industrial Ecology, there needs to be an increase in information sharing. The *Intelligent Materials Pool* (IMP) is a database of the inputs and outputs of industrial processes. By studying an IMP, industrial processes can see links between processes that were otherwise invisible and potentially wasted. The Eco-park in Kalundborg has put together an IMP between the industrial processes. This has allowed them to see more connections that can be utilized (Superuse Studio, 2009). The IMP is analogous to the work of Superuse Studio through their Harvest Map and Flow analysis.

By applying the IMP to construction, renovation and demolition waste, new opportunities may arise. Some materials may still have great reuse potential and not need to be downcycled or landfilled.

4. Material Reuse in Architecture

Recorded reuse of materials in architecture dates back to ancient Rome. In 397 A.D. the Count of the East was instructed to use materials from pagan temples to construct bridges, roads, aqueducts and other city infrastructure. Aqueducts that no longer served their initial purpose were closed in, so that they could become the homes for the cities poor (Lynch, 1984).

Drop City / Earthship

More recent examples of material reuse in architecture came out of the Counterculture movement of the late 60s and 70s. Much of the youth had been disillusioned by the Vietnam War and decided to create communities that were self-sufficient and in rural locations. One community in Colorado called “Drop city” created dome like structures reminiscent of Buckminster Fuller’s geodesic domes. The domes were constructed out of discarded waste and car-tops (Fig. 9), (Matthews, 2010).

Fig. 9 Drop City
(Photo Credit: Unknown, 1965)

Another contributor to the Counterculture movement was Mike Reynolds who in the 1970s started building “Earthships” in Taos, New Mexico. The Earthship is constructed out of waste tires and glass bottles. Rammed earth is hand driven into stacked tires to create foundation walls (Fig. 10.) The homes are self-sufficient and rely mainly on manpower to build (Reynolds, 1990).

Both Drop City and the Earthships offer unique ways of building inexpensively but their widespread application is questionable. Aside from the use of waste materials that

are often free, a main factor for their inexpensiveness is the cost of labour. Drop City structures were built by the “sweat equity” of the owners and friends and often took long periods of time to build. In the case of the Earthships, the organization relies on volunteers to construct the homes and as well the owners take part in the build. The concept of having students and people who want to learn the process of building off the grid is beneficial but the cost of constructing an Earthship is not accurately represented. Earthships are for the most part off the grid homes but they require large south facing facades to heat the home, which may not be as feasible in an urban setting. Both structures would be very difficult to obtain building permits in most municipalities because they do not meet building codes. In the 70’s when Mike Reynolds was initially building Earthships he faced strong opposition from the Taos building officials and had to speak with State Legislators in order to be allowed to build (Hodge, 2007). The rammed earth tires could also pose health issues from the rubber heating up in the summer months and off-gassing harmful chemicals to the interior.

Drop City and Earthships both utilized materials that had become reduced in value. The car tops sitting in scrap yards are arguably valued more when they providing a home for someone and providing a function. Discarded rubber tires are an issue all over the world, in Ontario alone there are over 12 million tires discarded annually (Ontario Tire Stewardship, 2013). Many of these tires end up in the landfill but there is effort to recycle more. In areas where recycling is not available for the tires, using them as retaining walls could be an option. Both Drop City and Earthships are positive steps in expanding the dialogue of material reuse in architecture and provide a new way of constructing homes and communities but their widespread application is limited.

LOT-EK

Contemporary examples of waste from other industries being used in architecture come out firms like LOT-EK and Superuse Studios. LOT-EK’s work often utilizes shipping containers like the Puma (Fig. 11) and Uni-qlo Pop-up retail shops but they have also used airplane fuselages in their designs (Ruby & Ruby, 2010). In countries where imports are higher than exports, like Canada, shipping containers are available in abundance. They can either be recycled back into steel or reused within architecture. The reuse of shipping containers often requires cuts in the walls, roof or floors, which

greatly reduces their structural stability and extra reinforcement is required. Shipping containers also have an industrial aesthetic as they are commonly seen in industrial settings. Used in a commercial application such as the Puma retail store may be appropriate but their use in a residential neighbourhood may face backlash from the community or planning departments that often have design guidelines for the materials and style of homes.

Fig. 10 Earthship Mike Reynolds
(Photo Credit: Mary Caperton Morton, 2011)

Fig. 11 LO-TEK - Puma Pop-up Retail
(Photo Credit: Mike Pinder, 2010)

Tres Birds Workshop

In Denver, CO there is a design-build architecture firm that specializes in material reuse called Tres Birds Workshop. One particular built project that features the reuse of an entire building is The Horse Barn in the Curtis Park neighbourhood. The building was an old police horse stable that had been converted into a cooperative office for companies and organizations with environmental/humanitarian goals. Various parts of the building showcase material reuse. One material in particular that was used throughout the project is reclaimed flooring from old rail cars. The planks are used as treads and risers in a feature staircase in the middle atrium and also as work surfaces throughout the building.

Fig. 12 Tres Birds Workshop Table

Fig. 13 Tres Birds Workshop Stair

The rail car flooring in both the stair and table application had been finished. At first glance they might appear to be new but after closer examination you can see fragments of its past life. The ends of the stair and table show the tongue-and-groove joints of the laminated 2" boards. The ends of the table show remnants of the spikes that held the boards together (Fig. 12). By finishing the wood as if to make it look new but still allow small details of its past life is an interesting feature of Tres Birds Workshop's work. The viewer has an almost "ah-ha" moment when they realize the material was once used for something else. The use of the old rail car flooring is a great example of a material that is in abundance and is then upcycled into a product that looks beautiful and is quite strong as it is solid wood. To get the flooring to the same quality as in the Horse Barn requires sanding and finishing, which will add to the costs of using the material. This added cost may still result in a lower overall cost if the initial cost of the material is less than new. Mike Moore did not say how much the flooring planks cost but it can be assumed that they would be less expensive than new 2" solid tongue-and-groove planks.

Community Engagement Through Material Reuse

Aside from the ecological benefits of material reuse, the community can also benefit from repurposing goods. Since repurposing materials often utilizes materials that would otherwise have been discarded, the costs involved can be quite minimal. For small-scale projects, the only thing potentially required is the sweat equity of an individual or a community. Reuse techniques have the potential for great impact in areas where income is low and need for community engagement is high.

Rural Studio

Rural Studio: Samuel Mockbee and an Architecture of Decency discusses the work of the late Samuel Mockbee. Mockbee was an American architect who taught a design studio for Auburn University called the Rural Studio. Rural studio takes place in Hale County Alabama, an area that has a 40% poverty rate and living conditions are often inadequate (Dean & Hursley, 2002). The concept of the studio is to provide inexpensive homes with quality environmentally sensitive, contemporary designs and to bring the community together. The students, in collaboration with the residents, design and build homes and community buildings. Having the residents work along side the students is a key part of the rural studio. Many of the residents have distrust for professionals and authority so working together instills a level of trust.

Auburn University only pays for the salaries of the professors, so the money required to build the homes is by donation. Students have to be very resourceful with their designs because budgets are small. This is solved partly with the selection of materials, many are reclaimed from deconstructed buildings or creative uses of waste. The first home built was the Bryant House, which utilized hay bales for super insulated exterior walls. A smokehouse built next to the home was built from demolished street curbs and old street signs “superused” for the roof. The budget for the smokehouse was only \$140. Another project that was built for the community was the Mason’s Bend Community Center in 2000. The center at first glance looks vernacular in form, similar to a country barn, but at closer inspection is a sophisticated contemporary structure. One of the distinguishing features is the “fish scale” glazed façade constructed out of 80 Chevrolet Caprice windshields (Fig. 15). Other experimental materials used are shredded cardboard bale walls, license plate cladding (Fig. 14) and rammed earth in tires similar to Earthships.

Fig. 14 Rural Studio - Podhouse Cladding
(Photo Credit: Dean & Hursley, 2002)

Fig. 15 Mason's Bend Community Center
(Photo Credit: Dean & Hursley, 2002)

In 2001 Samuel Mockbee passed away due to cancer. Fortunately, the studio is still running with the same goals of social and environmental sustainability. As time has passed the projects have become more ambitious in scale and complexity.

For projects like Rural Studio to function they require direct engagement with the community as often they are the individuals building the projects. Architecture's role in scenarios like this is to facilitate the design process, source materials, detail connections so that they can be put together with ease. Not all projects are suitable for this kind of arrangement, as office buildings are not usually connected to the community. Homes and buildings and structures for the community are ideal for the reuse of waste and to be constructed by locals. When the community is directly involved in the construction, often with their "sweat equity", the flow of money for labour can be negated. Also, the sense of pride attached to the building will be much stronger vs. having a construction crew do all the work.

Superuse Studio

In 2008 Superuse Studio designed a playground in Rotterdam built out of five discarded wind turbine blades (Fig. 16). Each year many wind turbines have to be

replaced in the Netherlands so Superuse Studio reused the blades in a playground (Superuse Studios, 2008). Before the new playground was built the site was neglected and in desperate need of care. Blades are positioned horizontally and vertically as small towers. Children can play inside and on top of the blades and there are even benches built for parents to rest and watch their kids play. The reuse of the wind turbine blades is a fun and creative way to restore a dilapidated urban site. Wind turbine blade reuse should be limited to countries that use wind for energy generation. Otherwise the energy required to transport the blades may outweigh using local materials.

Fig. 16 Superuse Studio - *Wilkado Playground*
(Photo Credit: Allard van der Hoek, 2008)

5. The Waste of Buildings

The built world consumes roughly 40% of the natural resources and energy, making it one of the largest consumers next to agricultural activities (Goodbun & Jaschke, 2012). Of this, nearly 10% is considered waste.

Obtaining data on CRD waste in Canada can be quite challenging, as there is very little regulation on managing and tracking waste generated. Each municipality has their own policies on how waste is handled. In Ontario the government has attempted to regulate waste being generated from construction through *Regulation 102/94: Waste Audits and Waste Reduction Work Plans* (ServiceOntario, 1994). 102/94 stipulates that large construction projects over 2,000m² must implement a waste reduction plan. The reduction plan outlines the amount, type and strategies for reducing waste. Reduction is the main objective, if this is not possible; reuse of the material is to be done. If reuse is also not possible then recycling of waste is the final objective. The regulation is a positive step forward but needs further work, as it does not stipulate a percentage of waste diversion, which would aid in reducing waste.

Aside from the lack of regulations there are also very few studies available other than Statistics Canada. Every two years Statistics Canada publishes a report called *Human Activity and the Environment: Waste Management in Canada*. The report quantifies waste being generated, diverted and landfilled by province and Canada as a whole. Waste is separated into three categories: Residential, Industrial Commercial and Institutional (IC&I) and Construction Renovation and Demolition (CRD). 2013 was the last report published and the data collected was from 2010 so there is a lag in information presented and actual quantities produced. In 2008, Canadian CRD activities generated 3.6 million tonnes of waste, of that 702,076 tonnes (20%) was diverted with the remainder being sent to landfill (Statistics Canada, 2012). In Ontario for the same year, 1 million tonnes of waste was generated from CRD activities with 209,000 tonnes (20%) being diverted. Statistics Canada unfortunately does not specify the composition of waste generated, this information was available through Natural Resources Canada (NRCan). NRCan published a report in 2006 called *An Analysis of Resource Recovery Opportunities in Canada and the Projection of Greenhouse Gas Emission Implications* and had information on Ontario waste in 2002 from CRD activities. In 2002, CRD

activities in Ontario produced roughly the same amount of waste as in 2006, just over 1.1 million tonnes. Of the 1.1 million tonnes, 1,014,000 tonnes was disposed and 144,000 or 14.3% was diverted (Natural Resources Canada, 2006). The composition of materials disposed of is as follows:

Concrete	17%
Asphalt	8%
Wood	31%
Drywall	11%
Ferrous Metals	1%
Nonferrous Metals	3%
Paper Products	1%
Other	29%

Of the waste being disposed, wood is the majority with 31%. One category that is unknown is the “Other” material with a large portion of waste at 29%, it is assumed that this is referring to waste excavated soil but as it is not specified there is missing information in the study. This information does tell us a few things though, in Ontario alone there is a large amount of waste produced from CRD activities, especially wood waste.

The Recycling Council of Ontario (RCO) conducted a study in 1990 to understand construction waste more thoroughly; the study was called *Making a Molehill Out of A Mountain*. The study focused on new home construction and renovation waste. In 2005 another report was conducted by the RCO called *Let's Climb Another Molehill*. This report expanded upon the first to include onsite monitoring activities and 15 case studies from various types of construction, renovation and demolition projects throughout the GTA. Included are three case studies, one from construction, renovation and demolition. Many of the case studies are quite specific in the waste materials generated so case studies with materials that can be applied to a wider range of construction

projects have been selected. The goal of reviewing the case studies was to see what the composition of waste materials is and also what is being done with this waste.

Construction Case Study: St. David's Custom Home Framing

In 2004 a custom 3,200sf home was constructed in St. David's, ON. The builder wanted to reduce the amount of waste generated from framing and other construction activities so they implemented various strategies:

- Provide dedicated wood waste bin onsite
- Communicate waste reduction plan with framing crew and labourers
- Reduce offcuts and order appropriate amount of wood
- Separate and weigh all waste materials produced

The builder initially ordered two bins for waste collection, one for wood and one for misc. waste, but only one was delivered at the start of construction so all materials had to be placed in one. Two bins would make recycling easier as there is no need for sorting. Once the bin was full it was taken to a facility to be hand sorted into seven categories: Dimensional Lumber, Manufactured Wood, Metal Strapping, Misc. Metals, Assorted Plastic, Cardboard and Garbage.

From the waste material generated from the framing of the home, understandably, dimensional lumber was the majority with 930kg, which was taken to a composting facility. 570kg of Manufactured wood waste was generated and could not be composted so it was sent to the landfill. The remainder of the materials excluding the garbage was recycled. By incorporating a reduction plan the builder was able to divert 80% of the waste generated from landfill by composting and recycling.

Renovation Case Study: Etobicoke, ON Residential Home

In 2003, homeowners in Etobicoke decided to renovate their 1,700sf, 40 year old split level home to include a new kitchen, two additional bathrooms and a new upper floor bedroom. The objectives of the renovation were to:

- Recycle all demolition wood waste and asphalt shingles
- Deconstruct and reuse kitchen and bathroom cabinets and plumbing fixtures.

The permit process took longer than expected so many decisions had to be made quickly. As a result many of the waste reduction strategies were compromised such as finding appropriate recycling facilities and closing up the home as construction was done in the winter months.

In the beginning of the planning process the waste hauler was not able to attend the waste reduction meetings. As a result there was a miscommunication about recycling of the waste. The waste hauler said their typical practice with wood waste was to recycle, yet after closer review it was discovered that it was being taken to a waste to energy plant where it was burned. This is generally not considered recycling. The waste hauler was also not able to find a recycler of asphalt shingles so they were disposed of at a landfill.

The deconstruction crews had made arrangements with Habitat for Humanity's ReStore to donate the kitchen cabinets to be sold. Once work began it was discovered that the cabinets were site built which made removal difficult. The doors were salvaged but the remainder had to be landfilled. Fortunately the bathroom cabinets could be reused in the renovation, yet the toilets were landfilled.

In order to reduce the amount of waste from renovations it is important that all parties involved clearly understand the goals. In the case of the Etobicoke renovation, the waste hauler misunderstood the goals and recycling was not done. The reusability of cabinetry varies whether it was site built or pre-assembled. Site built cabinetry cannot easily be reused in the same configuration but components such as shelves, doors and hardware offer great reuse potential on another project. Cabinetry renovations should be built so that they can be disassembled later or rearranged for extended use.

Demolition Case Study: Department of Defense Downsview Park Housing

In 2003, the Department of Defense no longer needed four row-house buildings so they decided to demolish and deconstruct the homes where possible. Defense Construction Canada handles all Department of Defense construction and they have a mandate to reduce waste. Their demolition tendering process incorporates points for diversion rates proposed. Tenders are not accepted unless they meet the minimum rate. This ensures that the demolition crews are experienced in deconstruction and share the same goals. The goal of the deconstruction was simple: divert as much material as

possible from landfill, either to be reused or recycled. In the end, a 90% diversion rate was achieved.

The row-houses were constructed with concrete block party walls, exterior brick facades and wood framed interiors. The concrete block and bricks were deconstructed carefully first for reuse and if that was not possible they were crushed and recycled. The concrete foundations were crushed and steel rebar was removed to be recycled along with the concrete. 34 toilets were salvageable for reuse and 11 had to be recycled. Removing the wood from the homes was more difficult due to nailing but because of a growing market it was salvaged for recycling.

By implementing deconstruction strategies over demolition the Department of Defense was able to divert 9,300 tonnes of material from landfill and saved over \$600,000 in landfill tipping fees. The project serves as an example for future demolition projects with regards to its savings, diversion rates and unique tendering process.

A review of the three case studies highlights common trends related to construction waste. Even though the projects were unique and only provided a small glimpse into waste created from construction activities, the processes and some of the materials are common throughout the industry. Waste coming out of the framing of new wood frame home construction primarily consists of dimensional lumber, which may offer reuse potential. Also, by incorporating multiple bins whenever possible, the reuse of materials can be increased as there is less of a need for sorting. Millwork detailing is often part of the architectural package and if detailed correctly can lead to increased reuse potential. Architects need to design cabinetry and site built components of buildings to disassemble, which would allow for reuse of the materials. Specifying fewer nailed connections and glued surfaces is important. In the case of the Etobicoke renovation, the cabinetry was unable to be salvaged because of how it was detailed and installed.

A Building's End of Life

At the time of construction it is known that the building will not last forever. The average expected lifespan of a building today is between 30-50 years (Calkins, Materials for Sustainable Sites, 2009). No product in a building has a warranty that lasts forever.

Throughout the life of a building, systems or even the entire building no longer function satisfactory and removed. Components such as window seals and motors or pumps in mechanical systems fail or are too inefficient and can lead to whole building demolition if it is too costly to fix or replace. The New York State Energy Research and Development Authority and landlords of various iconic mid-century New York skyscrapers commissioned a study to determine what should be done with inefficient skyscrapers. The result of the study concluded that the buildings should be demolished and replaced with larger buildings that consume 5% less energy and within 15-28 years the carbon cost of construction would be offset (Karni, 2013). If buildings are built with the knowledge that they will one day come down, should they not be built so that they can easily come apart rather than torn apart?

Demolition

Demolition creates large amounts of debris that includes: concrete, asphalt pavement, roofing material, tiles, wood, metals, and gypsum wallboard (Calkins, Materials for Sustainable Sites, 2009). These materials are generally rendered useless for reuse because of the way they were initially installed. When welds, glues, brick mortar and pneumatically driven nails are used it can be very difficult and time consuming to disassemble the parts in whole form. Additionally, building components are often composite materials that are mixtures of wood, plastics and metals, which make recycling very difficult and usually impossible. These assemblages lead to a building's demolition because it is the easiest way to take a building down.

Demolition is the simplest way to take a building down for various reasons. The labour that is required does not need to be relatively specialized, as the equipment used is common to many heavy labour activities including; wrecking balls, bulldozers, excavators and jack hammers. The time required is relatively low when compared to deconstruction. Crews do not need to be precise when demolishing a building because the material will be landfilled or broken down to be recycled, but not reused. Although studies have shown that demolition may end up costing more than deconstructing a building as there is the potential to sell salvaged materials to offset the costs (Calkins, Materials for Sustainable Sites, 2009). As landfill tipping fees increase and materials become scarcer, demolition is less likely to continue.

Deconstruction

Material reuse and recycling from deconstruction can have many benefits to society. The need for resource extraction, habitat destruction, energy use and emissions are reduced. When more buildings are being deconstructed, the salvage and reuse market is strengthened, often positively effecting the local economy rather than a mining company on the other side of the planet. At a project scale it can be cost effective. By deconstructing a building there are fewer materials going to the landfill, which reduces fees paid for disposal, these materials can also be sold and generate a potential profit. Depending on the location and material being extracted, the cost of purchasing salvaged goods can be lower than purchasing new, thus reducing the project budget. Diverting material from the landfill can result in two direct LEED credits; “Construction Waste Management: Divert 50% from Disposal” and “Divert 75% from Disposal”. Also, additional points can be earned from “Material Reuse” and “Regional Materials”. Using reclaimed materials can add to the design aesthetic, giving it a unique look and historic cultural relevance (Calkins, Materials for Sustainable Sites, 2009).

Design for Disassembly

As mentioned earlier, resources are becoming scarce, thus it is likely that more buildings will need to be designed to be taken apart to salvage materials for reuse. In the past there were fewer concerns about resource depletion so buildings were not designed with this in mind. Now that resource scarcity is more of a pressing issue, buildings designed today should be designed for disassembly (DfD).

Aside from current construction practices not being educated in DfD, lack of incentives also limits the practice of DfD. If a developer or client is planning on selling the building once it is constructed, there is little incentive to build it to come apart in the future when they have no financial involvement. This unfortunately requires policy changes as developer built buildings is not likely to change. As governments become more involved and educated about sustainable construction practices, possible tax incentives could be offered for DfD. The European Union has implemented a policy called *Environmental Liability*, which requires manufacturers to pay for the proper handling of the good at the end of its life (European Union, 2014). Many manufactures take their goods back at the end of its life, or lease the good as a service in response to

the legislation. It does not apply directly to the construction industry but if included it would change the way architects design buildings to include more detail into the end of their useful life.

The first step in DfD is that architects and designers become more informed on the process. Without the knowledge of how to implement these decisions in a design it will not happen. Some key parameters that should be taken into consideration when designing for disassembly are (Crawford, 2011):

- Having all consultants, owners and builders involved in the project early in the design process and with the goal of DfD
- Material connections should be designed to be easily taken apart. Instead of adhesives use fasteners, instead of nails and welding use screws and bolts
- Design the connections so that they are easily accessible with the tools necessary to take them apart
- The weight of components and equipment should be minimized so it can easily be taken out when it no longer meets the requirements of the users or the building is being taken apart
- Composite materials should be avoided if they cannot be distilled into their original materials easily

When designing with waste materials it is important to design with deconstruction and DfD strategies just as much as it is for new materials. Allowing the material to be used once again as a technical nutrient is part of the solution in creating a cyclical ecosystem (McDonough & Braungart, The Upcycle, 2013).

6. Temporary Structures & Programs

The term temporary can be somewhat misleading. Nothing is actually permanent as all buildings and structures eventually have to be torn down or simply degrade from exposure to the elements. Webster's Dictionary defines Temporary as such: "continuing for a limited amount of time, not permanent, intended to be used for a limited amount of time" (Merriam-Webster, n.d.). It is in the last version of the definition that is most applicable to its use in architecture. Yes, all buildings are temporary but they can only be defined as such if their intended use is limited. All buildings should be termed temporary but they are most often built with no plan for the end of their useful lives.

Temporary structures and programs are an ideal test bed for using waste as construction material. Temporary structures with a short lifespan allow the material to be tested first and if it is a successful application it can be applied in buildings with longer lifespans. This logic is in parallel to Tactical Urbanism, both of which have informed the program of the design. The architect David Adjaye designed a temporary pavilion for the London Design Festival in 2008 called *Sclera* (Fig. 17). The structure was built out of tulipwood, a material previously not used on the exterior of buildings. The pavilion was a test bed and showcase for further use of the material within an architectural context (Adjaye Associates, 2008). The structure is quite simple as it is only a semi-enclosed space but it is successful in showcasing the material for its exterior application.

Fig. 17 Adjaye Associates, London Design Festival, Sclera, 2008
(Photo Credit: Adjaye Associates, 2008)

Temporary structures by definition will be taken down, there is the knowledge that it is not going to last indefinitely so its design must take this into account. If it is going to be taken down, reinstalled in another location or reused in other projects, DfD strategies will need to be included. Even if it isn't being built again, designing so that it can easily be repurposed or recycled is ideal. Temporary structures are more analogous to natural systems. Natural systems are never static and are constantly changing, regenerating and feeding back into other systems.

Not all programs are ideal for impermanence, so understanding what can and should not be temporary is important. Civic institutions should be somewhat permanent in their location. Police stations, hospitals and other municipal buildings for instance should be static so that they can easily be located. If they are transient, it will confuse people who are trying to use the services offered. Programs that are seasonal can easily be designed for temporality. Greenhouses and community gardens are less likely to operate in winter months so during colder periods, the structures can be disassembled, stored or used for another function. During festivals, often all the structures that are built

are temporary, these can range from one night like Nuit Blanche or World Expos, which last months.

Urban planning initiatives are often focused on long-term projects to increase the quality of public space. These projects require large amounts of capital, political will and time and once completed are not always easily measureable for their success (Lydon, 2012). The Planner, Mike Lydon argues for “short term action for long term change” when it comes to planning for the public realm. Short-term interventions can be done quickly and with little capital investment. Large projects are not always easily understood by the public and if they are not successful require even more capital. Temporary projects if successful can be applied to a larger more permanent project. Temporary architectural projects are ideal for this type of urbanism.

The interdisciplinary design firm Rebar focuses on “solving the design problems of the commons” and much of their work lies in the realm of short-term, public interventions. In 2010 they designed and built *Walklet* in San Francisco, where they took over parking spaces on the street and installed seating, planters, bike parking and tables (Fig. 18). The intention was to increase the usable sidewalk space for pedestrian use. The intervention was only planned for six months but due to its success has been extended indefinitely (Bishop & Williams, 2012). Another temporary project Rebar was involved in was the *Panhandle Bandshell*. The bandshell was constructed out of 65 automobile hoods, computer circuit boards, plastic water bottles, reclaimed doors and wood and recycled steel (ReBAR Group, 2010). In 2007 it was constructed in San Francisco’s Panhandle Park for almost two weeks where it was used for both informal and formal performances. It was designed so that it could be disassembled and rebuilt in other locations. In 2009 it was installed in another San Francisco park for the same use. Since then it has remained in storage but can be rebuilt once again. The bandshell is successful in spreading the message of material reuse as it is placed in public parks, which attract many visitors. Also, designing it with the ability to move from one location to another further increases its exposure.

Rebar’s work has been very influential to the design work of this thesis, as there is a focus on short-term, public interventions as a way to showcase waste and increase its value. As well, there is a similar approach to Adjaye’s Sclera project for its program of

showcasing a material that previously had little exterior applications in architecture.

Fig. 18 Rebar – *Walklet*
(Photo Credit: Rebar, 2010)

Fig. 19 Rebar – *Panhandle Bandshell*
(Photo Credit: James Addison 2007)

Tactical Urbanism

Another way reuse can positively affect a community is through DIY Urbanism, a topic that is discussed in *Tactical Urbanism* by Mike Lydon. He found that planners often focus on large-scale permanent public projects such as stadiums or museums. These interventions require large amounts of capital and political will. Public is not easily able to engage in design process because the project's scale is often too large for the public to engage with.

Lydon's reaction to this process was to work at a smaller, neighbourhood scale. This is referred to as "Guerilla Urbanism", "Pop-up Urbanism", "D.I.Y. Urbanism" or "Tactical Urbanism". The projects worked on by "guerilla urbanists" are at times sanctioned by city planners but most often not.

Lydon argues that these types of interventions have a greater impact on the community because they are local solutions to local issues. They are done with the intent that they are short-term, low cost so there is little risk involved but potentially high rewards. They are a test bed for ideas that if successful can be applied at a larger scale and more permanently.

In New York City there were many inefficient traffic islands in the roads that were not being used by vehicles or pedestrians. Tim Tompkins of the Times Square Alliance, a non-profit organization that works to promote Time Square, thought that people might

want to occupy these spaces. So 376 inexpensive folding chairs were bought and placed in the underutilized space within Time Square. These chairs proved to be very effective as citizens and tourists occupy them at all hours of the day. In the future, because the intervention has been successful, a more permanent intervention can be developed.

Another example discussed in *Tactical Urbanism* is the work of DoTank Brooklyn. They are a group of community activists who come from a range of backgrounds that work to turn neighbourhoods into communities. One of their projects that dealt specifically with urban waste is Chair Bombing. They collected waste pallets and repurposed the wood into Adirondack chairs. Once the chairs have been built they placed them in areas of Brooklyn that were in need of public seating (Fig. 20).

Pallets for various reasons are taken out of the reuse cycle of being used once again as a pallet. This can happen when there isn't a system in place to return the pallet to the manufacturer or it is missing boards, which make them structurally unsafe. Throughout any urban setting, the pallet is a ubiquitous waste material that can be expected on curbs and in alleys. These pallets have very little perceived value but taking them apart and reusing the wood to build public seating, they once again have a value. The added value comes in the time someone spends building the chair and the value the community places on public seating. Aside from the labour required to build the seat, the value a community gives it is difficult to quantify but it does have an effect. More public seating means more people will use a public space, which means more activity in an area. By activating a public space with people there is a potential to lower crime, as people will be less willing to commit a crime if people are near by. This in effect puts more "eyes upon the street" as Jane Jacobs discusses in *The Death and Life of Great American Cities* (Jacobs, 1961). All of this combined aid in making an area more desirable to be in.

Fig. 20 DoTank - *Chair Bombing*
(Dan Balles, 2012)

For the design portion of this thesis, tactical/pop-up urbanism concepts have been applied for smaller more community scaled interventions that are used by the public. Having the public engage with projects built from waste is a way to increase the discussion regarding reuse of waste and also increase the quality of public space. Not only is the reuse of waste materials beneficial to communities like in Hale County Alabama, but can have a positive impact on urban settings as well.

7. Ryerson Student Learning Centre Waste Study

To understand the waste generated from construction, renovation and demolition, reviewing the case studies from *Let's Climb Another Molehill* was important and informative. To get further insight into construction waste material make up and quality the construction of the Ryerson Student Learning Centre provided an opportunity to carry out an audit.

The Student Learning Centre is located on the corner of Gould St. and Yonge St. and has a large architectural impact with its irregular curtain wall façade and proximity to Yonge and Dundas Square. The centre provides a place to study and collaborate for the Ryerson student body along with the surrounding community. The building is designed with sustainable principles in mind and is targeted to achieve LEED Silver.

In January 2014, Ryerson Capital Projects staff along with representatives from the construction firm responsible for the build provided some insight into what materials were being discarded, how much of it was generated and where it was going. The aim of carrying out this research was to understand which materials, if any, could be reused in an architectural context. The first thing to be done was to get on site and see firsthand the waste being generated. On January 26th 2014, a tour of the site was arranged and photographs of waste in various areas of the building were taken. Work being done while on site was mainly concrete pouring of floor slabs and lower level mechanical system installation. At this point, only the 5th floor slab had been poured, out of eight storeys in total. The building is of concrete structure with an atypical curtain wall system. Aside from the fact that it is primarily concrete, the bulk of the waste present on site was wood. The following is a description of the waste in major categories.

Wood

Stair Tread Covers

On each stair tread there were ½" plywood covers to protect the concrete stair during construction (Fig. 21). Once construction is finished the covers are taken off and discarded. In the building there is a total of 690 treads divided among 3 primary exit stairs. There is approximately 460m² of plywood material that is discarded.

Fig. 21 Stair Covers

Formwork

The SLC has irregular concrete columns and floor slabs, which mean some of the formwork cannot be reused for more concrete pours. Once the concrete has set, the plywood formwork is removed and discarded. On the site visit is witnessed piles of used plywood formwork waiting to be taken to the waste bin on site (Fig. 22).

Fig. 22 Waste Plywood

Temporary Wood Guards

At slab edges and in the stairwells, wooden temporary guards are used to prevent workers from falling (Fig. 23). Once the curtainwall or stair guards are installed the wood 2x4s are taken down and discarded. The guards are constructed out of 2x4 SPF dimensional lumber.

Fig. 23 Temporary Wood Guards

Concrete

Concrete Waste

When the concrete work is being done, there is excess concrete that cannot be used in the pour. This concrete gets placed in bins where it eventually hardens. Once it has hardened it is taken to the waste bin. Wherever there was concrete work being done while on the site visit, concrete waste was present (Fig. 24).

Fig. 24 SLC Concrete Waste

Concrete Blocks

The lower level has concrete blocks for partition walls and this work had been done prior to the site visit. Many of the concrete blocks have to be cut for the end pieces in doors and corners. These offcuts are then unusable and are discarded.

Metal

Mechanical Ducts

While onsite there were mechanical ducts being installed in the basement, as this area was the furthest along. The ducting is held in place with steel brackets and rods, which are cut to fit on site. There were many offcut pieces lying around after the ducts had been installed (Fig. 25). These pieces were not usable so they were discarded.

Fig. 25 Metal Ducting Waste

Concrete Reinforcement

Around the site there were many rebar offcuts laying around waiting to be cleaned up and taken to the waste bin. There was also excess rebar that could not be used and was being treated as waste (Fig. 26).

Fig. 26 Rebar Offcuts

Packaging

Many products that are delivered to site come wrapped in plastic wrap, which is then treated as waste (Fig. 27). Paints and coatings come in buckets, which are disposed of, also many products are delivered to site in cardboard that is treated as waste. Pallets

are not treated as waste on the SLC project as each supplier is responsible for their own pallets. They are collected onsite and taken back by the suppliers or subtrades (Fig. 28).

Fig. 27 SLC Packaging Waste

Fig. 28 SLC Pallets

Typically when waste is produced on a large construction project, it is handled by a third party. For sites that have a lot of free space for material storage, multiple waste bins for dedicated materials are stored onsite. There are separate bins for wood, metals and miscellaneous waste. Depending on the phase of construction there may also be dedicated bins for concrete and drywall. When these bins fill up they are taken to a recycling facility or landfill. For urban sites that are constrained for space, storage of multiple waste bins are impossible so all waste materials are comingled in one bin. Comingled bins are taken to an offsite sorting facility to be separated. Comingled waste bins are more expensive because of the additional sorting that is done. After meeting with a project manager from the construction firm responsible for the SLC further insight into the costs associated with waste handling was gained. General costs for construction waste handling provided by the construction firm are as follows (Visconti, 2014):

Pickup Rate (20/30/40 Cubic Yard Bin)	\$60.00/pickup
Comingled Waste	\$65.00/tonne
Clean Wood	\$35.00/tonne
Mixed Wood	\$65.00/tonne
Drywall	\$45.00/tonne
Steel	\$100.00/tonne

Concrete/brick	\$250.00 flat rate
Cardboard/Plastics	\$35.00 flat rate

In the case of the Student Learning Centre, the site is quite constrained so only one bin is provided. All waste materials are comingled in one bin, when it is full it is taken to a sorting facility by a waste handling company. The sorting facility for the SLC is located 17km away in Etobicoke (Fig. 29).

Fig. 29 Offsite Waste Sorting Facility

Materials are separated into five major groups: Wood, Metals, Concrete, Paper/Cardboard and Gypsum. Once separated they are taken to other facilities that recycle the material or when that is not possible they are landfilled. Cardboard is taken to a facility in Mississauga where it is recycled back into cardboard. Gypsum is taken to a recycling facility in Oakville where it is recycled into gypsum powder to be made back into wallboard. Concrete is delivered to a facility in Toronto where it is crushed and used as gravel fill or as concrete aggregate. Metals are also taken to a facility in Toronto but

only to be sorted and then shipped to various mills throughout Ontario to be melted back into usable metal. Wood is taken 66km to Orangeville where it is chipped and downcycled into animal bedding and landscaping mulch. Also, wood does not have the potential to be recycled back into the product it originally was, as mulch, wood is close to the end of its lifecycle. Mapping out the material flows is an important part in justifying the reuse of materials. Also, potential connections can be made apparent. This way of mapping is similar to Braungart and McDonough's Intelligent Materials Pool but for waste materials.

Fig. 30 SLC Waste Recycling

During the month of December 2013, six bins were filled with waste material and taken to the sorting facility with a total weight of 44.6 tonnes (Waste Management Inc., 2013). The majority of waste was wood and concrete, this is due to the fact that work being done was concrete pouring (Fig. 31). An estimated cost for waste management for the month of December works out to just over \$3,200 based on the previously mentioned waste costs with wood making up \$1,280 of this. This may seem insignificant but when multiplied over the course of the construction project it could be in the tens of thousands.

Fig. 31 December 2013 Waste, (Waste Management Inc., 2013)

An alternative solution to construction waste management would be for people who have a direct use of the material to be able to collect it directly from the site. These people would be “super-users” as Jan Jongert and Césaire Peeren of Superuse Studios would describe them. In the case of the Student Learning Centre the waste materials produced onsite could potentially be of use for projects within the campus, like landscaping and urban furniture, similar to the work of Rebar and Tactical Urbanism. Waste materials leaving the SLC project could in total travel a distance of 160km or more before they are of use, not to mention the energy required to recycle the materials. This scenario would be mutually beneficial to both superuser and construction company. For this to occur it would first require a re-educating of the construction company to see the environmental and economic benefits of material reuse. The superuser would be able to source the material for a reduced cost or free and the construction company would have a reduced amount of waste being sent to a sorting facility or landfill, thus reducing their costs. The superuser would need to enter into an agreement or contract with the construction company especially with regards to safety. The superuser would need to have a safety orientation, wear proper safety gear and assume a degree of

liability. As sustainable issues are becoming more known, this could be a marketing point that the construction company advertises.

Of the waste materials generated from the SLC project, some more than others have greater reuse potential within an architectural context. In order to determine which materials can be reused from the Student Learning Centre and other construction projects a matrix of parameters has been developed (Table 1). A square with a blue circle indicates that it meets that category. A half blue circle indicates that it meets the category but there are issues or limitations. An empty square means that it does not satisfy the needs of the category.

The first parameter that the materials must meet is that they can be found on other construction sites. If the material is unique to the SLC then their widespread reuse potential is quite limited. The next parameter that must be met is that the material is relatively undamaged. A material may be ubiquitous in construction but if it is damaged, it has very little reuse potential and recycling is the best option. If reuse is to take place, the materials generated need to be quantifiable for both the superuser and construction company. If the amount generated is unknown then it will be very difficult to coordinate the logistics of the material, also knowing the amount can help the construction company measure the benefits of reuse over paying for disposal. In order for a superuser to coordinate the logistics of the material with the construction company, the time of its disposal needs to be known, this is an important factor and parameter. For example, you can predict when the temporary guards are going to be taken down because the date of the curtain wall installation will be scheduled. If a material can be recycled back into the same material it was when delivered to site but not reused, then recycling is the best option. Small rebar offcuts are of no use in further concrete pours so recycling back into usable steel is preferable. Whether a material was previously used as a construction material is important but not critical as these materials can always be used in new creative ways.

	Cardboard	Plastic Wrap	Concrete	Conc. Block	Formwork	Tread Covers	Wood Guards	Ducting Metal	Conc. Rebar
Widely Available	●	●	●	●	●	●	●		●
Minimal Damage							●		
Reusability			◐	◐	●	●	●	◐	◐
Measurable Quantity				●		●	●		
Timing of Generation Known					●	●	●	●	
Recyclability	●	●	◐	◐	◐	◐	◐	●	●
Construction Material			●	●	●	●	●	●	●

Table 1 SLC Waste Material Reuse Parameters

Suitable materials for reuse have been determined from the evaluation. Packaging waste such as plastic wraps and cardboard are challenging to reuse because of their inherent low strengths and variability of type. The majority of the waste formwork has irregular cuts and is of varying size so the reuse would need to be specific to the generated pieces. Concrete block reuse potential is slightly higher, for example it can be used as landscaping retaining walls. Excess concrete is difficult to reuse due to its weight creating logistics issue but it too once broken into smaller pieces for use in a gabion retaining wall. The plywood stair covers have reuse potential as the side facing the stair is untouched but the side that is walked on will be dirty and potentially damaged from wear. The pieces could possibly be used for flooring underlay and wall partitions. The standard size of the pieces increases its reuse potential and it will be discarded at a predictable time, when the building is near completion so logistics of this material can be arranged. Someone with a use for the stair covers could coordinate with the construction company to pick them up when they are removed. From the waste materials generated, the temporary wood guards have the highest reuse potential. The pieces are all standard dimensional SPF lumber. As it is only serving as a guard, there is little wear on the material. 2x4 lumber is a ubiquitous construction material so it can be reused in a large variety of ways. In order to reuse the pieces, labour is required to remove the nails but once this is done, they are restored relatively close to their initial state. Wood coming out of the SLC has half circles for recyclability on the matrix because they are essentially

downcycled. The typical recycling method for wood is to be ground into wood chips for animal bedding, landscaping and mulch and will never be recycled back into their original form, like waste steel that is melted back into usable steel (Calkins, Materials for Sustainable Sites, 2009). After evaluating the reuse potential of all waste materials, temporary wood guards have been selected for the project portion of this thesis.

The temporary wood guards are made from SPF dimensional 2x4 lumber, which is common in framing applications. The wood comes in three lengths: 1.2m, 2.4m and 3.0m. The 1.2m lengths are used as the structural stanchions with the longer pieces used for guardrails. On slab edges there is a stanchion every 2.7m with three 3.0m lengths forming the rails with .15m overlap at the stanchion. For the stairwells there is a 1.2m stanchion at the bottom of a landing, one in the middle of the run and another at the top with six – 2.4m lengths forming the rails.

A takeoff of slab edge length and stairs indicates that during construction the SLC had a total of 1,028m (3370') of slab edges and three stairwells with eight flights of stairs that required fall protection. The total amount of 1.2m and 3.0m lengths being generated from slab edges is 340 and 1,028 respectively. From stairwells the total amount of 1.2m and 2.4m lengths being generated as waste is 144 and 192 respectively. The stanchions are made from one 2.4m length cut in two, which works out to 242-2.4m lengths. In total there are approximately 1,028-3.0m lengths and 434-2.4m lengths delivered to site. One 3.0m-2x4 weighs approximately 6kg and a 2.4m-2x4 weighs approximately 5kg. The total weight of wood being generated as waste from temporary guards is 8,300kg.

In Canada and Ontario, wood is chipped into small wood fibres, which are used for animal bedding, wood chips, mulch and in cases where the wood waste is clean, fibre composite panels (Tam & Tam, 2008). Every year the organization Wood Resources International publishes a report on North American Wood Fibre markets. In 2011 the average price in Ontario for an oven dry metric ton (2200lbs or one metric tonne) of wood chips was \$122 CAD (Wood Resources International , 2011). If wood guards from SLC were to be chipped and sold as animal bedding or landscaping, the economic value would be \$1,010 CAD, based on the 2011 report by Wood Resources Int. On the other hand if you calculate the value of this waste wood as dimensional lumber you get a

higher value. The wholesale cost for 2x4 SPF lumber is 0.42 and 0.38 cents per board foot for 10' and 8' respectively. In total there are 10,280 board feet from 10'(3.0m) and 3,472 board feet from 8'(2.4m), which equals \$5,637 (Argo Lumber Inc., 2014). As the wood is not new and some pieces have been cut in half, assuming a reduction in price by 50% would still be over \$2,800. Both prices are strictly material costs. For the woodchips: transportation, energy costs to run equipment, taxes, storage and the labour required are not included. The cost of the wood guards for reuse does not include the cost to transport, store and labour to sand or clean dirty pieces or governmental taxes.

Aside from the increased economic value of reusing wood, there are many environmental benefits. As trees grow, they take in CO₂ as part of photosynthesis. The carbon continues to be sequestered within the tree until it is harvested. One kilogram of oven-dry harvested wood has the capacity to sequester 1.84 kilograms of CO₂ (Calkins, Materials for Sustainable Sites, 2009). By harvesting the wood an imbalance is created in the carbon cycle of the planet and contributes directly to global warming, 20% of the human-caused CO₂ emissions are linked to deforestation (IPCC, 2000). Deforestation also contributes to the loss of natural habitats and ecosystems that are vital to the planet. Once the harvested wood product reaches the end of its "useful" life either from natural decay or human causes such as landfilling or burning, the carbon is released back into the atmosphere, contributing to global warming (Calkins, Materials for Sustainable Sites, 2009). When sourcing reclaimed wood, the carbon that was sequestered while the tree was growing continues to be sequestered. 15,270kg of CO₂ is prevented from being released back into the atmosphere by reusing the 8,300kg of temporary wood guards.

8. Design Process

Introduction

This thesis included a series of design explorations related to the use of waste materials. Before the work focused on waste from construction some explorations were carried out using waste from the shipping of goods. This included pallets and cardboard tubes. Pallets are ubiquitous world wide as they make shipping small goods easier. They are designed to be movable via a standard forklift or pallet jack. Typically they are made out of wood and the assembly is quite ranging depending on the application. Cardboard tubes are used to ship paper, textiles and any other material that can be rolled. A bench was designed and built out of these two materials. The main goal of the bench was to test out connection details.

Bench Designed from Waste

The reason for a bench is that it is modest in scale and structurally it needs to support the weight of more than one person. It is the hope that the structural tectonics learned could be applied at a larger scale.

Toronto's downtown was used for the sourcing of waste materials. The key parameter focused on was waste sources that are constantly flowing and similar in properties. Often when walking around Toronto neighbourhoods you can count on there being waste furniture placed on the curb. This flow of waste is constant but cannot be anticipated and furniture properties vary. For small-scale projects discarded furniture is useful but when trying to develop a prototypical architectural response to waste, these items were disregarded. The initial investigations lead to areas where some manufacturing processes occur, or at least serve a manufacturing process.

Fig. 32 Queen St. Fashion District

Toronto's Queen St. West between Spadina Avenue and Bathurst Avenue is known as the fashion district (Fig. 32). There are various clothing stores but more importantly there are a significant amount of fabric wholesalers. The wholesalers sell fabric of various textures, colours and patterns that are rolled around cardboard tubes. When all the fabric around a tube is sold, the tubes are placed on the curb to be picked up weekly by city garbage and recycling crews. Some of the tubes are damaged from use but as there are many similar stores, there are ample tubes that are perfectly intact (Fig. 33). The cardboard tubes are quite strong as many have $\frac{1}{4}$ " – $\frac{1}{2}$ " walls. The tubes are also lightweight so carrying a few of them is not an issue.

Fig. 33 Waste Paper Tubes

Many tubes of varying length and tube thickness were initially tested for connection details. A 4" diameter tube was cut into 12" sections and mitered the ends so

that they could be joined at a 45° angle for a simple truss design (Fig. 34). This created complicated geometry that required a jig to ensure both ends had the same 45° cuts. Also by cutting the ends at 45° angles and gluing, the tubes could not be reused as easily later on if needed.

Fig. 34 Joint Connection Test

Fig. 35 Shigeru Ban Connection - *Library of a Poet*
(Photo Credit: Unknown, 1991)

To simplify the geometries, cardboard tube examples done by architect Shigeru Ban were studied. In particular the Library of a Poet, which utilizes a wood block connection detail (Fig. 35). A similar approach was used but instead of orienting the tubes orthogonally they were rotated 45° to create a truss like system (Fig. 41).

In the final bench, three 5' long, 4" diameter tubes, two from Queen St stores and one from the woodworking shop in Ryerson's architecture building were used. The tube from Ryerson was also a waste tube that was going to be recycled. The tubes were cut into eight - 20" long sections (Fig. 36)

Fig. 36 Cut Sections

Fig. 37 Unused Pallet

The connection of the tubes required wood blocks, there was a pallet waiting to be recycled in the architecture building that had wood blocks and boards that would become the bench seat (Fig. 37). Taking the pallet apart required a crowbar and power saw. Once the wood blocks from the pallet were free, work on the connection began. Attached to the block are plugs that were made from CNC waste circles that happened to fit the inner diameter of the tubes (Fig. 39, Fig. 40). In the future, CNC waste is not something that can be relied upon because it varies from project to project and is specific to the Architecture building at Ryerson.

Fig. 38 Disassembled Pallet

Fig. 39 Waste CNC Circles

Fig. 40 Joint Detail, Pallet Block & CNC Waste

Fig. 41 Bench Supports

With the tube sections fitted onto the plugs, carpenters glue and screws were used for fastening. For the bench seat, the boards that came from the pallet were used and cut into lengths that would span between the block connections. Cardboard tubes are good in compression but weak in tension so along the bottom truss section, steel cable and a turnbuckle was used to keep it from spreading apart (Fig. 42).

Fig. 42 Turnbuckle

Fig. 43 Completed Bench

The bench was constructed in parallel to other research so not all the final design parameters were realized as the research was still evolving. In particular, designing for disassembly was not addressed. The connection of the tubes to the blocks was done with adhesive and screws. By using glues, the bench could only have one use and if it was no longer needed as a bench, the components would have to be torn apart, which would potentially make it unsalvageable for recycling. If the wood plugs connecting the tubes had a tighter friction fit and only screws were used, the individual members would come apart easily. The seat was fastened to the connecting blocks with screws so the legs can be taken apart and potentially used in a truss for a canopy. The tubes from the Ryerson architecture shop had shipping labels attached. Aesthetically, this may appear to be an eyesore but they were purposefully left on. By leaving them on, the fact that the tubes once had another function was highlighted. Due to the material nature of cardboard tubes, the bench is also limited to interior applications. Outdoor precipitation and humidity will weaken the tubes and eventually it will fall apart. There are ways to treat the tubes with coatings but they then become difficult to recycle. The structure of the bench limits seating to only the middle portion, if one is to sit on the ends, it will tip over. In future iterations, this would have to be addressed by reconfiguring the legs or securing it the ground.

Next, the research was focused on waste generated from construction activities. Cardboard tubes and pallets are suitable for reuse but the applications are limited. Pallets are typically reused over and over to ship goods between manufacturers and consumers and only end up being recycled into wood chips once they are no longer structurally sound. At this point they would no longer be of use within an architectural context. The decision against cardboard tubes was made due to their limited exterior use. Construction waste was focused on due to its inherent connection to architecture. Also, construction activities in Ontario alone generate over 1 million tonnes of waste annually (Statistics Canada, 2012).

Architectural Response

In order to affect the most people for the least costs, similar to the work of Tactical Urbanism, the architectural response was to design small-scale urban interventions out of construction waste. This can materialize in the form of seating, shading/rain canopies, performance space and planters. These interventions were to be placed throughout spaces on Ryerson University's campus that are both heavily visited or under utilized. The reason for selecting Ryerson's outdoor space for the site was because it is in close proximity to the source (SLC). All interventions were to be built from waste and designed to easily come apart to be repurposed once again or when no longer structurally sound due to exposure and wear, downcycled into wood chips. By placing them in public areas, more people will have a chance to see/use the intervention thus potentially increasing the value of the material while informing the public on material reuse.

On discovering the availability of 2x4 dimensional lumber from the SLC, the next stage of the research focused on these materials. The following section includes design explorations with the waste 2x4. The design was constantly evolving so iterations with drawings, models and detail mockups have been included. In the end there is a final design presented but all of the work and iterations must be seen together to understand the process of returning value to waste materials.

Site Selection/Research

After reviewing the materials available and the distance they have to travel, Ryerson University's campus has been selected as the site for the project portion of this thesis. Using the waste materials as close to where they were created is important in reducing the energy demand in transportation. Also, by proposing the project on the campus it creates an opportunity for Ryerson to showcase its work and commitment to sustainability. The campus, due to its urban setting attracts thousands of visitors to the public realm, including the streets, and green spaces. Providing additional recreational space and planters can increase the quality of the public realm. The following section is a review of the Campus Master Plan for ways in which the project is analogous to and can fill in potential gaps.

Ryerson Campus Master Plan

In 2006, Ryerson President, Sheldon Levy put in motion a new Campus Master Plan to improve the growing urban campus and better integrate it into the also growing downtown of Toronto. A team of four visionary firms was selected to create the plan, Kuwabara Payne McKenna Blumberg Architects, Daoust Lestage Inc. in association with Greenberg Consultants Inc. and IBI Group. In 2008 after over 300 meetings and forums, the Ryerson Board of Governors approved the Campus Master Plan. The Campus Master Plan is divided into three overarching goals: Urban Intensification, People First: Pedestrianization of the Urban Environment and Commitment to Design Excellence (KPMB, Daoust Lestage Inc., Greenberg Cons. Inc., IBI Group, 2008).

Urban Intensification

"Reinvent the centre of the campus by creating a vital central zone in the precinct and invest in the urban seams by strategically intensifying them within a defined Ryerson University precinct." (p. 23)

Ryerson is located near one of the most active intersections in North America, Yonge and Dundas so the campus needs to fit contextually yet also have its own distinct presence. Ryerson's location also makes it very difficult to grow. The only way to add to the campus is by going up. As the campus grows upwards, the goal is to not lose a sense of place on the ground plane of campus. By focusing on Gould Street between

Victoria and Bond Street, a new heart of the campus is created. Closing this portion of the street off to pedestrians, aids in creating a lively central area on campus. Also, the creation of Lake Devonian gives the area a use in all seasons with it functioning as a skating pond in the winter, an informal place for people to skateboard in the shoulder seasons and a reflecting pond in the summer. Giving Ryerson a distinct presence in the urban context is important and is done through recognizable branding. The branding includes upgrades to sidewalks, urban furniture, landscaping and signage.

People First: Pedestrianization of the Urban Environment

“Create a distinctive public realm which defines the Ryerson University precinct within its urban context, enhances the vitality of all green open spaces, streets, and sidewalks, promotes a collegial pedestrian environment within the university and enhances accessibility to the campus by increasing public transit opportunities.” (p. 75)

People First focuses on creating a walkable, comfortable, safe and enjoyable urban campus for both the Ryerson and surrounding communities. This is done in part by creating distinct urban furniture and landscaping that is usable year round, regardless of the weather conditions. The idea is that these spaces will increase the collegiality between students, faculty and neighbourhood. Walking through the campus is more than just getting from A to B. Creating visual interest points and desire lines through furniture and landscaping will make walking across campus more enjoyable and also bring the neighbourhood into the campus.

Commitment to Design Excellence

“Expand Ryerson University’s academic and student focused spaces to provide new and improved state-of-the-art spaces for teaching, laboratories for research in multiple disciplines, student study space and student facilities.” (p. 117)

Commitment to Design Excellence has a strong focus on continuing to pursue high environmental standards, efficient energy use, renewable energy sources and responsible handling of resources. The Student Learning Centre with its LEED Silver rating is an example of this. Part of this goal is to communicate the commitment to the public through the distinct Ryerson Precinct and also showcasing student’s work.

After reviewing the Ryerson Campus Master Plan a program has been developed for an architectural intervention that is inline with the plan. The intervention is a set of urban furniture pieces built from the waste of the Student Learning Centre that are placed throughout the campus. They will incorporate seating, planters and a venue for both formal and informal performances. The seating will provide shelter from the sun, wind and rain so that they can be used year round. The placement of the urban furniture will be done so that they are visible from outside of the campus, this will help bring people in and increase Ryerson's presence. The urban furniture will showcase the work of students as well as Ryerson's commitment to responsible resource use as the materials have come from construction waste from a Ryerson building. Instead of using the energy to transport and downcycle the temporary wood guards, they can be reused and increase the quality of the Ryerson campus.

Design Exploration 1

This design was done early on and is not proposed for Ryerson's campus as it was done before the Master Plan research was carried out. The site location was Trinity Bellwoods Park, between Queen West and Dundas St. at Gore Vale Ave (Fig. 45). It involved two serpentine walls inspired by Richard Serra's sheet metal sculptures. The two walls created a corridor that could house artwork or protect people from the harsh Toronto winter winds (Fig. 44). The location proposed was next to the Dog Bowl, which is used in the winter as a toboggan hill and a place for dogs to go off leash year round. The location is also in close proximity to a skating rink. The two walls would provide some shelter from the harsh winter winds to both people tobogganing and skating. Seating was incorporated in the wall by cantilevering boards to create a bench (Fig. 46).

Fig. 44 Design Exploration 1 Sketch Model Plan View

Fig. 45 Design Exploration 1 - Trinity Bellwoods Site Plan

Fig. 46 Design Exploration 1 - Wall Seating

The construction was quite simple and explored further through subsequent iterations, it involved stacking two foot long - 2x4 pieces on top of each other with an offset. The boards are connected with screws at the overlaps. The offsets in the boards allowed for a semi-private space with both opaque and transparent sections (Fig. 47).

Fig. 47 Design Exploration 1 Plan/Elevation

The wall was designed so that it was modular, this is so that the structure could be temporary and taken down and moved to a new location if need be. This is done by building it in sections that have holes drilled in the end boards that allow rebar to connect the two modules together. The rebar would then fit into a PVC pipe that is embedded

within concrete in a concrete block buried in the ground (Fig. 48). The rebar, PVC and concrete block are all waste materials from the Student Learning Centre.

Fig. 48 Design Exploration 1 Connection Sequence

After further examination into the design it was apparent that there were quite a few issues that needed to be addressed. The modules at full scale would be awkward to put together as they would weigh over 50kg and would require a high degree of accuracy so that the holes in the end pieces could line up. Also, the full height rebar pieces were not realistic as the rebar waste coming out of the SLC project were only small offcuts, not long enough for the height of the wall. The walls would protect against some wind and sun but as they only curved in plan, they provided no cover from the rain.

Design Exploration 2

The next iteration incorporated the same, stacked wood structure but this time it included a double curve to allow for more shelter. The pieces were stacked and slightly offset to give it the double curve. Also, the new design allowed for more programs as it functioned as a bandstand (Fig. 49). Instead of only using two foot lengths, this design incorporated varying lengths of two, three, four and five foot 2x4 lengths. This design included a larger structure for the bandstand program and a smaller structure that was strictly for seating (Fig. 51, Fig. 52). This design was a study in double curvature of the 2x4 structure and was not taken further than the sketch models.

Fig. 49 Design Exploration 2a Elevation

Fig. 50 Design Exploration 2a Plan

Fig. 51 Design Exploration 2b Elevation

Fig. 52 Design Exploration 2b Plan

One-to-One Mockup

To get a sense of the aesthetic of the stacked structure and also test out double curve, a one-to-one mockup was built (Fig. 53). For the mockup it was important that the materials were from the SLC, fortunately four – four-foot lengths of the 2x4 wood guards were attained. Having only the four pieces a smaller mockup had to be constructed so the board was cut into smaller pieces than had been designed. Once the pieces had been cut, they were treated with organic linseed oil. Linseed oil is a natural wood finish that protects against decay for outdoor purposes. As it is a natural finish the length of time it protects is quite minimal, only 2 years (Calkins, Materials for Sustainable Sites, 2009). The benefit of Linseed oil is that after the structure is to be taken apart, they can still return to the recycling stream unlike pressure treated wood that can contaminate clean wood waste. Linseed oil does not drastically change the appearance of the wood;

only a slight yellow colouring was present. The staining of the pieces was done indoors, a process that should be done outdoors as it has a strong earthy smell when it is drying that could offend some people. To fasten the pieces, screws were used so that the mockup and future installation could be disassembled with ease rather than using nails.

Fig. 53 One-to-One Mockup

After completing the small mockup some observations were made. In order not to split the wood, pilot holes should be drilled first for the screw holes. This was not done of the first few holes and the wood began to split. The mockup was stable as the curve was very slight, future curved walls would need to be anchored if more curve was required. If it is required that the wood stay as close to the initial colour then linseed is useful as it only adds a slight yellow tint. Also, linseed oil gives the wood a slight gloss that may or may not be desirable depending on the application.

Design Exploration 3

Exploration 3 took what was learned from the previous iterations and expanded the program to include: public seating, bandstand/performance space, planters and some protection from the elements. The structure had a double curve that curved along a semi-circle in plan. With two together it created a yin-yang aesthetic that allowed for a semi-enclosed space, protected from wind, sun and rain but still allowing for views in and

out (Fig. 54). Half of the semi-circle was devoted to seating, which was covered by the wall itself. The other half of the semi-circle tapered down to create a connection to the earth with a series of planters (Fig. 55). The design used the same stacked 2x4s but with lengths of 3' for the wall and 2.5' for the seating and planter.

Fig. 54 Design Exploration 3 Exterior Plan/Elevation

Fig. 55 Design Exploration 3 Interior Plan/Elevation

In order to keep soil from falling out of the offset wood pieces, the planters were lined with discarded vinyl street pole banners. The banners are not part of the waste generated from the Student Learning Centre but Ryerson has seasonal banner campaigns that are collected by the advertising company at the end of the campaign and are discarded. The vinyl banners also provide clues that the structure was built from waste materials. As the vinyl banners would be partially covered from the offset structure, it would not at first be apparent what they were. After closer examination, the user would realize and potentially at this point make the connection that the structure was built out of waste. The wood guards are held together with nails and these holes would be visible, as well, the vinyl banners would provide clues to its previous life. This approach to aesthetics is similar to the Miele Space station by Superuse Studio and the Haida Air Jordan masks by Brian Jungen.

The structure was proposed for two locations on Ryerson's campus. The first was the open space just south of the Architecture building next to a fountain. This location was chosen for its connection to the Department of Architectural Science to showcase its

work and secondly for its connection to Pittman Hall, the main residence building on campus (Fig. 56). The amenity space on campus for student residences is lacking and it was the hope that this would expand upon this, something the Master Plan did not fully address (Fig. 65). The structure is also visible from Church St., which would create an interest point to bring pedestrians into the open green space, which is often unused.

Fig. 56 Design Exploration 3 Architecture Quad Site Plan

Design For Disassembly

The structure is designed to come apart and be moved to other locations or reconfigured. It is built in two modules (Fig. 58) that are connected in the middle with 2x4 pieces that have a hole drilled halfway through (Fig. 59). The 2x4 slides between the two modules, which have a hole drilled all the way through, similar to Iteration 2. Because the surface is double curved, one rebar piece would not be able to slide through the holes. Instead, small rebar dowels hold the connector pieces to the modules (Fig. 62). Using smaller rebar pieces is also more appropriate as there are rebar offcuts generated on site. When it is time to move the structure, a magnet is used to pull the rebar dowels out, one layer at a time.

Fig. 58 Exploration 3 Connection Sequence 1

Fig. 59 Exploration 3 Connection Sequence 2

Fig. 60 Exploration 3 Connection Sequence 3

Fig. 61 Exploration 3 Connection Sequence 4

Fig. 62 Exploration 3 Connection Sequence 5

Fig. 63 Exploration 3 Connection Sequence 6

Once it is taken apart into the two modules they can be picked up by a forklift and placed on a flatbed truck for transport. The offset pieces allow for the forks of the forklift to slide through and pick up the structure as the heaviest portion weighs 636lbs, well below the maximum limit of most forklifts. The bandstand is created when it is reconfigured with two of the seating modules connected together in the same way as the planter to seating connection (Fig. 64).

Fig. 64 Design Exploration 3 Bandstand Elevation/Plan

Fig. 65 Design Exploration 3 Architectural Quad Rendering

Fig. 66 Design Exploration 3 Lake Devonian Rendering

Fig. 67 Design Exploration 2 - 1:25 Model

The first three iterations address some aspects of the thesis but it was apparent that some aspects were not successfully addressed. The waste 2x4s came in lengths of 4', 8' and 10' but all of the proposed structures required cutting of the wood into smaller pieces. By cutting the 2x4s their reuse potential after they were no longer needed in the designed structures would be reduced. Instead of cutting the pieces, it would be preferable to use wood waste as it came: in 4', 8' and 10' lengths. By adding this constraint, the project became more real and directly related to the thesis. Also, all previous designs were placed directly on the ground. This would create moisture issues with the lower pieces being exposed to snow and rainfall.

By using the wood pieces in their original sizes it changed the scale and form dramatically. This at first seemed daunting but after experimenting with new designs, was able to retain many of the initial ideas and concepts learned from the previous iterations. The structures were adapted in order for the new sizes to work. Regardless of the structure, the programmatic needs were carried over to the final design.

Final Design

For the final design, the locations and program have remained. The structural stacking of the 2x4s has also been retained but the form and character has changed. It features a platform, bench seating, linear singular curved wall and planters. The wall curves over the front bench to provide some protection from the elements. The curving is achieved by slightly offsetting each row as they go up, similar to the 1 to 1 mockup. At each end of the wall there are curved wing walls, these define the space yet also offer structural stability. The platform can be used for seating or a venue for performances.

Unlike the previous iterations, which were placed directly on the ground, the final design is lifted off to protect against moisture damage, this is done by building the structure on concrete pavers (Fig. 71). By including a platform, people with accessibility issues would have problems using the structure. A ramp has been included, made from the same 2x4 guards and the waste stair covers from the Student Learning Centre to allow for accessibility.

Fig. 68 Main Structure Perspective View

Fig. 69 Main Structure Plan

Fig. 70 Main Structure Section

The platform is constructed out of the 3.0m lengths and supported by the 2.4m lengths on the pavers. The 2.4m lengths are doubled to increase structural stability. The wall is built out of the 1.2m lengths with the bench utilizing the 3.0m lengths (Fig. 71). The platform is 0.15m above grade with the wall extending 2.2m in height (Fig. 70). All connections will be done using screws so that the structure can come apart in the future, a task that would be tedious yet retain the value of the wood for reuse.

Fig. 71 Main Structure Exploded Axonometric

Architectural Quad Structure

The main structure is located in the same place as Exploration 2 but faces towards the green space (Fig. 72). The platform can be used for performances, which can be viewed from the grass (Fig. 77). The rear of the structure faces the fountain and a seat has been included so people can enjoy the water (Fig. 75).

Fig. 72 Arch Quad Site Plan

The structure incorporates three planters, one on the front and two on the rear elevations (Fig. 74, Fig. 75). The planters are constructed in the same fashion as iteration 2, being lined with the vinyl banners. As the plants mature they would be able to weave in and out of the stacked structure. The plants would aid in creating a welcoming space for people to use.

Fig. 73 Arch Quad North/South Site Section

Fig. 74 Main Structure Front Elevation

Fig. 75 Main Structure Rear Elevation

Fig. 76 Main Structure Side Elevation

Fig. 77 Performance Venue

Fig. 78 1:25 Model

Fig. 79 1:25 Site Model

Lake Devonian Structures

For the structures at Lake Devonian the over all form and character is identical at the Architectural Quad structure yet its program and size are not. They are reduced in size and do not include a platform for performances (Fig. 80). They function as seating year round but their main purpose is for the winter. The smaller structure has fewer openings created from the offset boards so less wind will penetrate the wall. During the winter the lake is used for skating but there is no place for skaters to escape the winds. By providing shelter from the wind, more people would use the ice surface, which would increase the activity of the campus.

Fig. 80 Lake Devo Structure Perspective View

Fig. 81 Lake Devo Structure Front View

Fig. 82 Lake Devo Structure Rear View

Fig. 83 Structural Wall End Pieces

The structure includes seating on the front and a planter on the rear (Fig. 81, Fig. 86). There are two structures around Lake Devo, one to the north and another to the west (Fig. 84). Typically winter winds from the northwest in Toronto so by placing them here, people will be able to escape the winds.

Fig. 84 Lake Devo Site Plan

Fig. 85 Lake Devo East/West Site Section

Fig. 86 Lake Devo Structure Plan

Fig. 87 Lake Devonian Front Elevation

Fig. 88 Lake Devonian Side Elevation

Fig. 89 Lake Devonian Summer Rendering

Fig. 90 Lake Devonian Winter Rendering

To build the structure there would require some work done to the waste 2x4s. Many of the pieces would be rough and potentially have splinters and even nails. The boards would require sanding to remove splinters and full inspection to ensure all nails had been removed. SPF lumber does not hold up well from exposure to moisture so applying a weather protectant like linseed oil would be required. The previous sanding would aid in the application of the weather protectant. Longer SPF 2x4s tend to bend and twist so these pieces may need to be clamped during the construction or possibly not used. At the ends of the walls, small pieces would be required for structural stability; these are highlighted in blue in Fig. 83. These pieces would be comprised of offcuts from throughout the site so no additional cutting would be necessary. The remainder of the boards would also not require any cutting, as they are the lengths that are being generated from the temporary fall guards.

9. Conclusion

This thesis outlines a theoretical and practical investigation that indicates that architecture has a role to play in adding value to a material at the end of its life. The World Bottle by Heineken is an example of where a material that had no value but by creatively redesigning, its value was increased to provide shelter for people in need. Unfortunately, Heineken did not realize this. The design explorations in this thesis were able to add value to waste 2x4s that would have otherwise been landfilled or downcycled into woodchips. By reusing the temporary fall guards in the proposed structures they would continue to have a useful purpose as they were and increase the quality of Ryerson University's outdoor public spaces.

The reuse of waste in an architectural context has been by and large of a smaller scale and in many cases not the traditional idea of architecture as building. Many of the examples of reuse of waste materials by architects come in the form of installations and upgrades to the urban landscape like the Miele Space Station and wind turbine playground designed by Superuse Studios. The design work of this thesis has also focused on increasing the quality of the urban landscape through small-scale interventions. Designing and building large-scale projects out of waste material can be quite challenging, as there are very few precedents and familiarity in building this way. The small scale can be used as a test bed for new materials, concepts and connections. Architects can play a role in this exploration by utilizing their technical knowledge of materials, connections and coordination skills. As well, architecture's artistic merits aid in creating environments that are both functional and a delight to be in, on or near.

Can waste materials be used universally within architecture? This is a far more challenging objective and is far more difficult to put into place, as currently the necessary infrastructure does not exist to allow this to happen. Some waste materials are appropriate for specific situations but will not be appropriate everywhere. Homes with walls built from rammed earth tires would not be suitable for an urban location where space is a premium as the tires create very thick walls. But many of the examples of waste reuse in architecture suggest that it is appropriate for multiple situations. In areas where income levels and employment rates are low, building with waste materials can

have great benefits. The work of Rural Studio in Hale County demonstrates this quite well. Poverty rates are high and many people are unemployed so building with new materials would be difficult or impossible. By using waste materials like old road signs and windshields they are able to create quality and unique examples of contemporary architecture for limited budgets. The reuse of waste materials often requires work done to return the material to a usable state. In areas where unemployment rates are high, this labour to restore the materials can be done through the “sweat equity” of the participants or homeowners, as seen in Hale County, Drop City and Earthships.

Using waste materials in areas where community engagement is high or in desperate need is also appropriate. This can materialize in temporary installations, public seating/shelter or artwork. The playground designed and built out of wind turbines by Superuse Studios illustrates how waste materials can play a role in community building as the site was previously neglected. The blades could no longer be used in wind turbines, so by using them as playground material value has been restored. This value can be seen in the increased quality of space, as the park was once derelict.

When designing with waste materials there are two ways in which aesthetics can be dealt with and both have merits. The first is to leave the material as close to its original form as possible. This strategy showcases the material for being a waste material and makes it very clear that it is being reused. In the Earthships, many tires are patched but the form of the tire is still visible and also, many tires are exposed to highlight their reuse. In the future it is possible that showcasing waste materials will not be necessary as it could be the norm. The other strategy is to disguise the fact that the material was once considered waste. This can be done by cleaning, finishing or reconfiguring the material to obscure its original use. The windshields used in the Mason’s Bend Community Center were removed from the cars and reconfigured and their original use is obscured at first impression. Although, after closer examination it would likely be apparent that they were windshields. This strategy is also implemented in the Miele Space Station, as people did not initially realize they were parts from washing machines. In the proposed designs, the wood 2x4s would appear to be new materials when initially viewed due to some sanding and weather protectant. After the user got closer he or she would notice nail and screw holes from previous uses and also some of the wear from its use on the construction site. This strategy has strong merits in going

forward with waste reuse. If people perceive the material to be new and then discover they are actually being reused it may change the way they perceive all materials in that they can have multiple functions and having “new” things may not be as important. As well, the aesthetics of the architecture is less limited and can take on any variety of styles.

Currently, the reuse of waste materials from construction activities is quite challenging and may not be feasible at a large scale. The cost of labour in Canada is quite high so construction companies are not able to sort out usable materials for direct reuse. In the case of the Student Learning Centre, it was not possible to obtain the materials that were required for the proposed designs. It would have required a crewmember to separate the materials, which due to a tight schedule could not be done. On the other hand, the construction company has to pay to have the materials taken from the site, a cost that could be avoided by having the materials taken by someone with a direct use of the materials. It is difficult to predict what the state of the economy will be in the future but as resources and energy continue to increase in value due to scarcity, the reuse of construction waste may be of greater importance. This is also an issue that cannot be solved completely through architecture and requires governmental policy changes. As environmental issues regarding energy use, material scarcity and pollution become more apparent, governments should implement material reuse policies with respect to construction waste. This thesis does not propose a universal solution to the reuse of waste materials but a systemic approach to the issue. As materials and energy become scarcer, the reuse of waste materials is an inevitable future. Construction sites of the future could become mines for nutrients for the technosphere and aid at creating a more cyclical ecosystem.

Appendix

Waste 2x4 Bench

Aside from the more static structures designed, there was also a design for a set of movable benches made from the same waste 2x4s. The benches were designed to function in a pair but can also be utilized on their own. It was intended for use on the platform of the larger structure but can be moved to other locations (Fig. 93). This would require at least two people to carry as they weigh approximately 90kg. For the form of the bench the cardboard tube bench has been expanded upon with the same diagonal structure but also included was a lounge chair (Fig. 92). Also, the cardboard tube bench was susceptible to tipping if someone sat on either end; this has been redesigned by extending the base outwards for extra support (Fig. 92).

Fig. 91 Movable Bench Front View

Fig. 92 Variable Seating Configurations

Fig. 93 Platform Additional Seating

Fig. 94 Gould Street Benches

The benches can be arranged in multiple configurations depending on the desires of the user (Fig. 95).

Fig. 95 Multiple Configurations

The base of the bench is made out of the 2.4m boards. The seat, angled legs and lounge portion are 1.5m, 0.6m and 0.3m respectively, all being cut from a 2.4m board (Fig. 96). The remaining angled legs can be cut from a 2.4m board. This was to ensure that no unnecessary waste was created. The boards have holes drilled through and are connected with threaded steel rods, nuts and washers. This connection allows the bench to easily come apart to be reused in other applications or downcycled into mulch.

Fig. 96 Waste 2x4 Bench Construction Axonometric

Unfortunately, it was not possible to get the waste 2x4s needed for the bench or the larger structure from the Student Learning Centre construction waste. This would have required someone from the construction company to sort the 2x4s and set aside, which due to the cost of labour was not seen as an option. As well they could not have students come on site to take the material due to safety concerns.

In tandem to the thesis work, the bench design was submitted to the 2014 DesignbyNature competition. The purpose of the competition is to showcase material reuse through public furniture and sculptures. The jury selected the bench among 6 other designs to be on display at Evergreen Brickworks for the fall of 2014. As materials could not come from the construction site, other sources had to be found. There were discarded 2x4s from two old bedframes in the backyard of a Toronto home, which the owner allowed to be taken (Fig. 97). As well there was a food cart used in The Stop's 2014 Night Market that was designed and built by Ryerson Architectural Science students that was taken apart for its 2x4s (Fig. 98).

Fig. 97 Disassembled Wood Bedframe

Fig. 98 Stop Night Market Food Cart
(Photo Credit: Gabriel Li, 2014)

Fig. 99 Constructed Bench

To transform the 2x4s from the bedframes and food cart into the bench took many steps. First, the bedframes and food cart had to be disassembled, fortunately they were both constructed using screws so this was done with an impact driver. Once the boards were

freed they needed to be cut to the specified lengths, this was done with a chopsaw. A drill press was used to make the holes, which the threaded rod fit through. The wood needed to be sanded because the public was using the bench, so there could be no splinters. The wood was all SPF, which if left untreated will decay from moisture and because they were being installed outdoors they needed to be treated with a weather protectant. A natural water based finish was used for this.

Both the sanding and finishing give the wood an almost new aesthetic. At first glance, they may appear to be new but after closer inspection the original screw holes and wear from initial uses is visible. This way of treating the material is similar to how Superuse Studio treated the washing machine components in the Miele Space Station. If the user initially does not think they were made from waste materials but then discovers they were, it might make them think differently about materials in general. When one function of a material has ran its course, there is no reason it cannot take on a new function.

By cutting the 2x4s from their original lengths their reuse potential after the use in the bench is reduced. The 0.3m lengths for the seat will be the most difficult to reuse for a new function as they are smaller and also notched. The 0.6m truss legs are cut at an angle of 45° so reuse of these members will need to take this into account. The 1.5m seat will not have lost as much reuse potential as the work that has been done are the drilled holes, 50mm filleted corner where the seat meets the lounge portion and removing 0.9m of board.

When designing with waste materials, the source of the material is very important. Originally the bench had been designed using standard 2.4m long boards coming out of the waste from the Student Learning Centre. The modules were based on the 2.4m boards so that little waste would be created. The boards that came from the bedframes and food cart were of different lengths, which resulted in more waste offcuts. In the end value was added to the waste wood but there was some waste created. The bedframes would have been sent to landfill and the food cart wood was going to be sent to a facility to be downcycled into wood chips if they had not been used in the bench.

Works Cited

- Adjaye Associates. (2008). *Special Projects*. Retrieved 07 14, 2014, from Adjaye Associates: www.adjaye.com/project/special-projects/sclera/
- Assadourian, E. (2013). *Reengineering Cultures to Create a Sustainable Civilization*. The Worldwatch Institute. The Worldwatch Institute.
- Argo Lumber Inc. (2014). *Wholesale Cost of SPF Lumber*. Toronto: Argo Lumber Inc.
- Bauman, Z. (2007). *Consuming Life*. Cambridge: Polity Press.
- Babaian, S. (1998). *The most benevolent machine : a history assessment of cycles in Canada*. Ottawa: National Museum of Science and Technology.
- Bahamón, A., & Sanjinés, M. C. (2010). *Rematerial: From Waste to Architecture*. New York: W.W. Norton & Co.
- Bishop, P., & Williams, L. (2012). *The Temporary City*. London: Routledge.
- Calkins, M. (2009). *Materials for Sustainable Sites*. Hoboken, New Jersey: John Wiley & Sons, Inc.
- Calkins, M. (2009). *Materials for Sustainable Sites*. New Jersey: John Wiley and Sons.
- City of Toronto. (2013). *Depot Fees*. Retrieved November 10, 2013, from City of Toronto Garbage and Recycling: http://www.toronto.ca/garbage/depots_fees.htm
- Crawford, R. H. (2011). *Life Cycle Assessment in the Built Environment*. New York: Spon Press.
- Crawson, P. (1992). *Mineral Handbook*. New York: Stockton Press.
- European Union. (2014, August 22). *Environmental Liability*. Retrieved August 24, 2014, from European Commission Environment: <http://ec.europa.eu/environment/legal/liability/index.htm>
- European Environment Agency. (2014). *Highest recycling rates in Austria and Germany – but UK and Ireland show fastest increase*. Retrieved August 23, 2014, from European

Environment Agency: <http://www.eea.europa.eu/media/newsreleases/highest-recycling-rates-in-austria>

Encyclopaedia Britannica. (n.d.). *Crystal Palace*. Retrieved August 24, 2014, from Encyclopaedia Britannica: <http://www.britannica.com/EBchecked/topic/145293/Crystal-Palace>

Dean, A., & Hursley, T. (2002). *Rural Studio Samuel Mockbee and an Architecture of Decency*. New York: Princeton Architectural Press.

Frosch, R., & Gallapoulos, N. (1989). Strategies for Manufacturing. *Scientific American* , 144-152.

Goodbun, J., & Jaschke, K. (2012). Towards a New Materialist Practice. *Architectural Design* , 28-33.

IPCC. (2000). *Land use, Land-use Change, and Forestry - Intergovernmental Panel on Climate Change Special Report*. Cambridge: Cambridge University Press.

Hodge, O. (Director). (2007). *Garbage Warrior* [Motion Picture].

Jacobs, J. (1961). *The Death and Life of Great American Cities*. New York: Random House.

Jongert, J. (2012). *Inside Flows*. The Hague: The Royal Academy of Art.

Karni, A. (2013, March 25). Landmark Battle Turns Green. *Crain's New York Business* .

KPMB, Daoust Lestage Inc., Greenberg Cons. Inc., IBI Group. (2008). *Ryerson University Master Plan*. Toronto: Ryerson University.

Lydon, M. (2012). *Tactical Urbanism*. The Street Plans Collaborative.

Lynch, K. (1984). *Wasting Away*. San Francisco: Sierra Book Club.

Lim, J. S. (2003). *Identifying the Variance in the Magnitude of Landfill Impacts on Residential Property Values Using Multiple Regression Analysis*. Toronto: Ryerson University.

Natural Resources Canada. (2006). *An Analysis of Resource Recovery Opportunities in Canada and the Projection of Greenhouse Gas Emission Implications*. Ottawa: Government of Canada.

Natural Resources Canada. (2006). *An Analysis of Resource Recovery Opportunities in Canada and the Projection of Greenhouse Gas Emission Implications*. Ottawa: Natural Resources Canada.

National Research Council Canada. (2010). *National Building Code of Canada 2010*. Ottawa: National Research Council Canada.

Matthews, M. (2010). *Droppers: America's first Hippie Commune*. Oklahoma City: University of Oklahoma Press.

McDonough, W., & Braungart, M. (2002). *Cradle to Cradle*. New York: North Point Press.

McDonough, W., & Braungart, M. (2013). *The Upcycle*. New York: North Point Press.

Merriam-Webster. (n.d.). *Definition of Temporary*. Retrieved November 20, 2013, from Merriam-Webster Dictionary: <http://www.merriam-webster.com/dictionary/temporary>

Ontario Tire Stewardship. (2013). *Off-Road Tire Stewardship Fees*. Toronto: Ontario Tire Stewardship.

Peeren, C., Jongert, J., & van Hinte, E. (2007). *Superuse*. Rotterdam: 010 Publishers.

Superuse Studio. (2009). *Recyclicity: Industrial Ecology Applied to the Urban Environment*. Palo Alto: ISSUU.

Superuse Studios. (2008). *Wikado*. Retrieved August 20, 2014, from Superuse Studios: <http://superuse-studios.com/index.php/2008/10/wikado-2/>

ServiceOntario. (1994). *Ontario Regulation 102/94*. Toronto: Government of Ontario.

Statistics Canada. (2012). *Human Activity and the Environment*. Ottawa: Statistics Canada.

Statistics Canada. (2012). *Human Activity and the Environment: Waste Management in Canada*. Ottawa: Statistics Canada.

Stearns, P. N. (2013). *The Industrial Revolution In World Hlstory*. Boulder, CO, USA: Westview Press.

Ruby, I., & Ruby, A. (2010). Mine the City. In I. Ruby, & A. Ruby, *Re-Inventing Construcion*. Berlin: Ruby Press.

Reynolds, M. (1990). *Earthship* (Vol. 1). Taos, New Mexico: Solar Survival Press.

ReBAR Group. (2010). *Panhandle Bandshell*. Retrieved August 20, 2014, from ReBAR Portfolio: <http://rebargroup.org/panhandle-bandshell/>

Tam, C. M., & Tam, V. (2008). *Re-use of Construction and Demolition Waste in Housing Developments*. New York: Nova Science Publishers, Inc.

U.S. Environmental Protection Agency. (2012, April 20). *6 Common Air Pollutants*. Retrieved November 5, 2013, from U.S. Environmental Protection Agency: <http://www.epa.gov/airquality/urbanair/>

Vancouver Art Gallery. (2005). *Brian Jungen*. Vancouver: Douglas & McIntyre.

Visconti, A. (2014, July 2). Construction Waste Costs Email. Toronto, ON, CA.

Ward, S. (2012). Breathing Life Into the Corpse, Upcycling Through Adaptive Reuse. In S. Lehman, & R. Crocker, *Designing for Zero Waste* (pp. 247-266). Abingdon: Earthscan.

Wiecha, J. (Director). (2010). *Trashopolis Mumbai* [Motion Picture].

Wood Resources International . (2011). *North American Wood Fibre Review 2011*. Bothel, WA: Wood Resources International .

WWF. (2012). *Living Planet Report 2012*. Gland: WWF.